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A world-wide community demand for accountability when producing food products was the catalyst for, the Vegetable and Potato Growers' of Western Australia to produce a Code of Practice and a Best Environmental Management Practices Reference Manual.

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This Best Environmental Management Practices manual (referred to as the BEMP Manual) has been compiled by the Department of Agriculture, Western Australian in conjunction with the Water and Rivers Commission and Department of Environmental Protection for the Potato Growers’ Association of WA and Vegetable Growers’ Association of WA.

It is a companion publication to the Code of Practice for Sustainable Vegetable and Potato Growing in WA and is designed for easy cross-referencing.

The Code document describes the environmental issues, expected environmental outcomes and environmental management principles, and lists the best environmental management practices (BEMPs).

The BEMP Manual outlines how to conduct best practices for sustainable vegetable and potato growing. It covers those growing operations that potentially have the most impact on the environment, describing techniques, methods and procedures that minimise environmental impacts. The Manual uses the same structure as the Code. Each section has numbered principles, under which are described the best environmental management practices underpinning each principle.

Environment is defined as the surrounding conditions that sustain all forms of life. This is taken to include the natural environment – soil, water, air, bio-diversity and the human environment.

The BEMP Manual is not an occupational health and safety guide, although it does cover some practices for safe use of chemicals, clean air and minimising noise, which can have significant impacts on the broader human environment. Neither is it a ‘how to grow’ guide. Crop-specific agronomy, control of specific pests and diseases, business practices and marketing are beyond the scope of this Manual.

Practices that are essential to the environmental sustainability of annual horticultural cropping in Western Australia are covered. Examples of crops to which the Manual applies are potato, cauliflower, carrot, onion, sweet corn, broccoli, tomato, cucurbit, pumpkin, melon and strawberry.

Production of cereal crops, mushrooms and perennial horticultural crops such as tree fruit, nuts and vines and any crop grown by hydroponics is not covered in this BEMP Manual.

The practices described are the best known to the editorial committee at the time of writing. Much of the text is taken directly from:

- Department of Agriculture WA Farmnotes and Bulletins. These can be accessed on the Internet at www.agric.wa.gov.au
- Information notes from the Water and Rivers Commission, Department of Environmental Protection and other government departments.

Other information sources include:

- Personal comments from experienced leading growers and consultants.
- Personal comments from horticulture and resource management staff of government agencies and universities.
- Internet websites of Australian and overseas horticultural and environmental institutions.

The philosophy behind the Manual is one of continually improving best practices. Whenever additional or better practices are developed, sections will be updated. Growers will receive the information to append to their Manuals.
Disclaimers

The Chief Executive Officer of the Department of Agriculture Western Australia, the State of Western Australia and the Potato Growers’ Association of WA (Inc) accept no liability whatsoever by reason of negligence or otherwise arising from use or release of the information in this Manual or any part of it.

This material has been written for Western Australian conditions. Its availability does not imply suitability to other areas, and any interpretation or use is the responsibility of the user.

Mention of product or trade names does not imply recommendation, and any omissions are unintentional. Recommendations were current at the time of preparation of the original publication.

Explanatory Note

The best environmental management practices (BEMPs) described in this manual are taken directly from the Code of Practice. They are highlighted in bold text indicated with a square symbol.

The Code of Practice explains why the BEMPs are important. This Manual gives technical information that should enable growers to conduct the BEMPs where appropriate for their operations.

In some cases the information is detailed and in others, brief. The authors have endeavoured to treat each practice in appropriate depth.

However we recognize that some growers may need more information. The references at end of each section are provided for this purpose.

The manual also deals with other practices that are not BEMPs, but are unavoidable some exceptional situations. Examples are fumigation, broadcasting, chemigation and irrigating with marginally salty water. In these cases, environmentally sustainable alternatives are presented. For growers who still consider that there is no alternative for their situation, precautions and techniques that minimize the environmental impacts are outlined.
**Farm Planning**

1.1 *Select suitable sites where environmental problems will be minimal*

**Starting a new horticultural enterprise**

Horticulture can have negative impacts on the natural and human environments in which it is located. These include land use conflicts arising from noise, dust, spray and other nuisances, removal of native vegetation and biodiversity values, and pollution of surface and groundwater. A number of agencies have legal responsibilities and controls relating to the use and management of land and water resources to avoid these negative impacts. These include Local Government, Department of Agriculture Western Australia, the Water and Rivers Commission and the Department of Environmental Protection. It is essential to obtain the necessary statutory approvals from these agencies as a first step to planning any new horticultural enterprise.

For example, most areas of the Swan Coastal Plain, Darling Scarp and Manjimup-Pemberton are **proclaimed water areas**. In these areas, a license will be required from the Water and Rivers Commission to divert ground or surface water for private use for horticulture. Contact the Water and Rivers Commission on (08) 278 0300 to find out what the requirements may be.

It may not be necessary to submit a proposal to all these agencies. This depends on where the proposal is located and the potential impact of the proposal. For example, if there is no proposal to clear or drain land then these approvals will not be required from Agriculture Western Australia.

Growers planning new or expanding horticultural operations should find out what legislative approvals they must obtain by referring to either:

- The Code of Practice (Potato Growers’ Association et al, 2002), Section 13 ‘Legislative requirements for new or expanding horticultural operations’, or
- AGMAPS Horticulture Land Capability Maps CD (see below), section entitled ‘Getting Government Approvals’.

**Useful maps and reports**

(Agriculture Western Australia, 1999)

In order to assist in the selection of areas suitable for horticulture and other agricultural land uses, the Department of Agriculture WA has prepared the Land Resource Series (LRS), of maps and reports.

The LRS maps are intended for regional planning purposes and most are produced at a scale of 1:50,000. By nature of the mapping techniques and sampling density, the maps are not detailed enough for property-specific planning but will give a broad indication of land suitability.

Detailed land resource and capability information is available on CD-ROM for the Swan Coastal Plain area. Less detailed land resource information is available for other areas and other uses, but the scale of mapping can be a lot smaller and therefore the reliability can be less. It is intended that CD-ROMs containing available land capability and resource mapping for other areas of the State will be prepared progressively.

The AGMAPS Horticulture Land Capability Maps, Swan Coastal Plain, Lancelin to Augusta CD ROM includes the following information sections:

- **Groundwater availability**

The maps show the groundwater sub-areas. A groundwater sub-area is a groundwater management area defined as part of a Groundwater Area Management Plan prepared by the Water and Rivers Commission. The amount of water generally available for allocation in these areas is also shown. An individual site assessment is required to determine specific groundwater availability on a site.
Where there is no groundwater sub-area mapped it has been determined that groundwater availability is sporadic and unreliable. A site assessment will be necessary to determine the groundwater and surface water availability of specific properties. Contact the Water and Rivers Commission on (08) 9278 0300 for more information.

- Horticulture Land Capability Maps

Land capability refers to the physical ability of a defined land unit to support a particular land use such as horticulture. It takes into account specific productivity and management requirements of the land use plus the risk of land degradation. Factors considered in determining horticulture land capability include water repellence, sub-surface compaction, wind erosion risk, water erosion risk, unrestricted rooting depth, phosphorus export risk, soil water storage, secondary surface salinity, salinity risk, soil pH, waterlogging risk, site drainage, soil workability, salt exposure, land instability, sub-surface compaction and flood risk.

Land with a capability rating of 1 or 2 is subject to few physical limitations, which can be overcome by planning and management. Land with a rating of 3 has limitations that will require attention but can be overcome. Land with a capability rating of 4 or 5 is subject to a high degree of limitations with extensive management measures required.

The AGMAPS CD can be obtained from:
Publications Officer,
Agriculture WA, Baron- Hay Court,
South Perth.

Site Selection and planning
(Department of Agriculture Western Australia Land Management Services, 2002)

It is recommended that growers selecting and planning a new site should contract professional land management consultants, such as Department of Agriculture Western Australia Land Management Services, to help them undertake water, land and soil assessments. These can be done as a condition of purchase or after the block is purchased. However, the Department of Agriculture Western Australia strongly suggests that pre-purchase land and water appraisals (1 and 2 below) are carried out and the necessary Government approvals obtained prior to purchase of any land for intensive horticultural purposes:

1. Pre-purchase assessment

A general suitability report is prepared from a broad assessment of existing data and a brief field visit. This survey can be undertaken by the vendor pre-sale, or as a condition on the offer and acceptance by the purchaser. Cost is usually around $1000 but is dependent upon the block size (mileage not included).

2. Water assessment

One of the major limiting factors for horticultural development is water availability. Water requirements depend upon the type of enterprise and the evaporation measurements for the area. It is recommended that growers obtain professional services to assess their block for availability of water resources. The assessment should include:

- Preliminary water assessment.
- Assessment of current and potential water demand.
- Assessment of all existing property water supplies and potential supplies.
- Calculation of safe yields versus demand.
- Planning of potential bore or dam sites.
- Recommendation and costing of proposed works.

The cost for this service is around $1000 (mileage not included), but depends upon the size of the property.

3. Detailed soil survey

Once a suitable site for the horticultural enterprise has been selected, the next essential step is to undertake a soil survey. This
investigation of the soils will help in defining limitations to enterprise establishment, planning irrigation requirements and other management decisions. There are several scales of survey depending on requirements.

4. Water supply construction plan preparation

This involves the investigation of a selected site for the construction of required water supply earthworks:

- Field assessment by drilling or backhoe pits
- Survey of construction site and pegging of works
- Report and diagrams of construction details
- Water supply construction supervision
- Supervision of construction of proposed works
- Survey of completed works to calculate actual stored volume

Costing of these services is site specific.

Contact for further information

For more detailed information on fee structure or for a quote, contact:

Land Management Services
Department of Agriculture Western Australia
Baron-Hay Court
South Perth WA 6151
Telephone: (08) 9368 3829

1.2 Plan the whole farm to minimise environmental impacts

A farm plan examines the natural resources of the property, presents options for sound management and makes appropriate conservation treatment recommendations:

- Erosion and salinity control
- Revegetation
- Remnant vegetation protection
- Farm water supply
- Farm layout
- Access

Producing a physical farm plan for horticulture

(Rose, 1997)

The following 9 steps are a suggested procedure for farm planning. Farmers can produce their own farm plan or have all or part of it done professionally. It is recommended that professional land management consultants be contracted to assist with steps 4-soil survey, 5-water supply, 6- surface water control earthworks (if applicable) and 9- irrigation system plan.

Department of Agriculture WA Land Management Services can be contracted to produce whole farm plans. The cost of a whole farm plan is site dependent:

1. Obtain an aerial photograph and maps of the farm

- Purchase a colour aerial photo or digital photo from the Department of Land Administration (DOLA) (see Table 1.1), at a scale of 1:2500 to 1:5,000, depending on farm size.

- Purchase a contour overlay map of the farm, to accurately match the aerial photo. This can be obtained from mapping consultants or DOLA. They will need a location plan with the location number and the actual length of two boundaries or long fences marked on it. Most surveyors and land management consultants can conduct a more accurate contour survey, which may be required for the irrigation plan.

The contour information is necessary to design an efficient and effective irrigation layout. The cost of the contour plan will vary according to block size and complexity.
2. Obtain materials for mapping

The following basic materials are required:

- Translucent paper which can be drawn on with lead or coloured pencils, or alternatively, transparent film. Fine, permanent overhead projection markers are required to draw on film and they can be rubbed out with an eraser.

- A transparent grid overlay for measuring the area of paddocks. Agriculture Western Australia can supply one with conversions for different scales. Alternatively, centimetre/millimetre graph paper can be photocopied onto an overhead transparency.

- Accurate ruler. Other drawing implements such as compass, protractor, parallel rule, scale rule are also useful.

An option is to digitise the farm plan and scan the aerial photo onto a computer. Suitable software is available, for example, Arcview, Mapinfo or ‘stand alone’ farm planning software such as PAM. The choice of manual or computer methods will depend on the individual’s skills.

For those who have large or complex farming operations and own a modern computer, the digital option is likely to be a worthwhile investment. Digitised plans can be more easily updated and information such as fertiliser, crop and other monitoring information can be entered on disc and related to the map.

3. Draw the first overlay maps

Tape or clip the farm photo to a board to make it easier to work with (clothes pegs work well)!. Tape transparent overlay paper or film over the photo.

Draw on one overlay sheet:

- Catchment divides and ridge lines
- Natural drainage lines
- Arrows to indicate where run-off water flows.
- Areas that are not suitable for cultivation such as rocky or waterlogged areas
- On a second overlay sheet, draw in existing infrastructure

Existing vegetation and fence lines should be visible on the aerial photo.

A colour photo will usually show winter waterlogged or saline areas as darker and summer damp areas as greener.

Distance can be measured on the map, for example, on a map with scale 1:5,000, one cm = 50 metres on the ground.

4. Detailed soil survey and soil map

The main purposes of a detailed soil assessment are to define areas of soil suitable for irrigated horticulture. It is essential that blocks contain soils of similar physical and chemical
characteristics so that a uniform quality of produce can be obtained through a planned fertiliser and irrigation strategy. This approach enables easier management and should also save water and money.

A detailed soil survey for horticulture involves digging a series of backhoe pits in order to describe the soil profile through the rooting zone. The contracting of the backhoe operator is normally the responsibility of the client. The cost of this is estimated at $60-80/hour and depending upon the size of the block should take between half a day and two days.

The soil surveyor uses a stereoscope to delineate soil patterns on aerial photographs. Field inspections are then carried out to check soil unit boundaries, depth, texture, pH, gravel content and soil moisture and if necessary, to take samples for detailed chemical and physical analysis. The surface characteristics of the land, its slope, drainage and susceptibility to erosion are also noted.

From this field information, a map is produced showing areas of similar soils (management units), available moisture and proposed delineation of horticulture blocks. The accompanying report describes the soil units, the soil characteristics and management relevant to intensive horticultural use. Detailed profile descriptions for each soil pit are also included.

It is recommended that professional soil surveyors such as Department of Agriculture Western Australia Land Management Services be contracted to conduct the survey. The cost of the soil assessment depends upon the size and complexity of the area being surveyed.

5. Audit and plan water supply

Map the location of existing developed water supply resources. Calculate the storage capacity of dams and annual supply from bores (this may be dependent on license conditions. If new water supplies need to be developed, contract professional land management services to locate dam or bore sites and design earthworks if these are required. (refer to point 4 under ‘Site selection’ above).

6. Plan surface water control earthworks and drainage

If cropping is to be conducted where run-off occurs at any time, properly planned surface water control earthworks to prevent soil erosion and nutrient export are essential. The exact location of these will need to be determined on the ground but the 5 metre contour overlay and aerial photo are useful for conceptual planning.

- Mark in safe disposal areas for run-off. These should be left permanently grassed or vegetated to act as waterways for disposal of excess run-off water. Natural drainage lines are the best disposal areas. An adjacent paddock that has been grassed for at least a year or is under forest or plantation may also be suitable if the land slopes away from the cultivated plot. A thorough on-site investigation is essential to ensure that the disposal areas have minimal effect on the workability of the farm or neighbours’ properties.

Where there are no such safe disposal areas in or adjacent to the paddock, grassed waterways can be constructed with a grader (Section 2.1). They must be permanently vegetated and not be cultivated. Ideally they should not be used as vehicle tracks, but access tracks can often be located beside them. Space waterways in such a way that temporary grade furrows running into them are no more than 100 m long.

- Sketch a concept plan of surface water control earthworks (refer to Section 2.1 for details). Grassed waterways and diversion banks may be needed to divert water running off roads, yards, catchments or waterlogged areas up-slope of the paddock. These will be surveyed on a 0.25% – 1% grade which means they can be pencilled in on a slight angle to the contour lines. They must lead to a stable, grassed disposal area.

Grassed waterways within areas to be cropped need to be located between cropping bays. The width of cropping bays will depend on the width of the cropping machinery to be used, such as the boomspray.
Sketch where temporary grade furrows will be required to protect cultivated slopes. They must run into stable grassed disposal areas or grassed waterways.

- Use the area grid overlay to estimate the catchment area of surface water control earthworks. If the catchment is too large, run-off will exceed the flow capacity of the waterway and may cause soil erosion (refer to Section 2.1 ‘Permanent grade banks and grassed waterways’).

- Surface water control earthworks such as banks and grassed waterways and can be planned so that they empty into existing hillside dams or proposed dams sites, thus increasing water storage.

Note: In cases where surface water control earthworks or drainage may alter flows across the property boundary, neighbours must be consulted. It is also wise to contact the district Department of Agriculture’s Land Conservation Officer who can advise whether a formal notification to drain should be submitted to the Commissioner for Soil and Land Conservation.

Contrary to common belief, surface water control earthworks do not exclude much land from cropping. One kilometre of waterway 3 m wide is only 1/3 of a hectare in area. One kilometre of temporary grade banks is less than 1/10 of a hectare in area.

7. Outline workable cropping paddocks

- Using the scale on the map and the area grid overlay, measure of the required area (this method is accurate to within 5%). Irrigation layout will obviously be a major consideration when determining the shape of cropping areas. Use a compass if a centre pivot irrigator is to be used and a ruler if straight irrigation runs are required. Pencil in and rub out the various possibilities until satisfied the best layout is produced.

- Pencil in the area and dimensions of each paddock. Unsuitable classes of land such as steep slopes, waterlogged areas and natural waterways should be fenced off and not cultivated.

8. Plan fences, windbreaks, access tracks and other infrastructure

- Be prepared to move fences that are in the wrong places. Construction of new fences to a farm plan with surface water control for soil and land conservation purposes is fully tax deductible in the year of expenditure.

9. Plan the irrigation system and layout

Irrigation planning should be conducted by Certified Irrigation Designer (CID) accredited irrigation consultants. An accurate layout of the proposed horticultural enterprise is mapped over the contour plan. From this map, a plan of the irrigation system is prepared.

Existing systems can be analysed for their efficiencies and, quite often, major problems can be cheaply overcome with a small change in design.

The pipes in the network are sized to compare the cost of pipe work against the cost of power. The design will include universally accepted irrigation efficiencies, generally set at a flow variation of 10%. This will allow for accurate irrigation scheduling and possible automation of the system based on soil moisture.

The integration of irrigation design and scheduling into the horticulture plan ultimately leads to better management of irrigation water and hence a higher economic return to the grower. The cost of this service is dependent upon block size and soil and landform complexity.
Permanent surface water control works are an essential component of the farm plan for cropping hill slopes.
SECTION 2

Soil Management
Soil Management

Soil management may well be the most important aspect of sustainable vegetable and potato cropping in the long term. Soil erosion, export of nutrients and chemicals, and leaching are among the most significant impacts of horticultural cropping and are caused entirely or in part by poor management of soil. Good practices to minimise all of these impacts are described in this section.

Growers will also find information that will help them to understand their soils, including soil biology, which is so vital to soil health. Methods of soil monitoring, appropriate cultivation techniques, cover cropping and mulching are explained, which will help maintain or increase soil fertility. Soil health issues such as acidity, salinity, sodicity and heavy metal contamination are also discussed.

2.1 Minimise or virtually eliminate soil erosion

Observing the signs of erosion

☐ Check cultivated paddocks regularly for signs of erosion

The obvious signs

The signs of severe water erosion are obvious:

- Rills. These are small shallow wash lines (less than wheel width), often numerous and usually seen first in wheel ruts. They are formed where water has run off, and removed soil. Rills may form gullies if left untreated.

- Gullies. Large scars on the landscape, where many tonnes of topsoil have been removed by water erosion. Erosion gullies often worsen rapidly if not treated. Gullies most often occur in natural flow lines – areas on slopes where run-off water will tend to collect and flow. For this reason, flow lines should never be cultivated.

- Build-up of soil on fences at the foot of slopes. Old fence posts are good indicators of soil build-up at the foot of slopes. It is not unusual to see posts ‘shortened’ 30 cm or more. This depth of washed or blown soil deposited along fence lines equates to many hundreds of tonnes removed from the paddock.

Rills, gullies and soil build-up at the foot of a slope are signs that either the site should not be cultivated or the grower’s soil management has been inappropriate for the site and soil type (see ‘Site water erosion risks’, this section).

In either case, immediate installation of surface water control earthworks is required to rectify the situation in the short term. In the longer term, if the decision is made to crop the site in the future, an improved soil management strategy is required. This would need to include appropriate minimal cultivation practices, cover cropping, mulch cropping and surface water control.

Less obvious signs of soil erosion

Unacceptable erosion may be occurring when there is no obvious scarring of the landscape. Growers should regularly take a closer look at their cultivated soil.

The following are signs that significant erosion is occurring and improvements to soil management need to be made:

1. Run-off from cultivated soil.

2. Washed appearance of the soil surface.

3. Windblown soil surface and/or dust blowing.

It is not acceptable to disregard any of these erosion signs in the knowledge that the paddock will be levelled and pastured after cropping, covering up the signs of erosion. Soil erosion is cumulative, with the topsoil and organic matter losses eventually leading to reduced soil fertility and soil structure decline which in turn eventually lead to worsening erosion and decreased productivity.

1. Run-off from cultivated soil

Observe the paddock during irrigation and rainfall for signs of run-off. Run-off may be occurring without rills being evident. Run-off
should not occur during irrigation or rainfall of normal intensity. If this does happen then soil management and/or irrigation is deficient.

If run-off still occurs when cultivation, cropping and irrigation management is being conducted according to best management practices, then either:

- The site should not be used for cultivated horticulture, or
- The site needs more protection by surface water control earthworks.

Surface water control earthworks effectively divert or control run-off into man-made channels, before it can increase in speed or depth sufficiently to erode the cultivated soil. The channels (temporary grade furrows or permanent grade banks) run on a gradual gradient, are shallow and may be grassed, allowing the water to run in them without causing significant erosion.

2. Washed appearance of the soil surface.

(McTainsh and Boughton, 1993).

Sheet erosion is the removal of soil in a thin sheet from the entire soil surface. The signs are a washed, sandy appearance of the soil surface and there may be a thin surface crust. It can occur even on very gently sloping land, where there may be no sign of rills.

Sheet erosion occurs by a process known as rainfall attachment and re-detachment. When a raindrop hits an unprotected soil surface, the water in it flows out very rapidly in a radial direction, tearing loose or detaching some soil in the process. This soil is then carried a short distance down-slope in a film of water before depositing again on the soil surface. As it is then more loosely bound than it was in the more cohesive parent soil, other raindrops re-detach it more easily, moving it a short distance each time. Although slower and less obvious than rill or gully erosion, this process is nevertheless significant.

Preventing sheet erosion on such sites requires attention to be paid to such things as:

- Protecting the soil surface by rapid establishment of crop cover.
- Avoiding cultivation at the times of year when there is significant risk of intense rainfall.
- Ensuring that the rate of sprinkler irrigation is not too high and causing run-off.
- Testing the soil for water repellence and treating appropriately if this is a problem.
- Testing for soil structure decline and treating appropriately.

3. Wind-blown soil surface and/or dust blowing

Wind erosion can cause the loss of many hundreds of tonnes of topsoil in dry windy conditions. Windbreaks, nurse crops, stubble retention and cover crops are all practices that can be used to prevent wind erosion (Section 2.1).

All growers need to have a soil erosion prevention strategy for each of their cultivated sites, according to site and soil conditions, seasonal risks and the cropping rotation.

(Refer to Sections 2.1 and 2.2 of the Code of Practice).

Site water erosion risks

Section 2.1 of the Code of Practice outlines land capability limits to cultivated cropping:

- Land with slope greater than 15% gradient should not be cultivated.
- Land that is waterlogged during the period of crop or post - harvest cover crop establishment should not be cultivated.
- All land with 10-15% slope should have adequate surface water control earthworks in place according to best practices, at all times during cropping.
All land with 5-10% slope will require some protection by surface control earthworks, depending on crop type and soil type.

Many other sites with less than five percent slope, such as those which become waterlogged in winter or which receive run-off from up-slope, should also be protected by surface water control earthworks during cropping. The erosion hazards may not be apparent until erosion occurs.

If erosion is experienced on any site, action should be taken, either to cease cropping and keep it under permanent pasture or vegetation or to install surface water control earthworks.

### Erosion prevention by surface water control

**When growing on hill slopes, plan a surface water control strategy at least one year prior to cropping the paddock.**

Walk over the site and decide where access tracks, surface water control works or windbreaks will need to be located (see below). Sketch these on a map of the paddock. Include such things as diagrams of the profile of the waterways and notes on how and when they will be vegetated.

Growers who are aware of erosion problems on the site, and are unsure of the techniques required can obtain expert advice on the layout of surface water control earthworks. The local Landcare Coordinator, Dept of Agriculture Land Conservation Officer or private soils consultant are usually able to do this.

**Cross slope cultivation**

(Crose, 1997)

**Cultivating across the slope on a gradient of 2-3% is recommended for slopes of up to 7% gradient. If this is done, grade furrows will not be necessary.**

- On slopes up to about 6% for potatoes and 7% for cauliflowers, erosion can be minimised without the use of temporary grade furrows by cultivating across the slope on a 1-3% grade.

- The grades should be checked with a clinometer every 50 metres or so down the slope in the same way as that described for grade furrows, to ensure that it is between 1-3% over the cultivated area. If this is not done, or if cultivation on a level contour is attempted, water may burst through where cultivation crosses a flow line, causing severe gully or rill erosion.

- Flow lines should be left uncultivated, to act as stable waterways. Cultivating across flow lines is a common cause of severe erosion.

- A suitable disposal area should be left grassed up at the lower end of the cultivation to take excess run-off.

- Potato harvesters with adjustable offset hitch and steerable wheels are necessary when operating on a side slope.

**Basin tillage**

(Rose, 1997)

The basin tillage implement is commonly known as a 'dammer dyker’. This is like a set of paddle wheels which form small banks about 70 cm apart across the furrows. These cause water to pond in small basins, aiding infiltration. For potato cropping, the ‘dammer dyker’ wheels are best mounted on the same tool frame behind the hillers and rippers.

This arrangement reduces cost and reduces compaction in the wheel ruts, as there are fewer passes with the tractor. Infiltration is greatly improved because the rippers break up compaction pans and the small ponds made by the basin tillage reduce run-off. Basin tillage is usually sufficient to prevent run-off and erosion during crop establishment on most sites with deep, well-drained soils and slopes less than about 3%. However, it is not a substitute for surface water control earthworks or cross slope cultivation on slopes steeper than 3%.
Installing surface water control earthworks  
(Rose, 1997)

If permanent grade banks or grassed waterways are part of the strategy, these should be installed immediately and sown, to ensure they will be adequately vegetated prior to cropping.

- Install surface water control works adequate to protect the site from erosion.

- Don’t gamble with the weather; have permanent structures in place before cropping and install temporary furrows straight after sowing.

- Plan earthworks carefully beforehand using an aerial photo to ensure that they fit in between cropped areas. Estimate areas of catchments; identify disposal areas.

- Start from the top of the slope. First locate banks or furrows above the cropped areas then locate others down-slope at the correct spacing.

- Graders are most cost effective. A 4.5 metre articulated machine at $65-$80/ hour can construct earthworks to protect a 20 ha paddock for less than $500.

- Waterways and disposal areas should be sown and grassed up immediately.

- Always have a cut-off diversion bank at the top of the cropped area to prevent run-off from upslope from running onto the cultivated area.

This is most important for all sloping sites. If any water runs onto the site from above, even if this is only during the most extreme rainfall events, it will be almost impossible to stop the cultivated area from eroding. Common sources of run-off are infrastructures located up-slope of the site, such as loading areas, yards, roadways and the rooves of buildings, all of which shed much more water than pastured land.

General guidelines are:

- A permanent diversion bank is recommended for all sites where there is more than 50 metres of catchment running on to the cultivated area.

- For paddocks where there is less than 50-70 m of pastured catchment up-slope, properly constructed temporary grade banks within about 10 m of the top of the cultivated area will suffice.

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**Table 2.1 Types of surface water control earthworks**

<table>
<thead>
<tr>
<th>Description</th>
<th>Permanent banks with a flat shallow channel on the up-slope side, running across the slope on a surveyed gradient.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Cut off run-off water from above or within cultivated areas and divert it onto stable vegetated disposal areas.</td>
</tr>
</tbody>
</table>
| Suitable for (site, soil types) | All soil types; very rocky ground may present problems in construction.  
Across slopes <5% for trafficable banks.  
Across slopes 6%-15% for non-trafficable banks. |
| Gradient of earthworks | Surveyed with a laser or optical level on a constant grade of 0.3% – 0.5%. |
| Profile | Flat bottom 1-3 m wide with 20-30% batter up-slope.  
Broad bank down-slope with compacted height 0.4-0.5 m. |
| Machinery required for construction | Road grader or tractor drawn wheel grader, 3-4 m blade; 4wd tractor of >80 kw. |
| Estimated cost | $500 per km to construct plus $200 km to sow grass sward. |
2. Grassed waterways

| Description | Permanent waterways running up and down the slope, not on a surveyed grade, ideally along flow lines. Permanent pasture cover is essential – leave grassed or sow with grass (kikuyu is best) immediately after construction. |
| Purpose | To dispose of run-off water from cultivated land, grade furrows or grade banks. |
| Suitable for (site, soil types) | Hill slopes up to 15% in stable gravelly or duplex soils. Not suitable for higher or permanent flows, sandy or other unstable soils (see ‘other stabilised waterways’ for these sites). |
| Gradient of earthworks | Variable; follows hill-slope. Up to 15% on suitable, stable sites. |
| Profile | Broad, shallow cross Section, 3-5 metres wide and 0.2-0.3 metres deep. Small waterways that are also used for vehicle access are slightly dished in the middle to prevent water from flowing in the wheel ruts. |
| Machinery required for construction | Road grader, Razorback™ type tractor drawn grader or square mouldboard plough. |
| Estimated cost | $200- 500 per km to construct plus $200 per km to sow grass sward. |

3. Temporary grade furrows

| Description | • Temporary, trafficable furrows running across the slope to divert water into grassed waterways or disposal areas. • Maximum length 50 – 100 metres depending on slope, soil type and furrow size. • Maximum spacing 30 – 60 metres depending on slope and crop type. Installed immediately after sowing potato, vegetable or cereal crops. |
| Purpose | Cut off and divert water from cultivated land. |
| Suitable for (site, soil types) | All soil types on hill slopes 5% -20%. |
| Gradient of earthworks | Grade 1 – 2% on sand, 3 – 4% on karri loams, 4 – 5% on clay loams. |
| Profile | 0.5-1 metre wide and 0.2-0.4 metres deep. |
| Machinery required for construction | One pass with back blade, single-disc or single-mouldboard plough. |
| Estimated cost | $200 per km. |
On slopes longer than 70 m and more than 5% gradient, install either temporary grade furrows or permanent grade banks across the slope to divert any run-off from the cultivated soil into stable waterways or onto pasture.

As a ‘rule of thumb’, the grade furrows or diversion banks should be at spacings of no more than 50 m, depending on slope and soil type. They should be surveyed on the correct gradient, properly constructed and maintained.

Plan to have pasture or grassed waterways in the right place to carry run-off from the cropped area safely without eroding. If the site is no more than 200 m in width across the slope and sloping away on both sides, it is often possible to divert run-off from the cultivated area onto stable pastured land. However many cropping paddocks are too large or else they slope inwards to drainage lines within the cropped area. In these cases it is crucial to have stable grassed waterways in place with vegetation established before the ground is cultivated.

- **Install and stabilise earthworks at least a year before cropping**

To prevent erosion, ensure that surface water control earthworks and access tracks are constructed and stabilised at least one year prior to planting. Sow grass swards in the channels of waterways and diversion banks during the season before the land is cultivated, to ensure the grass is well established. Established pasture swards, especially perennial grasses such as kikuyu, provide adequate and inexpensive cover to prevent erosion of most waterways that would be required to carry water diverted from cultivated paddocks. Extreme cases such as spillways or narrow waterways on steep slopes with unstable soils may require more expensive stabilisation such as rocking or concreting (see below).

- **Maintain waterways and diversion banks and tracks in a stable condition.**

Once these are in place and working well, make them a permanent part of the property infrastructure and never cultivate over them.

Construct earthworks and sow grass on them the previous year and cultivate around them. Do not cultivate the whole paddock and then try to construct earthworks.

- **Install grade furrows to divert water off steep or long cultivated slopes.**

Install temporary grade furrows on cultivated slopes to divert surface run-off into stable waterways or onto pasture during and after cropping. Construction is quick and easy, with one cut using a back blade, single-mouldboard or single-disc plough. Cutting the furrows after planting is not a problem as there is little loss of planted area and the narrow, shallow cross section enables most machinery to cross them without destroying the profile. Take care to get the grades to within one percent, by using a clinometer or laser level. As a rule of thumb, the grade is 3- 4% for temporary grade furrows on loamy/ gravelly soils. Ensure that grade furrows are not more than 50 m apart and 100 metres in length.

- **Be prepared to liaise with neighbours where surface water run-off to or from adjoining properties may impact on them.**

**Permanent grade banks and grassed waterways**

(Rose, 1997)

These are permanent structures that may carry quite large flows, so careful planning, design and surveying are essential. Figures 2.1-2.3 below show adequate cross sections for grade banks and waterways with the catchment areas specified. If larger catchment areas are involved, they should be designed and planned by a qualified Landcare technician or surveyor.

For both grade banks and waterways:

- Ensure that a stable area for water disposal is available, for example, a pastured paddock that will never be cultivated, a tree plantation or other permanently vegetated area.
An articulated road grader is the best machine for construction.

The channels can be used for occasional access or turning machinery but permanent tracks should run beside, not in the waterways.

Regular maintenance is essential. Any silt collecting in the waterway must be removed to prevent bank failure.

Factors to consider for permanent grade banks:

- **Steepness of slope.** Banks constructed across slopes greater than 8% will not be trafficable by most farm machinery.

- **Catchment area.** The area between the bank and the ridge line or next bank up-slope must not be too large (never more than 20 hectares), or breaching will occur. The area can be calculated from your farm plan map using an area grid overlay.

- **Surveying.** Never attempt to construct a grade bank without careful surveying. Survey with a laser or optical level on a 0.3 – 0.5 % grade across the slope (see Section 2.2). If this is not done, the channels will scour out and silt up in places, causing breaching of the bank which can result in gully erosion.

- **Channel profile.** Construct the channel with a flat bottom about 2-3 m wide, a gradual batter up-slope and 0.5 m high bank down-slope. The flat bottom is needed to ensure that the flow is as shallow as possible.

- **Stability of the channel.** Establish grass on the banks and channels as soon as possible and never cultivate them.

- **Silt accumulation in the channel.** To avoid silting, ensure that there is not more than 50-60 metres of unprotected cultivated land up-slope. Silting is an indication that erosion is occurring. If silting occurs, the channel will have to be re-graded and soil management rectified to prevent erosion.

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**Figure 2.1 Grassed waterway in crop**

<table>
<thead>
<tr>
<th>crop</th>
<th>slightly dished channel cut 0.1-0.2 metres below ground level and grassed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5 metres</td>
</tr>
<tr>
<td></td>
<td>3.0 - 5.0 metres</td>
</tr>
</tbody>
</table>

**Figure 2.2 Grassed waterway in natural flow line**

<table>
<thead>
<tr>
<th>earth bank pushed up from outside waterway</th>
<th>waterway channel is original pastured ground surface</th>
<th>bank height 0.5 - 0.75 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 - 10 metres</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.3 Permanent grade bank**

Grade = 0.3-0.5%
Maximum hill slope 12%
Maximum hill slope for trafficable bank 8%
Maximum length 800 m
For profile shown, maximum catchment area is 20 ha.
Factors to consider for grassed waterways

- **Location.** Locate grassed waterways in flow lines (areas on slopes where run-off water will tend to collect and flow) where possible. In these cases the existing pasture should be left intact and low banks graded in from outside (see Figure 2.1).

- **Profile.** To prevent erosion, waterway profiles must be at least 3 m wide, shallow and well vegetated because they run up and down the slope and are not on a surveyed grade.

- **Where there is no natural flow line.** Sometimes there is a need for a grassed waterway where there is no natural flow line. In these cases, narrow waterways 3-5 metre wide can be constructed by grading about 10 cm of topsoil from the channel into low banks on each side. It is important to leave some topsoil in the flat channel to help establishment of grass in the channel. These waterways are generally suitable for catchment areas less than 5 hectares, waterway lengths less than 0.5 km and slopes less than 10%. (Agriculture WA waterway design software, 1991).

- **Stability of the channel.** Grassed waterways must be well vegetated. They usually follow the slope of the land and are often quite steep. Hence, Erosion will occur if they are not broad, shallow and stabilised with grass cover. Where possible avoid cutting through the darker topsoil (A horizon), as the subsoil is often unstable and may erode quickly. Sow the waterways in spring and if possible irrigate. Waterways need to be grassed before the first heavy winter rains.

- **Suitable implements for construction.** Articulated road graders are the best machines for constructing waterways in most situations. A hydraulically adjustable back blade or square mouldboard plough can be used for constructing small dished waterways.

- **Trafficability.** In general, vehicles should not cross the banks of grassed waterways as this greatly increases the risk of breaching. Neither should they be used for vehicle or machinery access, especially on steep country, as erosion is likely to occur in wheel tracks. However, narrow waterways with small catchment areas can be designed to take occasional traffic. A slightly dished profile is constructed between the vehicle tracks and a grass sward established in it. This ensures that water will flow in the grassed area rather than in the vehicle tracks, which are prone to erosion.

**Temporary grade furrows**

(Rose, 1997)

These are small, temporary drains used to gather surplus run-off water from cultivated land and direct it across the slope to vegetated areas such as grassed waterways or adjacent pasture paddocks. The furrows are small in section (15-20 cm deep by 50 cm wide) and are trafficable. The potato harvester will fill them in before the wheels pass over. They can only carry a limited amount of water, so if the recommended spacings and lengths are exceeded, breaching and erosion are likely consequences. Grade furrows leading into grassed waterways are the best option for slopes over about eight percent, on which permanent grade banks would not be trafficable and cross slope cultivation is not possible.

Donnybrook potato grower Bert Russell remarked that his time spent to install grade furrows returns at least $1000 per hour in improved production in a wet year. The grade furrows prevented loss of topsoil and nutrients, enabled easier access for crop inspections and resulted in a reduced price dockage due to green potatoes.

‘Rules of thumb’ for temporary grade furrows are:

- The furrows need to be put in immediately after sowing the crop, not the next day, as there is the risk of rain making the paddock too wet to install them later.

- Furrows should not longer than 50 m. Furrows of 100 m long have been used in less erodible soils. However, for longer furrows a larger profile is required, making them more difficult to cross with machinery.

- The spacing between furrows must be between 30-60 metres (Table 2.3).
• Grade of furrows 3% on most soils – less on sands, more on clay loams (Table 2.2).
• Grade furrows should not be marked in by eye, as it is almost impossible to get the grade right.

To construct grade furrows, make one pass with a single disc three-point linkage plough, mouldboard, or back blade throwing the soil down-slope.

• Re-cut grade furrows immediately after sowing the post-harvest cover crop.

Table 2.2 Guide to grade (fall) of temporary grade furrows in different soils

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Grade of furrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sands</td>
<td>1-2 %</td>
</tr>
<tr>
<td>Sandy loams e.g. karri loam</td>
<td>3 %</td>
</tr>
<tr>
<td>Clay loams</td>
<td>4-4.5%</td>
</tr>
</tbody>
</table>

Table 2.3 Spacing of temporary grade furrows

<table>
<thead>
<tr>
<th>Slope of paddock</th>
<th>Spacing of grade furrows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heavy loam soils</td>
</tr>
<tr>
<td>Steep (15%+)</td>
<td>30 m</td>
</tr>
<tr>
<td>Medium (10-15%)</td>
<td>30-40 m</td>
</tr>
<tr>
<td>Low (up to 10%)</td>
<td>up to 50m</td>
</tr>
</tbody>
</table>

The distance between grade furrows and their grade (fall) is determined by the slope of the hillside, soil type, crop to be grown, the fineness of tilth and the likelihood of heavy rain over a short period. It is important that the furrows have the right grade for the soil type. Incorrect or uneven grade can cause scouring, silting and breaching.

• Steep slopes, light soils, poor soil structure, low organic matter and fine tilth are all factors that will require closer furrow spacings.
• For sandier soils, furrow grade must be less.

Using a clinometer to survey temporary grade furrows
(Rose, 1997)

One operator using a laser level, staff and shovel can survey grade furrows as described below. However two people can survey them using the much cheaper clinometer. This procedure is faster than using the laser level because the operator does not need to keep retracing his steps to shift the level. It is not as accurate as the laser level and is not recommended for grade banks, but is adequate for temporary grade furrows.

A pocket clinometer can be bought for about $200. However an even simpler instrument consisting of a weighted T square with marked graduations, suspended in the middle of the T can be easily made.

Equipment
Clinometer, two ranging poles (1.6 metre broomsticks painted red on top for visibility are ideal), coloured tape, shovel.

Procedure
• Start with the first furrow at the top of the paddock and move down.
• Use your knowledge of the paddock and the guidelines in Tables 2.2 and 2.3 to decide spacing and grade of the furrows.
• One person holds the clinometer on top of one pole and sights along the marking on the instrument corresponding to the required grade (3% for most loamy soils).
• The other person walks out about 20 m and holds the ranging pole upright.
The person sighting with the clinometer positions the other person so that the top of the upright pole is in his sights at the required grade.

Make a small mound with the shovel, and place coloured tape on top at each point to mark the line.

Where slope changes across the paddock, or the furrow crosses a flow line, it will need to curve to maintain an even gradient. Take more readings with the clinometer in these situations. Make curves gradual to avoid silting.

Tip: For accuracy, both operators should stand the pole on their boot, placed in a cultivation furrow to eliminate errors caused by uneven terrain.

Using a laser level to survey earthworks

(Rose, 1997)

Care of the laser level

- Avoid getting it wet or excessively dusty. Use the plastic cover if left standing during heavy rain or in extremely dusty conditions.
- Always transport the level in its case, in the cab, not on the tray of the ute.
- Keep it clean. Clean the glass window with a clean tissue to avoid scratching it.
- Check the low battery indicators (lower right corner of display on receiver and flashing light on the level transmitter). Replace batteries within 1 hour of low indication.

Setting up the laser level

- Fully extend the tripod legs and set tripod at about chest height. Gently push the pointed ends of the legs into the ground with your boot.
- Place level on tripod and loosely secure with the large knurled screw underneath, while steadying the level with the other hand.
- Move level around on the rounded tripod head until the bubble comes near to within the circle and tighten the screw underneath.
- Switch level on.
- Fine level adjustment can be done with the three flat knurled nuts at the base of the level. Move two at a time in opposite directions until the red ‘out of level’ light stops flashing. The laser beam will stop operating if the instrument is out of level.

Using a laser level to survey earthworks on a 3% grade

- Set up the level near where the top end of your furrow will be.
- Turn the laser eye receiver on and clamp it to the top of the staff. Turn on the audible ‘beeper’. Move to where you want the furrow to start.
- Slide the staff up and down until you hear a continuous beep indicating that it is on level.
- Shovel a small pile of earth where the staff stood to mark your first point (a piece of coloured tape will make this more visible).
- Slide the staff up the length shown Table 2.4 for a 3% slope, i.e. 60 centimetres.
- Pace 20 metres across the slope where you think the bank will go. You should first check how long your paces are by measuring 20 metres with a tape and pacing that distance. Most people have about 23 paces for 20 metres.
- Move up or down the slope until the beeper sounds continuously when the staff is stood on the ground vertically. Mark the second point with the shovel.
- Continue marking in the same fashion, extending the staff 60 centimetres more for every 20 metres you pace.
- Permanent grade banks can be surveyed using the same method. However the grade will be much less (usually 0.5%) which means the staff will only be moved up 10 centimetres for every 20 metres paced.
- If you need more help, an Agriculture WA officer can show you how to use the level in the field.
Table 2.4 Change in staff height per 20 metre distance to survey different slopes

<table>
<thead>
<tr>
<th>Required slope (%)</th>
<th>Fall in metres per 100 metres</th>
<th>Change in staff height in centimetres per 20 metres paced</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3%</td>
<td>0.3 in 100</td>
<td>6</td>
</tr>
<tr>
<td>0.5%</td>
<td>0.5 in 100</td>
<td>10</td>
</tr>
<tr>
<td>1.0%</td>
<td>1.0 in 100</td>
<td>20</td>
</tr>
<tr>
<td>1.5%</td>
<td>1.5 in 100</td>
<td>30</td>
</tr>
<tr>
<td>2.0%</td>
<td>2.0 in 100</td>
<td>40</td>
</tr>
<tr>
<td>3.0%</td>
<td>3.0 in 100</td>
<td>60</td>
</tr>
<tr>
<td>4.0%</td>
<td>4.0 in 100</td>
<td>80</td>
</tr>
</tbody>
</table>

Figure 2.4 Typical layout of surface water control earthworks on vegetable cropping land.
Purchasing or hiring equipment

Surveying equipment can be bought from surveyors’ equipment suppliers, for example, Associated Instrumentation, Spectraphysics or Tisco Instruments. (The authors show no preference to the retailers listed and other Australian retailers can be found in the ‘Yellow Pages’).

The equipment listed below can be hired from Manjimup Landcare District Committee. Phone 977 18180 for bookings.

- Surveying equipment – laser level, optical level, tripod, staff, clinometer
- Ausplow 3 point linkage deep ripper
- Single disc 3 point linkage plough for constructing grade furrows
- Soil aerator

Establishing grass cover to stabilise waterways

(Rose, 1997; Hawley, 1997)

Permanently grassed waterways are an essential component of an erosion control system for vegetable production in high rainfall hills areas such as Manjimup and Donnybrook. They enable the safe disposal of run-off water from slopes into the natural drainage system and help to minimise erosion.

Waterways can be constructed on land which is irrigated conventionally, or where centre pivot irrigation is used.

To minimise erosion, the ideal time of the year to carry out the earthworks is the summer/autumn period, when rainfall is at its lowest, although there is still a risk of thunderstorms causing soil movement on bare slopes. Many landholders, however, would find it more convenient to complete the earthworks in late winter to early spring when land is being prepared for production. Irrespective of what time of the year the works take place, it is essential to achieve revegetation of the waterways as soon as possible to minimise erosion.

By design some waterways are cut 15-20 cm below the ground surface to create a shallow channel to accommodate peak flows from the protected land. This frequently creates an unfavourable site for the establishment of plant cover because some of the topsoil, which contains the nutrients for plant growth, is stripped from the waterway and is not replaced. Often the subsoil is hard, lacks structure and provides an infertile, difficult environment for root penetration and plant establishment.

Breaking up the subsoil by ripping, to facilitate root penetration, can not be recommended, due to the increased risk of erosion where water movement is concentrated.

Suggested method for establishment of plant cover on waterways

- Direct sow by disc or tine three-point linkage-mounted drill, which is narrow enough to be accommodated in the bottom of the waterway. A small Connor Shea™ disc drill would be ideal. Drag light harrows behind the drill to cover the seed.
- If the ground is too hard to obtain effective penetration of 1 to 2 cm, lightly disc harrow to loosen up the surface.
- Where a suitable drill is unavailable, lightly disc to provide a seed bed for the incorporation of broadcast seed. Harrow after seeding.
- Sow the sides of the waterway as well as the base with seed and fertiliser.
- Sow a perennial pasture mixture to obtain stable, dense plant cover in the waterway.
- Carry out sowing as soon as possible after construction of the waterways to minimise erosion.
- Apply a heavy application of fertiliser to promote vigorous growth.
- During establishment it is essential that the soil be kept moist to the surface by irrigation, otherwise mortality of seedlings can be expected to be high in the warm to hot conditions of spring/summer.
**Suggested pasture mixture**

<table>
<thead>
<tr>
<th></th>
<th>kg/ha</th>
<th>$/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palestine strawberry clover</td>
<td>4</td>
<td>10.80</td>
</tr>
<tr>
<td>Whittet kikuyu</td>
<td>2</td>
<td>32.00</td>
</tr>
<tr>
<td>Ryegrass, e.g. Concord, Conquest, Richmond, Progrow</td>
<td>4</td>
<td>4.15</td>
</tr>
<tr>
<td>Oats</td>
<td>20</td>
<td>0.16</td>
</tr>
</tbody>
</table>

- A perennial pasture mixture is preferable because it provides stable cover. Rhizomatous grasses, including kikuyu and couch, are ideal because of the uniform, matted cover they provide to limit soil movement by trapping particulate matter. The same can be said for the perennial clovers, which should be sown with the grasses to provide nitrogen for growth.

- A disadvantage of the perennial species is that they could invade the cultivated land and become difficult to kill, especially couch which requires a high rate of glyphosate for effective control.

- Temperate perennial grasses, which generally have a tufted growth habit, are less desirable. There is an opportunity for soil movement between the clumps and rilling and erosion in the waterways.

- Phalaris, because leaf initiation commences below ground, would be the most suitable, with the ryegrasses and cocksfoot less suitable.

- Annual grasses and legumes are also less desirable owing to their instability in a sward, particularly where irrigation is conducted. This results in the sward being prone to invasion by weeds.

- Annual ryegrass and oats are included in the mixture to obtain quick ground cover to prevent soil movement. They are not expected to persist once the kikuyu and clover establishes a dense sward.

- If there is concern about the control of kikuyu in the vegetable areas, a suggested alternative grass to sow is phalaris. A fine seed bed is essential for successful establishment. Sow 4 kg/ha of Sirolan and roll the waterway afterwards, if possible.

- Kikuyu will not germinate unless soil temperatures reach 18-20°C.

- Clover must be inoculated and lime pelleted for effective nodulation and establishment.

**Suggested fertiliser application**

<table>
<thead>
<tr>
<th></th>
<th>kg/ha</th>
<th>$/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain super</td>
<td>200</td>
<td>0.30</td>
</tr>
<tr>
<td>Super copper zinc</td>
<td>400</td>
<td>0.43</td>
</tr>
<tr>
<td>Muriate of potash</td>
<td>100</td>
<td>0.44</td>
</tr>
<tr>
<td>Urea</td>
<td>100</td>
<td>0.57</td>
</tr>
</tbody>
</table>

**Procedure**

- Inoculate and lime pellet the clover the day of sowing.

- Drill or broadcast the seed mixed with the plain super.

- Broadcast the super copper zinc and muriate of potash after sowing.

- Broadcast the urea when the pasture mixture has germinated and the oats are 10 cm tall. Water the urea in after topdressing.

The total cost of establishing grass on a one kilometre of drain, three metres wide is less than $500.

**Cover Crops**

(Rose, 1997)

- Establishing a cover crop immediately after harvest is of prime importance, both on the high rainfall hills land to prevent water erosion and on the sandy coastal plain to prevent wind erosion.

**Minimise cultivation when establishing the cover crop or pasture**

There is no need to plough, rotary hoe, use a conventional wide point drill or roll the paddock. Further cultivation after harvest will do more damage to soil structure and may cause more soil compaction. It should not be necessary to fertilise the paddock as adequate nutrients for pasture or cereal establishment would normally remain in the soil from the horticultural crop.
Establishing a cover crop should be done with no more than one pass of a cultivation implement. The simplest and most effective way to sow a post-harvest cover crop is to broadcast coarse seed such as oats or lupins at twice the normal rate and follow with one pass of a tined implement or harrow. As well as reducing the risk of soil erosion, this method is simpler and cheaper than traditional cultivation sowing.

If there is risk of wet weather, broadcast the cover crop before harvest

Severe erosion events are most common after harvesting in late in autumn or winter when it has been too wet to sow a cover crop. Where there is a high risk of very wet weather, broadcast oats before harvest (use method 3 in examples below) and install temporary grade furrows immediately after harvest.

Ensure good vegetative cover and root structure

- Irrigate cover crops sown after summer harvest to ensure good establishment.

Irrigation of bare, cultivated soil during the period between crops or while the cover crop is establishing, is the only way to stop wind erosion on some sandy sites.

- Keep stock off the cover crop during winter to avoid pugging.

- Leave the roots of the cover crop intact. If establishing pasture in the following autumn, direct drill pasture seed into the cereal cover crop stubble. (see ‘Re-establishing pasture by direct drilling’, this section).

Install grade furrows to protect cover crops sown on sloping sites

This is particularly important to protect the soil from intense rainfall where root crops were harvested in late autumn or winter. On steeper sites (>5% slope) and longer slopes (>100 m), grade furrows should be installed immediately after sowing a cover crop at all times of the year. Where possible plan to avoid using the steepest country for crops that will be harvested in late autumn or winter.

Soil friendly methods of establishing post-harvest cover crops and pastures

1. Establishment of oats and pasture after harvesting potatoes

Growers in the Pemberton area use the following method to establish oats and pasture in one operation, after harvesting potatoes in April – June:

- Level the paddock by following the harvester with a crumbler (one pass only).
- Direct drill the oats and pasture seed.
  Or
- Broadcast oats and pasture seed together and cover the seed with one light pass of a crumbler implement.

Late maturing ryegrasses such as Concord or Conquest, with subterranean and balansa clovers are recommended. Ryegrasses have a vigorous root system that is good for restoring soil structure. The pasture must be sown as quickly as possible and with minimal cultivation, before the opening rains make the paddock too wet to work. The oats can then be grazed in spring, which will allow the pasture species to establish.

2. Alternative method to 1

- Broadcast oats straight after harvesting potatoes.
- Follow immediately with a deep ripper or chisel plough with harrows or railway iron dragged behind to level the ground. Work across the slope on a grade following the grade furrows.
- If pasture is to follow, broadcast and lightly harrow in or direct drill the pasture seed straight after the deep ripping.

A challenge is to develop an implement that deep rips, sows oats, levels and broadcasts pasture seed in one pass!

3. Recommended method for late harvest of potatoes

- Broadcast oats or an oat-lupins/vetch mixture immediately prior to harvesting. Vigorous oat
varieties such as Saia or Swan are best, and sow at a heavy rate (150 kg per hectare); fertiliser is not needed. The harvester will cover the seed and this results in acceptable germination.

- Follow the harvester with one pass of a crumbler to level the paddock.

This quick ‘fail safe’ method eliminates the risk of the paddock being too wet to sow a cover crop after harvest. It is recommended when another vegetable crop is to follow, as the oats can be grazed off in spring and/or turned in as a green mulch.

If a pasture rotation is to follow, seed should be direct drilled into the stubble in April of the following year. Hence, with this method, pasture establishment is delayed. Cultivation to sow the pasture should be avoided as this will leave the soil vulnerable to erosion and contribute to further soil structure decline.

4. For early harvest of potatoes, December to February

- Use method 1 or 2 to sow oats and pasture. Irrigate the cover crop several times to enable the pasture to establish with the oats

or

- Use method 2 to sow oats or a summer crop such as sorghum or Sudax. As early as January there is usually enough moisture left in the soil after harvest for the crop to establish. Graze or spray the crop off. Direct drill or broadcast and harrow in pasture seed in April/May.

5. For cauliflowers

Cauliflower stumps must be killed to prevent spread of pests and diseases. To do this with minimal soil disturbance, mulching with an orchard mulcher is the preferred method. A single pass with a rotavator at no more than 2 cm deep or a single pass with offset discs are other methods that are acceptable though less satisfactory as they entail more soil disturbance.

If a crop of potatoes is to follow, use method 2 (broadcast oats and chisel plough or deep rip) immediately after the cauliflowers are mulched.

If the paddock is to be returned to pasture, direct drill the pasture seed or broadcast and follow with harrows or crumbler as for method 1. Laneways and compacted areas may need deep ripping or chisel ploughing prior to sowing.

Practices that should not be used to sow cover crops

Traditional sowing methods, using the older types seed drills with conventional discs or scarifier points, should not be conducted when sowing cover crops.

These methods entail two or three cultivations with a scarifier or disc plough prior to sowing and sometimes rolling after sowing. This process completely destroys any root structure remaining from the crop, leaving a finely tilled soil surface with a cultivation pan at 15 – 20 cm depth. When heavy rain falls on soil in this condition, it cannot infiltrate into the compacted subsoil and runs off, carrying the loose topsoil with it. Use of traditional sowing methods for establishing post-harvest cover crops has been a major cause of soil erosion in the south west hills areas.

Cover crops and grazing

Stocking or driving machinery on wet paddocks that have been recently cultivated causes pugging and compaction which destroys soil structure. For this reason, the cover crop should not be stocked during winter. Two options are:

- Defer grazing until spring, graze lightly and cut for hay.

- If a summer vegetable crop is to follow, turn in the cover crop as a green manure in spring.

Re-establishing pasture by direct drilling

In the year following cropping, slash or graze the cover crop and use herbicides to kill the weeds. Direct drill the pasture with a minimum tillage pasture drill such as the Connor Shea 470 or 8000™ series.
These machines have specially designed narrow T boot tines and flat coulter discs that enable accurate sowing directly into the dry cover crop stubble or sprayed-off pasture, with minimal soil disturbance. Direct drilling involves only one pass and leaves old roots intact. This technique virtually eliminates erosion.

Direct drilling is not only better for the soil but also cheaper and more convenient than traditional intensive cultivation methods.

Points requiring close attention with direct drilling are:

**Depth of sowing**

Ideally fine seeds, such as clovers and grasses, should be sown at 1 cm depth and no greater than 2 cm. Germination will be reduced as depth increases. Oats and cereal rye will tolerate greater sowing depths and 3 to 4 cm will not affect germination.

**Speed of sowing**

If the correct ground speed is used there will be no need to cover the seed with trailing harrows, or by rolling. The T boot tine is designed to cause soil to collapse into the furrow to cover the seed, provided the soil moisture level is satisfactory during sowing.

**Fertiliser application**

Don’t drill compound or mixed fertilisers with fine seeds as they can be toxic to germinating seedlings. Toxicity is caused by the concentration of fertiliser salts in the soil solution, particularly in dry conditions.

Nitrogenous and potassic fertilisers are the cause of this problem when concentrated in solution. Fine seeds can be safely drilled with superphosphate at rates up to 200 kg/ha.

Broadcast nitrogen when oats or cereal rye have reached 10 to 15 cm tall, or when ryegrasses have reached 5 to 10 cm tall and have developed root systems to utilise the nitrogen efficiently. Potash can be applied at the same time, or, on loamy soils, broadcast prior to sowing. The foliage of the developing crop or pasture at the time of broadcasting should be dry to avoid burning.

**Insect control**

Frequent and close monitoring of insects at germination is essential. No till or minimum till seeding is more prone to insect damage than conventional sowing methods. Insects fall into the furrows left by the drilling operation and target the germinating seedlings. Watch for red-legged earth mite, pasture beetle, black beetle, weevils, grubs and slugs.

Inspect the reseeding closely every two days during germination. Inspection for weevils, grubs and slugs should be carried out in the late afternoon or evening, when they become active. If seedlings appear to be chewed, or are disappearing, scratch below the surface of the soil where holes are evident, or it appears to be disturbed, to identify the cause. Where damage is significant appropriate spraying will be necessary. Without spraying establishment is likely to fail.

**Wind Protection**

**Windbreaks**

(Farm Forestry Advisory Service, 1996; Lantzke, 1998)

- When growing in wind prone areas, include windbreaks in the soil management strategy.

On the Swan Coastal Plain in particular, high wind speeds can cause crop damage and reduce the efficiency of sprinkler irrigation problems. The south west coastal plain is generally the windiest areas in the state, with the dominant wind direction being from the east in the morning and from the south west in the afternoon. In winter, strong winds can also come from the north west with the approach of cold fronts. The establishment of well-designed windbreaks provides wind protection and thus helps achieve higher yields and quality for most horticultural crops.

Tree windbreaks slow some of the wind as it passes through, while the rest accelerates over the top. Wind speed at ground level is reduced for a short distance upwind and a much longer distance downwind. A windbreak’s effectiveness
at providing shelter depends on factors such as height, orientation to the wind, position in the landscape, permeability to wind and uniformity (or absence of gaps).

**Benefits of windbreaks**

Windbreaks can increase farm productivity by:

- Preventing soil erosion when paddocks are dry and bare.
- Reduced plant damage. Windbreaks decrease the incidence of broken stems, leaf loss and lodging of plants. The percentage of fallen and blemished fruit is reduced. Vegetable crops are protected from sandblasting.
- Increased plant performance. Trials of various crops have shown that windbreaks can increase yield. Strong, hot winds increase evapotranspiration, causing moisture stress so that more frequent irrigation is required.
- Tree windbreaks when managed appropriately can also reduce groundwater recharge, increase biodiversity and yield valuable timber products.

**Windbreak design**

Windbreak design will depend on their intended purpose – shelter, timber, aesthetic enhancement, or a combination of benefits. Next, consider your farm business and any limitations imposed by farm boundaries, roads, fences and soil types.

Because the cost of establishing windbreaks throughout a large farm can be high, give priority to:

- Areas prone to wind erosion, such as mid to upper slopes and crests on the windward side.
- Crops which are particularly susceptible to wind or spray drift.
- Paddocks used for young stock.
- Infrastructure such as dams, roads and sheds.

**Spacing between windbreaks**

Tree height is the main factor governing a windbreak’s effectiveness, so the taller the trees, the further windbreaks can be spaced apart.

Windbreaks are considered to give protection to the area around them where wind speed at ground level is reduced by at least 20 per cent. Using this yardstick, windbreaks can protect land for at least 20 tree heights in their lee, and up to four tree heights upwind. The area of greatest protection is between two and 10 tree heights downwind.

**Constructed windbreaks**

Artificial windbreaks can be used on the boundary of the property but, because of cost are usually used as smaller, internal windbreaks. Farmnote 24/84 ‘Building a synthetic windbreak’ details how to construct synthetic windbreaks.

Engineered windbreaks are designed to be between 40 and 55 % permeable, as the passage of some air through the fence prevents the turbulence created with dense or solid structures. Paraweb™ is one synthetic material used for windbreaks. Strong shade-cloth can also be used. Temporary Paraweb™ windbreaks 0.95 metres high, supported by steel pickets and slats, can be used for growing vegetables. (Schwartz, 1984).

**Tree windbreaks**

Trees make excellent windbreaks because they grow tall and are cheaper and more durable than other alternatives. To protect soil and crops, the ideal windbreak is about 30 to 40 % permeable to wind and has uniform foliage to ground level on at least one side. Number of rows and spacing will depend on tree species.

Large trees are generally only suitable for external windbreaks and need to be placed further from the crop area to prevent competition. Smaller trees can be used for both internal and external windbreaks

Many tree species can be used. Native *Casuarina* sp are popular, giving good protection all year. Native flowering species can provide added bio-diversity benefits as bird habitats. Deciduous poplars and alders are often used for summer protection. A single row of some species such as poplar planted closely, about 1.5m
spacing, can make a reasonable windbreak. Larger trees can be grown in two rows 3 – 4 metres apart with a similar distance between trees in the rows. An understory of shrubs and small trees to 5 m height between large trees is recommended. Root competition is a consideration. Some species, especially the larger ones, will require root pruning with a single-tined deep ripper if they are to be grown within one tree height of cropped areas. Root competition is a consideration and root pruning may be required with some species.

Table 2.5 Some suggested species suitable for windbreaks.
(Department of Agriculture WA, 1990, Bulletin 4147; Department of Conservation and Land Management Plant Propagation Centre)

<table>
<thead>
<tr>
<th>Species</th>
<th>Max. Height (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Casuarina cunninghamiana</em> (river sheoak)</td>
<td>15</td>
<td>Moderately dense canopy</td>
</tr>
<tr>
<td><em>Casuarina equisitifolia</em> (coastal sheoak)</td>
<td>10</td>
<td>Medium spreading canopy</td>
</tr>
<tr>
<td><em>Casuarina obesa</em> (swamp sheoak)</td>
<td>10</td>
<td>Salt tolerant</td>
</tr>
<tr>
<td><em>Agonis flexuosa</em> (WA peppermint)</td>
<td>10</td>
<td>Willow-like foliage</td>
</tr>
<tr>
<td><em>Cerotonia siliqua</em> (carob bean)</td>
<td>15</td>
<td>Dense canopy, edible beans, an introduced species</td>
</tr>
<tr>
<td><em>Callistemon sp</em> Kings Park Special bottlebrush</td>
<td>5</td>
<td>Fast growing, large red flowers</td>
</tr>
<tr>
<td><em>Melaleuca nesophila</em></td>
<td>5</td>
<td>Large shrub, mauve bottlebrush flowers, drought resistant.</td>
</tr>
<tr>
<td><em>Acacia celastrifolia</em></td>
<td>2</td>
<td>Ornamental</td>
</tr>
<tr>
<td><em>Eucalyptus cladocalyx</em> (dwarf sugar gum)</td>
<td>8</td>
<td>Fast growing</td>
</tr>
<tr>
<td><em>Eucalyptus lehmannii</em> (bushy yate)</td>
<td>4</td>
<td>Bushy mallee</td>
</tr>
<tr>
<td><em>Eucalyptus platypus var heterophylla</em> (coastal moort)</td>
<td>7</td>
<td>Spreading, dense canopy</td>
</tr>
<tr>
<td><em>Melaleuca lanceolata</em> (Rottnest Island tea tree)</td>
<td>6</td>
<td>Small dense tree suitable for coastal areas.</td>
</tr>
<tr>
<td><em>Eucalyptus botryoides</em> (southern mahogany)</td>
<td>30</td>
<td>Timber</td>
</tr>
<tr>
<td><em>Eucalyptus gomphocephala</em> (tuart)</td>
<td>20</td>
<td>Likes limestone soils, timber, fast growing</td>
</tr>
<tr>
<td><em>Corymbia maculata</em> (spotted gum)</td>
<td>25</td>
<td>Attractive tree, dense foliage, profuse cream flowers, timber</td>
</tr>
<tr>
<td><em>Eucalyptus saligna</em> (Sydney bluegum)</td>
<td>35</td>
<td>Timber, fast growing</td>
</tr>
<tr>
<td><em>Eucalyptus grandis</em> (rose gum)</td>
<td>35</td>
<td>Timber</td>
</tr>
<tr>
<td><em>Eucalyptus camaldulensis</em> (river red gum)</td>
<td>20</td>
<td>Timber potential, some salt tolerance</td>
</tr>
<tr>
<td><em>Pinus pinaster</em> (maritime pine)</td>
<td>20</td>
<td>Timber</td>
</tr>
<tr>
<td><em>Pinus radiata</em></td>
<td>30</td>
<td>Timber</td>
</tr>
<tr>
<td><em>Pinus canariensis</em></td>
<td>25</td>
<td>Attractive feature tree, timber.</td>
</tr>
<tr>
<td><em>Pinus pinea</em></td>
<td>10</td>
<td>Edible nuts</td>
</tr>
</tbody>
</table>

Note: There are other large trees with timber potential that are also suitable for windbreaks.

Refer to Section 8.1 for technical information on site preparation and tree planting.
Protecting bare, cultivated soil
(Agriculture Western Australia, 1993; Rose, 1997)

Minimise the time that the soil surface is left bare and dry.

Avoid cultivating large areas and leaving them bare before planting. It is usually not necessary to leave cultivated soil bare for more than a few weeks before planting, even if soil fumigation has been conducted.

After cultivating sites that are susceptible to wind erosion:
- Water dry soil regularly to stabilise the exposed surface
- Plant post-harvest cover crop and irrigate them after harvesting vegetable or potato crops on sandy soils during summer.
- Treat water repellent soils to ensure thorough wetting
- Install grade furrows where needed on sloping sites
- Leave crop residues on the soil surface as mulch.

Retention of crop residues is a proven method of preventing wind erosion in cultivated soils where there is risk of wind erosion after harvest. Only a small amount of material is needed – 50% ground cover is usually sufficient to prevent erosion. The roots of the crop residue should be left intact where possible.

Soils with greater than 50% gravel content are generally less susceptible to wind erosion.

Note: Grazing pea or faba bean stubbles should be avoided. They provide poor protection as their stubbles break up easily and blow away. The soil may be left completely bare resulting in a high risk of severe wind erosion.

Cultivation

Fast, dry cultivation increases the risk of wind erosion.

If soil moisture is adequate, it may be possible to maintain high cultivation speeds (up to 20 km/h) without significant damage to soil structure. Speed must be reduced if moisture declines.

Trash handling seeders and minimum tillage can improve the soil’s ability to resist erosion.

Cultivation should be stopped when clods are being excessively shattered and sand is being knocked out of the plant root balls. A cloud of dust can signal this stage.

On water repellent soils it is particularly important to conduct practices such as stubble retention and minimum tillage and ensure that the soil is thoroughly wet before cultivation.

Shelter crops

Shelter crops, sometimes known as ‘nurse crops’ are a way of protecting young plants.

Nurse crops of cereal species

Nurse crops of cereal rye or other cereal species can be planted between the rows of direct seeded vegetable crops such as carrots and onions to reduce sandblasting of emerging seedlings. Cereal rye is tough and withstands sandblasting much better than other cereals. It is sown at a rate of about 50 kg per hectare. The cereal rye is killed with a selective grass herbicide once the crop is established and before the cereal rye seriously competes with the vegetable crop. Nurse crops only protect the emerging seedling and do not offer many of the other advantages of windbreaks that are listed above.

All weather access
(Department of Natural Resources, Qld, 1995)

Good practices for constructing access tracks are as follows (see Figure 2.7, page 66).

- Construct tracks at ground level where possible.

In most situations, low cost unsurfaced tracks should be constructed at ground level by grading as lightly as possible and leaving no windrows alongside. This avoids cutting into unstable subsoils and channelling water in or alongside the track.
• Locate tracks on ridge-lines or directly up and down slope where possible.  

This will minimise the tendency for the track to collect water, thus reducing erosion.  

Where a track must cross a slope, it is good practice to construct it immediately below a surveyed diversion grade bank. In some cases the track can be run along the bank itself, but never in the channel. This minimises the land used, and protects the track from erosion.  

Avoid locating tracks on grassed waterways except where the waterway is specially dished in the middle to run water on stable ground between the wheel tracks (Rose, 1997).  

• Install ‘speed humps’ to divert water off the track.  

Construct ‘speed humps’ (low earth banks) across the track every 20-100 m to divert water off the track onto pasture on the lower side. Steeper grades require closer spacings.  

Maintain access tracks – any erosion damage should be repaired and drainage rectified promptly. Speed humps and diversion drains need to be maintained as necessary.  

Constructing built-up roadways is expensive, but may be necessary in situations of high use or poor drainage. If not properly constructed, they can intercept and channel water, thus causing erosion. Construct drains beside roadways where necessary. To minimise erosion of the drains:  

- Construct drains with a flat bottom, at least 0.5 meters wide.  
- Run the drains off into pasture or vegetation every 20-100 m depending on slope and volume of run-off.  

Where this cannot be done and the grade is steep, the drain may need to be lined with rock (see ‘Rocked chutes specifications and construction’ below).  

A qualified consultant should be employed to plan roadways so that gutters, diversion drains and pipe crossings are adequately designed and properly located.  

Rehabilitation of eroded and landslip areas  

❑ Establish and/ or maintain perennial vegetation on waterways.  

Fencing and/ or permanently vegetating streams and flow lines is much less expensive in the long run than taking a risk and trying to repair erosion after it has occurred. When waterways have degraded to deep eroding gullies, stabilising these is a costly exercise involving rocking or concreting at costs of up to $50,000 per km or more. The situation is best avoided by not clearing the natural vegetation from streams and fencing it to keep stock out. If waterways have already been cleared but are not yet eroding, they should be fenced as soon as possible to maintain vigorous perennial vegetation on them. Introduced species such as kikuyu grass and bull-rushes are easy to establish and suitable for degraded sites with no native bush conservation values.  

❑ Timely action is needed to treat erosion gullies as soon as possible after they start, as the damage may worsen rapidly.  

The eroding gully will need to be repaired in summer when there is little chance of rain. If the eroded section is short, the catchment less than 10 hectares and the slope less than about 3%, it may be possible to fill the gully and stabilise it by sowing a grass sward.  

Gully filling procedure  

(Department of Agriculture WA Farmnote 56/79)  

1. A road grader is the best machine to use for filling erosion gullies. Make the first 4-6 runs along the side of the gully taking up to 15 cm of topsoil away from the gully edge. Stockpile the fertile topsoil containing grass and clover seed in two windrows about six metres away from the gully edge on both sides.  

2. Switch the angle of the blade to cut off the edge of the gully and push subsoil into it. Work around and around the edge of the gully until it is filled to a gentle depression.  

3. Respread the windrowed topsoil over the filled gully area. Reseed with grass, oats and clover (see ‘Establishing grass cover to
4. To protect the filled gully while grass establishes, install temporary grade furrows at intervals of less than 50 m to divert run-off away from filled area and onto stable pasture. Construct a large horseshoe shaped diversion bank at the top of the filled area to divert larger flows from up-slope.

5. Fence the area immediately to keep stock off. Two electric tapes or wires are sufficient and cost effective to keep cattle off while vegetation establishes.

6. Keep the filled area grassed so it functions as a stable waterway. Do not attempt to cultivate over it again.

In cases where flow is confined to steep unstable eroding gullies and cannot be diverted to another more stable area, grassed waterways cannot be constructed. However, timely treatment is essential as hundreds of cubic metres of soil may be eroded away each winter, rapidly multiplying the cost of rectification. In these situations, more expensive constructed waterways are required.

Table 2.6 Constructed waterways
(Rose, 2000)

<table>
<thead>
<tr>
<th>1. ROCKED CHUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>Suitable for (site, soil types)</strong></td>
</tr>
<tr>
<td><strong>Gradient of earthworks</strong></td>
</tr>
<tr>
<td><strong>Profile</strong></td>
</tr>
<tr>
<td><strong>Machinery required for construction</strong></td>
</tr>
<tr>
<td><strong>Estimated cost</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. CHUTES LINED WITH CONCRETE REVETMENT MATTRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>Suitable for (site, soil types)</strong></td>
</tr>
<tr>
<td><strong>Gradient of earthworks</strong></td>
</tr>
<tr>
<td><strong>Profile</strong></td>
</tr>
<tr>
<td><strong>Machinery required for construction</strong></td>
</tr>
<tr>
<td><strong>Estimated cost to survey and construct</strong></td>
</tr>
</tbody>
</table>
Rocked or concreted chutes
(Rose, 2000)

Rocked chute- specifications and construction
(Rose, 2000.)

• Calculate the required cross sectional area of the chute. For catchments of larger than 20 hectares, 20 year peak flows should be calculated and the cross section designed accordingly. For paddock situations within the limits specified, dimensions in Figure 2.5 will be adequate.

• Part fill deeply eroded sections of the gully with suitable clay based fill and compact.

• Shape the gully into a shallow spoon cross section (see diagram) with a flat bottom 0.5 m wide (Figure 2.5). A road grader or track mounted excavator with wide bucket are the most economical machines to use for this operation. Choice of machine will depend on site terrain.

• Estimate the volume of rocks required. The rock layer is about 0.5 metres thick down the chute. A chute of the dimensions shown in Figure 2.5 will need a 10 cubic metre truckload of rock for every 7 metres of drain.

• Cart rocks and stockpile them down the gully adjacent to the chute so that they can easily be installed with a front-end loader, backhoe or excavator.

• The size of the rocks is very important. Approximately equal volumes of rocks 20 -50 cm diameter and rocks of around fist to golf ball size are needed. If the rock fill does not have a mixture of rocks between these sizes, make paired stockpiles of the smaller and the larger rocks.

Figure 2.5 Cross section of a rocked chute (suitable for slopes of 5% to 15%, with a cleared catchment area of up to 20 hectares).

• Purchase geo-textile – Bidum A24 or 34 grade. This comes in rolls 150 m long by 4 m wide (Geofabrics Australia phone 93094388).

• Bury the top of the geo-textile in a substantial trench at the top of the chute and fill with rock. Run the textile down the spoon drain.

• Spread a layer of the smaller rocks about 10-15 cm thick on the bidum cloth.

• Place the larger rocks on the smaller rocks.

• Fill around the large rocks with small fist sized rocks, packed in to make a uniform rock layer 40-50 cm thick.

• The geo-textile blanket should be wide enough to extend about 0.3 m outside the lip of the spoon drain on each side. After the rock is in place, grade about 0.5 m of earth in over the edges of the geo-textile.

Sow a strip a few metres wide along the edges of the drain with kikuyu, ryegrass and clover. Keep stock off while this establishes. This will stabilise and protect the edges of the drain in the event of over-topping.
Treatment of landslips
(Rose and Bennett, 1999)

Landslips can occur on steep slopes along geological lineaments or at the intersection of lineaments. These lineaments may be dolerite dykes, quartz seams, faults or shear zones. The slips are caused by clearing of forest allowing more water to infiltrate into the subsoil where it is channelled along the lineaments. This can lubricate the interface between the soil profile and saprolite (weathering rock), causing sections of the soil profile to slip. An extreme event such as heavy rain provides the ‘trigger’ for the slip to move.

Though usually less than one hectare, there are larger slips covering several hectares. Slippage is more common on steep, cleared, sites with shallow soils and bedrock close to the surface, such as found in the Blackwood Valley around Balingup and Bridgetown.

- Treat landslips early by fencing and planting with trees and shrubs to prevent worsening erosion and slippage.

It is helpful to map the lineaments on an aerial photo of the whole farm and tackle rehabilitation as part of a whole farm plan. AgWA staff can assist with this.

- Fence the slippage, including a hectare or more above, and keep stock off.
- Plant large waterlogging tolerant trees below the slip to stabilise it, e.g. *E. patens*, *E. botryoides*, *E. grandis*, *A. melanoxylon*, *E. robusta*. This helps prevent continued soil movement down the slope.
- Plant small shrubby deep-rooted trees directly above the slip, for example ornamental/flowering native species such as *Melaleuca*, *Acacia*, *Grevillea* and *Callistemon* are ideal. Their role is to bind the soil together and prevent erosion. Perennial grasses such as kikuyu can also be encouraged to grow in the slip. It is important not to use larger trees on the active slip as their weight and wind forces can actually make the slip less stable.
- Plant a tree-lot along the lineament up-slope of the slip as far as possible to help use the excess water. Commercial blue gums or eucalypts for sawlogs are good options.
- Pumping from a groundwater bore above the slip and using the water is another option, if the water is of good enough quality.

2.2 Maintain or improve soil physical and biological health

Understanding soil quality and health
(See Code of Practice 2.2)

Field tests for soil health
- Monitor soil health and where necessary change or modify soil management.

Why assess soil health?
(Murphy and Abbott, 2000)

Western Australian topsoils generally consist of material that is low in clay, organic matter and biological activity. Consequently their inherent soil quality is naturally low. These soils are widely used for farming but they are highly vulnerable to inappropriate management practices, which cause a decline in soil health. For sustainable soil management to be achieved, the growers need early recognition of soil health problems. To combat a decline in soil health with the intention of maintaining long-term productivity, the adoption of improved land management practices is required.

Soil quality index and benchmarks

University of WA researchers are developing a soil quality index based on the simple physical, chemical and biological soil tests listed in this section. The index will show critical levels for these soil quality indicators and active soil organic carbon for soil types within WA cropping regions. Farmers will be able to compare their test results over time and against the critical levels for their soil type and region. This will enable them to determine whether their soil health is improving or declining and adjust their management practices accordingly.
Organic matter – a key component of soil quality (Milton et al, 2002)

Sustainable management of soil, in particular soil organic matter, has been identified as essential for the continued viability of the Western Australian agricultural industry. Soil organic matter plays a key role in carbon, nitrogen, sulphur and phosphorus cycling and also improves soil structure.

Total soil organic matter content changes slowly (unless soil erosion occurs, in which case there is a rapid decline), due to the relatively small input of organic matter each year compared to the soil reserve. The reason is that a large fraction of soil organic matter in Australian soils is charcoal, which is essentially inert carbon. The size of the charcoal fraction is not influenced in the short-term by management practice.

Total soil carbon is therefore not suited to monitoring short-term (less than approximately 5 years) changes in soil fertility. However it is still common soil analysis requested by farmers.

The biologically active or ‘labile’ fractions of soil organic matter do reflect changes in soil quality. Methods of detecting them are appropriate for use within laboratory-based soil quality packages (see test 9, ‘Soil organic carbon and biological activity’, below). It is to be hoped that these tests will soon be available to growers.

Country-based training courses in soil fertility for farmers are presented in association with the Land Management Society. An intensive, university-based course on soil fertility, that specifically targets agricultural consultants and agri-business representatives, is held annually. These courses are supported by a ‘Soils are Alive’ newsletter (4 editions/year) and associated website (www.soilhealth.com). General aspects of soil biology and agricultural sustainability are also being promoted through a regular science section in the Western Australian No-Tillage Farmers Association (WANTFA) newsletter (www.wantfa.com.au) and a question-and-answer column (‘Ask Dr Dirt’).

How to test soil health (Rose, 1997)

To thoroughly assess a paddock, the physical and biological tests should be done for at least four sites per paddock to account for soil variability. The 10 simple tests described can be conducted and recorded in 30 minutes. It is recommended that paddock soil health and cultivation records are kept, as they can be compared over time and against local benchmarks when these are developed.

Equipment needed:
Spade, 10 cm soil sampling tool, plastic bags and tape, infiltrometer ring, clear dish standing on square of black plastic, watch, ruler/tape, soil penetrometer or sharpened 6 mm rod, 10 litres of rain water, recording sheet on clipboard, pencil.

A good set of tests for soil health is as follows:

Physical indicators
1. Soil moisture and time since last rain
2. Soil surface condition
3. Penetrometer test for compaction pans
4. Water repellency test
5. Infiltration rate
6. Slaking and dispersion
7. Soil profile description

Biological indicators
8. Large soil organisms
9. Soil organic carbon and biological activity

Chemical indicators
10. Chemical tests

Tests 2, 3 and 4 are important to determine the erosion prevention strategy.
Test 3. (Penetrometer test for compaction pans) can be repeated many times over the paddock concentrating on areas where compaction is suspected, such as loading areas.

Test 4 (Water repellency) should be done on dry surface soil from at least several locations in the paddock.

Tests 9 and 10 are laboratory tests, conducted on bulked surface samples taken over each soil type.
Digging two or more holes to 40 cm depth with a spade for each paddock is sufficient for the other tests. Test 5 (Infiltration rate) should be done next to the hole on undisturbed pasture. Tests 6-10 are conducted on soil from the holes.

**Procedure for ten soil tests**  
(Rose, 1997; Abbott, 2002)

**1. Soil moisture and time since last rain**

The physical and biological soil tests should always be done when the soil is moist, as results of some tests will vary with soil moisture. Recording soil moisture and time since last rain will also indicate how well drained the soil is.

Procedure – Feel handfals of soil from 0-10 cm and 10-20 cm depth.

<table>
<thead>
<tr>
<th>Dry</th>
<th>Dusty; no moisture present.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist</td>
<td>Moisture present but cannot be squeezed out by hand.</td>
</tr>
<tr>
<td>Wet</td>
<td>Moisture can be squeezed out by hand</td>
</tr>
</tbody>
</table>

**2. Soil surface condition**

This ranks the extent to which the soil surface has become degraded as a result of erosion, aggregate breakdown or compaction and the degree of protection by vegetation.

Observe the soil surface on an undisturbed 4 metre square area adjacent to the soil profile hole:

**Erosion.** Rills are where water has run and carried soil with it. Visually estimate the % of area affected by rill erosion and depth and length of rills. Repeat for gully erosion. Estimate % of area affected by sheet erosion (Section 2.1 ‘Observing the signs of erosion’). A more accurate way to measure erosion is by inserting pins marked at soil surface level. The amount of soil removed can be measured by measuring the length of pin exposed.

**Surface crusting** usually occurs in soils with a dispersible clay fraction. These are usually sodic. A crust up to 2 cm thick forms when the surface dries out. Record presence or absence.

**3. Penetrometer test for compaction pans**

Soils with sandy loam to sandy clay loam textures have a continuous range of particle sizes. These are more susceptible to compaction than poorly graded sands. Compaction can be detected visually by observing hard layers when digging, where roots will not penetrate. Direct measures can be obtained with a penetrometer.

A penetrometer measures soil hardness or degree of compaction. The readings can indicate (but are not directly correlated to) ability of roots to penetrate into the soil. Taking readings at every 5 cm depth will indicate whether compaction pans are present. Note that penetrometer readings can be unreliable in peaty or very gravelly soils and should be repeated several times.

There are several types of penetrometers. The simplest ‘home made’ version is a 6 mm rod with a handle. The depth of penetration under the user’s weight can be measured with a ruler. Another type, a 10 mm graduated, pointed rod with a sliding 1 kg weight, can be made for about $150. More accurate penetrometers can be purchased. These are sharpened rods with force gauges attached to the handle.

Record the force or number of blows (depending on the type of instrument used) required to penetrate each 10 cm depth of soil profile to at least 40 cm.

**4. Water repellency test (Water drop penetration test)**

Place a drop of water on the soil surface. On non-wetting soils the water will form a ball and stay on the surface for a while. Record on the sheet the time taken for the drop to infiltrate.
<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>wettable</td>
</tr>
<tr>
<td>3-60</td>
<td>slightly water repellent</td>
</tr>
<tr>
<td>60-600</td>
<td>strongly water repellent</td>
</tr>
<tr>
<td>&gt;600</td>
<td>severely water repellent</td>
</tr>
</tbody>
</table>

5. **Infiltration rate**

An infiltrometer ring is used to test for soil permeability. This measures the rate of water entry into the soil. Slow infiltration may mean compaction, unstable aggregates, poor soil structure or surface crusting.

To make the infiltrometer ring, cut the top and bottom out of a tin 15 or more cm in diameter. Make six indented marks 1 cm apart with a screwdriver up the outside of the tin starting three cm from the sharp edge. Twist the sharp edge of ring into the soil to the 3 cm mark and pack clay soil around the outside to form a seal. Avoid disturbing the soil surface inside the ring. Gently pour a few cm of water into the ring and wait for it to soak in completely and wet the soil. Then pour 5 cm depth of rain water into the ring (to top indented mark). Record the time taken for the water to infiltrate. Record the depth infiltrated after 5, 10, 20, 30 minutes.

6. **Tests for slaking and dispersion**

Aggregate stability tests measure the ability of soil crumbs (aggregates) to maintain their structure when subjected to forces, for example cultivation and raindrop impact.

The **slaking test** measures the extent to which these soil aggregates disintegrate into finer aggregates when placed in rainwater. The **dispersion** test measures the extent to which finer aggregates break down into clay (the aggregate appears to dissolve and makes the water ‘cloudy’).

Take a few 0.5-1.0 cm diameter crumbs of soil and immerse them in a shallow, clear dish of rainwater standing on a sheet of black plastic.

Record whether they slake or disperse after about 10 minutes.

7. **Soil profile description**

This essentially describes the soil type, i.e. the depth, texture, colour and gravel content of the soil layers, depth of root penetration and presence of plough or compaction layers.

Dig a 40-50 cm deep square-sided hole 30 cm wide. For the A horizon (top, darker coloured) and B horizon (soil below this), record:

<table>
<thead>
<tr>
<th>Depth</th>
<th>Use a ruler of steel tape.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Black, light or dark brown, orange, yellow or grey.</td>
</tr>
<tr>
<td>Gravel content</td>
<td>Estimate to nearest 10 % by volume of gravel stones larger than 2 mm.</td>
</tr>
</tbody>
</table>

**Texture**

Use the **ribbon test**. Take a golf ball sized quantity of soil free of gravel stones and work it up in your hand, adding drops of water until it is moist but not so that water can be squeezed from it. Work it out between thumb and forefinger into a ribbon. The length of the ribbon that can be formed and the feel of the soil determines its classification.

sand – S – will not form a ribbon, cannot be moulded, feels gritty.

loamy sand – LS – minimal ribbon about 5 mm.

clayey sand – CS – sand grains stick to and colour fingers, ribbon 5-15 mm.

sandy loam – SL – can be moulded but feels gritty, ribbon 15-25 mm.

loam – L – spongy, smooth feel (not gritty or silky); ribbon about 25 mm.

sandy clay loam – SCL – gritty feel but plastic; ribbon 40-50 mm.

clay loam – CL – smooth, plastic, ribbon 40-50 mm.

clay loam, sandy – CLS – plastic but some grittiness; ribbon 40-50 mm.

light clay – LC – plastic, smooth, slight resistance to ribboning shear; ribbon about 75 mm.
clay – C – smooth, very plastic, moderate to firm ribboning shear, can be moulded into rods, ribbon 75 mm or more.

**Roots**  
Record presence, depth and quantity.

**Compaction layers**  
Record presence or absence and depth. A pocket penetrometer can be used for down-hole testing of soil hardness.

8. **Large soil organisms**

The presence of earthworms indicates a healthy soil as these animals dig through the soil and exude ‘glues’ that help form soil aggregates. Many other soil micro-organisms, especially fungi, do the same thing but will not be visible to the naked eye. Although some beetles and weevils and most mites are beneficial to the soil, others, such as white fringed weevil, are pests of root crops. Either way, they are worth recording.

Examine the darker soil from the A horizon, especially the root zone. In pastures this is the vegetated sod of soil removed from the top of the holes. Record soil animals.

9. **Soil organic carbon and biological activity**

Biological fertility predominantly occurs in the surface layers of Western Australian agricultural soils (Murphy et al., 1998). Total organic carbon is measured by most laboratories, as part of their standard soil chemical analysis of samples taken from the top 10 cm. This test is of little use because most of the carbon in WA soils is charcoal, which gives no indication of the biological activity in the soil.

There are simple laboratory tests that are accurate and reliable enough to show changes in the biological health of soil in less than a 5 year time span. In the past these tests have not been available commercially in WA. However, due to promotion by researchers at the University of WA (Milton et al., 2002), they are becoming available in some laboratories.

Examples of useful laboratory tests for soil biological activity are:
1. Potentially available nitrogen
2. Hot water soluble C extraction
3. Cold water extractable C extraction
4. Microbial biomass

Growers are advised to seek laboratories that can do some or all of these tests and request that they be done in addition to the normal soil nutrient analyses.

Soil samples of 0-5 cm depth are required to detect changes in soil biological activity in the short term.

10. **Chemical tests**

Standard analyses of soil nutrients are available commercially through companies such as CSBP™ or Analabs™. Kits and sampling tools can be purchased from rural supplies retailers.

To get nutrient application right, it is essential to conduct a soil sampling and testing program, aiming to test each main soil type in each paddock or land management unit at three yearly intervals.

Sampling technique is important (Farmnote 94/84), as it is the usual source of inaccuracy of soil test results. Take at least 20 core samples to 10 cm depth for each soil type and bulk these together for testing. Samples should preferably be taken along marked transects so that these can be re-sampled in later years, enabling more accurate detection of changes in the soil nutrient status.

Have the soils tested at an accredited laboratory, e.g. CSBP™, Summit™, Chemistry Centre™ or Analabs™. Specify that the PRI test is required. It is often cost effective to engage an independent soil consultant to interpret the results and recommend fertiliser types and rates.

Keep the soil nutrient test records with the other data for each paddock.
Recording the health of your soil
(Rose, 1997)

The farmer can conduct and record most of the tests in the field. Table 2.7 below is provided for the grower to photocopy and use as field recording sheets. Soil nutrient status and soil organic carbon tests are conducted in the laboratory but can be attached to this recording sheet or entered into the tables.

Table 2.7 Soil quality and health test recording sheet

Farmer name ..............................................................................................................................................
Location No ..............................................................................................................................................
Paddock name ............................................................................................................................................
Date of this test ........................................................................................................................................

Paddock cropping history
Date cleared
Number of times cropped
Rotation interval between crops (years)
Crops grown
Current crop rotation
Original vegetation on site in order of abundance, e.g. marri, jarrah

Cultivation techniques

<table>
<thead>
<tr>
<th>Year that minimal tillage first used</th>
<th>List all cultivations and chemical applications used for last crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ...................................................... 2 ......................................................</td>
</tr>
<tr>
<td></td>
<td>3 ...................................................... 4 ......................................................</td>
</tr>
<tr>
<td></td>
<td>5 ...................................................... 6 ......................................................</td>
</tr>
<tr>
<td></td>
<td>7 ...................................................... 8 ......................................................</td>
</tr>
<tr>
<td></td>
<td>9 ...................................................... 10 ......................................................</td>
</tr>
</tbody>
</table>
1. **TOPSOIL MOISTURE AND TIME SINCE LAST RAIN**

<table>
<thead>
<tr>
<th>Soil moisture in A horizon (tick box)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry (D), moist (M), wet (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time since last rain (days, hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note that the soil should be moist for all of the physical and biological tests*

2. **SOIL SURFACE CONDITION**

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent of rill/ sheet erosion (% of area, depth of rills in cm), e.g. 25/8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface crusting (yes/no)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface soil structureless, massive – forms clods when cultivated (yes/no)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetative/ crop cover (type of pasture or crop or bare)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **PENETROMETER TEST FOR COMPACTION**

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (kPa) or number of blows to penetrate first 10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force (kPa) or number of blows to penetrate next 10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force (kPa) or number of blows to penetrate next 10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force (kPa) or number of blows to penetrate next 10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **WATER REPELLENCY TEST**

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (seconds) for a drop of water to soak into firm, dry soil surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. **INFILTROMETER TEST FOR SOIL PERMEABILITY**

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to infiltrate (minutes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>..............................cm in........minutes, e.g. 5/15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. SLAKING AND DISPERSION

<table>
<thead>
<tr>
<th>Aggregate stability test</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Tick box for A &amp; B horizons)</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td><strong>Dispersion:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no dispersion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>incomplete dispersion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>complete dispersion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Slaking:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aggregate retains shape</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>partial collapse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>complete collapse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. SOIL PROFILE DESCRIPTION

<table>
<thead>
<tr>
<th>A horizon</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel, approx. percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colour, e.g. orange, yellow, grey, brown,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture, by ribbon length (mm) and feel (see test description for codes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root abundance (0-3) 1 = few, 3 = many</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plough/ compaction layer? (yes/ no)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B horizon (subsoil)</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel approx. percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard pan present? Depth to pan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root depth (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. LARGE SOIL ORGANISMS

<table>
<thead>
<tr>
<th>3.1 Soil animals (tick if present)</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthworms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weevils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beetles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (name)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect larvae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eggs of earthworms or other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9. SOIL BIOLOGICAL ACTIVITY AND ORGANIC CARBON

Laboratory tests for organic matter and biological activity.
Take 0-5 cm samples taken at the same places as the samples for chemical tests.

<table>
<thead>
<tr>
<th>Paddock soil type, e.g. A-brown sand.</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>site D</th>
<th>site E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potentially available nitrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water soluble C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzyme activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbial biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

10. SOIL CHEMICAL TESTS

Notes:

- If the soil type is the same for all sites the samples can be bulked into one 0-10 cm sample and one 20-30 cm sample.
- PRI is only necessary on light sandy soils.
- Trace elements are only necessary every three or four crops or if deficiency is suspected.

<table>
<thead>
<tr>
<th>Soil type e.g. A-brown sand</th>
<th>pH (CaCl2)</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>Ca</th>
<th>PRI</th>
<th>Reactive elements</th>
<th>Trace iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>site A 0-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site A 20-30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site B 0-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site B 20-30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site C 0-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site C 20-30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site D 0-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>site D 20-30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site E 0-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>site E 20-30 cm</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Modifying soil management to treat soil health problems
(Rose, 1997)

**Erosion**
Treat by:
- Minimising tillage.
- Maintaining vegetative cover by post-harvest cover crops (high rainfall) or leaving stubbles intact (low rainfall).
- Constructing surface water control works such as grade banks, grade furrows, grassed waterways.
- Cultivating across the slope on a controlled grade.

**Surface crusting**
This indicates soil sodicity. Treat with gypsum.

**Cloddiness**
Increase organic matter. Introduction of a perennial pasture phase and growing mulch crops will help achieve this. Application of gypsum is beneficial in some soils and this can be determined by trying test strips. If the cause is compaction, treat by modifying cultivation practices (see ‘minimising soil compaction’ below). Don’t deep rip if the subsoil is clay.

**Poor infiltration**
Treat as for compaction. Minimise tillage and grow perennials where possible, to keep root channels intact deeper in the soil profile. Also see ‘Water repellency’ below.

**Soil compaction**
A short-term solution is deep ripping with a narrow tined implement. However, compaction is a symptom of using cultivation practices inappropriate for the soil type and needs to be addressed by improving the soil management strategy. Practices that minimise compaction are described under ‘Minimising soil compaction’ below.

**Water repellency**
(Blackwell and Morrow, 1997)

Practices that reduce water repellency:
- Applying clay to the topsoil by clay spreading or delving (bringing subsurface clay into the surface soil).
- Furrow sowing using press wheels is most cost effective for large areas. Similarly, press wheels can be used to flatten the tops of the hills when cropping potatoes.
- Liquid soil wetting products can be sprayed in furrows using specially adapted furrow seeders.
- Straw mulching is another means of improving infiltration.

**Slaking soils**
Build up organic matter by maximising vegetative growth, planting mulch crops or adding mulches or compost. Control surface water run-off to minimise erosion.

**Dispersive soils**
Treat with gypsum.

**Low biological activity/ organic carbon**
- Practise minimal or no tillage.
- Grow green mulch crops or adding compost or manures.
- Apply lime if pH <4.5.
- Introduce a perennial pasture phase such as kikuyu, lucerne or perennial rye.

**Water repellent soils**
- **Furrow sowing**
  Furrow sowing using press wheels most cost effective for large areas.
- **Straw mulching**
- **Application of liquid soil wetting products**

This is expensive but may be more practical for more intensive applications on smaller areas.
Minimising soil compaction
(Rose, 1997.)

The degree of traffic compaction increases with number of passes but the first pass does 90% of the damage.

• Control traffic during all cropping operations

Controlled traffic farming is the repeated use of the same wheel tracks for every tillage, planting, spray and harvest operation. The benefits are that damage to soil structure through continual compaction and re-loosening is confined to a small percentage of the cropped area. Tractive and field efficiencies are also improved.

Good practices in horticulture that are based on the principle of controlled traffic farming are:

- Standardising and widening the span of boomsprayers and fertilising machinery so that all post-planting tractor traffic can be confined to fewer, wider spaced tracks.

- Cropping on raised beds, which are the same width as the inside of wheel tracks standardised for all implements used.

• Make a single pass with a narrow-tined implement in the wheel ruts after planting.

For the final cultivation, make a pass with a three-point linkage mounted implement with tines following in the wheel ruts. This breaks up the compacted layer and aids infiltration of water.

• Keep tyre pressures as low as possible and use lighter machinery where possible.

Reducing ground pressure will reduce soil compaction. The most practical way to do this is to lower tyre pressures as far as possible. This effectively enlarges the ‘footprint’ of the tyre to a longer, flatter shape, spreading the weight of the machine over a larger area. Another way to reduce ground pressure is to use lighter machinery or tracked machinery where possible.

• Treat only the compacted areas by deep ripping.

Where traffic compaction hardpans do occur they can be broken down by deep ripping to 30-50 cm depth with a narrow-tined ripper. However, deep ripping should not be necessary as a regular practice. It is far preferable to minimise compaction by practicing minimal, appropriate tillage as described in the sections above. Ripping can have detrimental effects on soils with shallow clay B-horizons, by causing subsoil smearing and bringing clay to the surface.

• Keep stock and machinery off wet soil.

Most severe compaction occurs when the soil is worked by machinery or pugged by stock when wet. Stock and machinery should be kept off cropping paddocks in winter when the soil is wet.

• Practice mulching of crop residues and grow green mulch crops.

Leave the roots intact and the crop residues standing or slashed and lightly incorporated in to the top few centimetres of soil. This maintains the root channels, increasing soil organic matter and soil micro-organisms which improve soil structure and infiltration.

Minimising cultivation
(Rose, 1997)

The aim when cultivating is to minimise damage to the topsoil structure. This means minimising inversion, mixing, pulverising and smearing of the soil profile.

Table 2.8 summarises the ways in which topsoil can be damaged, the implements that cause the damage and the best implements to use to avoid it.

Frequent or fine tillage destroys soil structure by:

- Breaking up the natural crumb structure by destroying soil aggregates
- Destroying root pathways
- Compaction, creating traffic hard pans.

Compacted, poorly aerated soil has no crumb structure, fewer air spaces and high resistance to penetration (hardness). These factors limit root growth and reduce infiltration resulting in lower
crop yields, more run-off and more erosion. Contrary to common belief, fine tilth does not aerate the soil but has the opposite effect. Rotary hoes tend to destroy soil structure by their pulverising action. Disc and mouldboard ploughs smear and seal the subsoil causing ‘plough pans’ which limit root penetration.

Although horticultural cropping, particularly for potato and root vegetables, requires relatively intensive cultivation, there is great variation in the number and type of cultivations used. While the traditional method was to cultivate as many as 10 times (including planting and hilling), leading potato growers are now cultivating only four times, without any decrease and sometimes with increased yield and quality.

- Minimise tillage to maintain soil structure, reduce soil compaction.
- Keep cultivation and soil disturbance to the minimum required to grow the crop successfully.

Guidelines for good cultivation practice
(Rose, 1997)

In general:
- Narrow-tined implements are far less damaging than broad bladed implements.
- Slow rotation and travel speeds are less damaging than fast speeds.

The following are guidelines for good cultivation practice:

- *Minimise the number of cultivations.* Less cultivation means less destruction of soil structure and less compaction in wheel ruts. In the Manjimup-Donnybrook area, accepted best practice conducted by leading potato growers involves only four cultivations to prepare the paddock, plant and grow the crop.

- *Minimise depth of cultivation for all cultivations* other than when deep ripping hard pans. Deep ploughing reduces soil biological activity by inverting, mixing and diluting the crucial surface organic layer. This top five to ten cm of aerated soil is where most of the soil organisms, organic matter and nutrients are stored, readily accessible to crop roots.

- *Never cultivate through valleys or flow lines.* Leave at least a five metre wide uncultivated strip down flow lines to function as a stable waterway. Stabilise by planting a permanent grass sward.

- *Do not cultivate when the soil is wet.* Working wet soil is the quickest way to destroy soil structure and cause severe soil compaction.

- *Cultivate across the slope where practical.* If the slope does not exceed six percent, it is possible to cultivate, plant and harvest across the slope on a grade of two to three percent. This greatly reduces or eliminates the need for surface water control earthworks such as temporary grade furrows.

Don’t cultivate pasture to a fine tilth and don’t it leave fallow for long periods. Spray pasture off several weeks in advance. The root material and most of the plant matter will rot down on or near the surface. Best pre-planting cultivation practice is a maximum of two passes with a tined or scalloped disc implement (not a rotary hoe). Growers in south east NSW have grown excellent crops with only one pass of a ‘power harrows’ implement (see ‘Other good soil management techniques, this section).

Leave fallow for only long enough to ensure complete breakdown of plant material before planting. This minimises the time that the tilled soil is vulnerable to erosion.

Avoid the practice of soil fumigation where possible. Fumigation destroys soil structure and increases the risk of erosion because:

- It involves rotary hoeing the soil to a fine tilth.
- The soil is left bare for several weeks after the fumigant is incorporated.
- Fumigation temporarily reduces soil biological activity.

If fumigation must be done and the site is on a slope, install surface water control earthworks immediately afterwards to protect the bare soil from erosion.
**Implements**

- **Minimise the use of ploughs and rotary hoes.** Where possible avoid using rotary hoes at all as they destroy soil structure. Rotavators with straight blades, rotating at slower speeds are less destructive. Mouldboard ploughs invert and mix the soil profile, which is undesirable from a soil biological health perspective. Both implements cause smearing and cultivation hard pans, thus reducing infiltration. Mouldboard ploughs may have occasional application where lime needs to be incorporated deeper in the soil profile.

- **Use narrow-tined implements** such as deep rippers, chisel ploughs, and direct drills.

**Following with narrow tined rippers in the wheel tracks** after planting or spraying operations is good practice on hill slopes.

**Use of a basin tillage implement such as the Dammer Dyker™ is good practice** for post-planting cultivation on hill slopes. For potatoes, these can be mounted behind rippers and hillers on the same tool bar, to conduct all three operations in one pass. On gentle slopes of less than five percent grade, where crops are planted when there is little risk of intensity rainfall. This method is sufficient to prevent soil erosion.

**Table 2.8 Appropriate implements to minimise soil structure damage**

<table>
<thead>
<tr>
<th>Type of soil structural damage</th>
<th>Implements that cause this type of damage</th>
<th>Best implements to avoid damage</th>
</tr>
</thead>
</table>

* Rotary hoes have blades that are bent horizontally. These smear the subsoil. Rotavators and rototillers with straight tines are generally less damaging.
Minimising the impacts of soil fumigation
(Rose, 1997)

Fumigation is currently the most effective way to control whitefringed weevil in potato crops. Metham sodium fumigant is incorporated into the soil prior to planting. For the fumigant to be effective the soil has to be ploughed and rotavated to obtain a fine tilth and the fumigant is incorporated with a blade plough.

This treatment is costly and destructive of soil structure. It can and should be avoided where possible, where monitoring determines that it is not necessary.

Potato paddocks should be monitored for whitefringed weevil in the summer before planting by using the simple procedure described in Section 7.2 under ‘Monitoring for whitefringed weevil’.

If monitoring determines that soil fumigation must be conducted, then good surface water control practice is crucial. Grade furrows should be installed immediately after fumigation to protect the finely cultivated soil from erosion. They should be re-cut immediately after planting and again after sowing of the post-harvest cover crop.

Soil treatment for control of African black beetle without soil fumigation

An effective method for black beetle control is to spray chlorpyrifos on the soil in front of the planter or incorporate it using only a single pass with tines and a crumbler. These methods of incorporation are much less destructive of soil structure than fumigation because they do not involve rotary hoeing and leaving the soil bare. Also, the pesticide acts only on insects, not other soil organisms such as fungi that may be beneficial to soil structure. However, for chlorpyrifos to have any effect on controlling whitefringed weevil as well as black beetle control, thorough incorporation with a rotary implement is necessary.

Biofumigation—another way to minimise soil fumigation

Biofumigation is the sowing of plant species that contain natural chemicals toxic to soil borne insect pests. These plants may be grown as inter-row ‘nurse crops’ or between rotations and incorporated into the soil. The potential of some Brassica species containing high levels of biofumigant chemicals called glucosinolates is currently being researched, but proven biofumigation strategies are yet to be established.

Other good soil management techniques
(Rose, 1997)

Other good soil management techniques that have potential for use in WA vegetable and potato growing are outlined below.

Sowing of post-harvest cover crops from the potato harvester

A small, hydraulically driven seeder can easily be mounted on the potato harvester. Large seed such as cereals, vetches and lupins is dropped via tubes beneath the conveyor belt where it is covered with soil while the harvester is operating. This technique is used in the USA. It eliminates the risk of failing to sow a cover crop and saves the cost of broadcasting or drilling seed.

Minimum tillage for brassicas

There has been interest from some growers in growing cauliflowers by planting directly into pasture that has been sprayed off. A special planter incorporating rippers, coulters and press wheels would need to be constructed to do this. Some growers are already reducing the number of cultivations from several down to three or four.

Permanent beds for cauliflowers and potatoes

These are used extensively on flood irrigated flats and some sprinkler irrigated hills areas in
Queensland and South Australia. They have been tested successfully on winter waterlogged dry land cropping sites at Mount Barker, WA. The benefits are that the tractor wheels always pass over the same tracks and the beds are raised, thus reducing soil compaction and waterlogging. When permanent beds were used in conjunction with minimum tillage, improvements in soil structure were demonstrated on some sites. A bed-shaping implement is needed to construct the beds.

**Power harrows**

The power harrows was developed by the Robertson District Potato Advancement and Landcare Association in NSW, with the help of a National Landcare grant. It is essentially a three- point-linkage deep ripper with tines fitted with a set of side sweeps to lift and fracture the subsoil. A gearbox driving two vertical ‘roto-tillers’ and driven by the tractor power take off is bolted to the frame. The ‘roto-tillers’ cultivate 40 cm strips to coincide with the potato hills. Minimum till trials in which the only cultivation prior to planting was one pass with the power harrows showed yield increases of two to 34% in five of seven trial plots. Improvements in gross margins were even greater than the yield increases as production costs were considerably reduced.

**Straw Mulching**

A mechanical straw mulching machine is used to apply clean cereal straw to the inter-row furrows at rates of 600 to 1000 kg/hectare. The Hobson Straw Mulching machine uses baled straw and can be operated by one man from the tractor seat.

The machine, which is patented, consists of a series of bale chambers attached to a head frame spaced to match furrow widths. Each chamber is an individual unit that has its own hydraulic motor for operation. It applies the straw in 20 – 25 cm lengths evenly on the soil surface and presses it in with a flat cleated press wheel.

A straw mulching machine of a different design, constructed from a self propelled cereal crop harvester, is currently being used to apply mulch in swaths under grape vines in the south west of WA.

Trials conducted in Idaho, USA, have shown that straw mulching increased potato yields by seven to 40%, reduced soil loss by up to 95%, nitrogen loss by at least 46% and phosphate loss by at least 65%.

The machine has not yet been demonstrated in WA, but trials have been conducted in the Manjimup area by spreading straw manually between potato ridges. Visual observations confirmed decreased run-off from the treated area.

**Cropping rotations**

- **Adopt cropping rotations that restore structure and organic matter to the soil**
  
  For potatoes and cauliflowers, the recommended rotation time between crops is three to four years. The usual reason for this is to control soil borne diseases but the practice also has a crucial role in restoring soil structure and increasing soil organic matter.

  Pasture grasses such as ryegrass and some cereals such as oats have dense, fibrous root systems which exude substances that ‘glue’ soil together, thus restoring the structure, organic content and biological activity.

- **Aim to have at least two years in ryegrass/legume pasture or cereal crops grown under minimum or no till between the horticultural crop phases.**

**Increasing soil organic matter**

(Rose, 1997)

Adding organic matter to the soil improves the water holding, structural, pH and nutrient availability qualities of the soil.

- **Maintain or increase soil organic matter by:**
**Green mulching**

Growing a ‘break crop’ and mulching it in before growing the vegetable crop is known as green mulching. This practice has two-fold benefits in that it improves the soil biological health and is an effective pre-plant weed control. The medium term gains are reduced cost of weed control and increased vegetable yields due to enhanced soil biological activity. These usually outweigh the costs of sowing the crop and foregoing grazing production for a few months.

To mulch a ‘break crop’, slash it a few times before it becomes too rank and fibrous, leaving the plant matter to break down on the surface. Finally, kill it by spraying with a selective herbicide.

It is not necessary to deeply plough in crop residues as this destroys the soil’s essential surface organic layer. If there is still fibrous stubble, it can then be chopped up and partly incorporated in the top few centimetres of soil, leaving the deeper roots intact. Suitable implements to achieve this are orchard mulchers or scalloped offset disc ploughs.

Leave it for long enough for the stubble and roots to break down before planting, to reduce the risk of *Rhizoctonia* disease (Section 7.1 ‘Pest habitats and hosts’). Hill slopes may need to be protected by soil conservation earthworks during this period (Section 2.1 ‘Erosion prevention by surface water control’).

**Applying compost**

Compost is beneficial to soil health in the same way as green manures. Compost application may be more economic than green mulching for intensive, frequent cropping, where the property is close to a compost manufacturer, as transport is a major cost.

There are many grades of compost, ranging from green waste compost, which is relatively low in nutrients, to spent mushroom compost and composted poultry manure, which are much higher in nutrients. The nutrient analysis of the compost should be taken into account when calculating fertiliser application rates.

All composts increase the soil biological activity, buffer soil pH, improve nutrient availability, improve soil structure and increase the capacity of the water to hold and retain water. Economic yield increases have been obtained in trials for a range of vegetable crops with compost applied to the surface before planting at rates as low as 25 tonnes per hectare (Paulin, 1999).

**Compost for sustainable horticultural production systems**

(Paulin, 1999)

*What is compost?*

Compost is a biologically active material of largely organic origin. It can have widely differing texture and is a typically dark brown colour with an earthy smell.

Compost is the result of a managed decomposition process in which a succession of aerobic micro-organisms break down organic matter into a range of complex organic substances, loosely referred to as humus. Some of these substances are very stable, with a half-life in the soil of greater than 100 years, whilst others have are broken down much more quickly.

The presence, effectiveness and build-up of soil organic matter and, more importantly, effective organic cycles, is a function of climate, soil type and management practices. These factors will ultimately determine how much compost is needed to increase soil organic matter.

**Potential benefits**

The benefits of using compost will largely result from its effects on soil organic matter levels and increased organic matter cycling.

Using compost can be expected to reduce production costs and improve crop performance by:

- Improved crop yields, quality and storage life.
- More efficient and reduced use of fertilisers and pesticides, including soil fumigants.
Increased ability of the crop to resist pests and diseases.

Using compost can also improve soil quality and health by:
- Improved soil organic matter levels and organic cycles.
- Increased plant available water.
- Increased nutrient availability and nutrient holding capacity.
- Improved soil structure.
- Reduced levels of soil borne plant pathogens and pests.

It is important to accept that these changes will accumulate with its continued use and that the full benefits, especially in terms of disease and pest control may take several years to develop.

**Compost production**
(See Appendix 2.3)

**Compost quality**
Compost quality depends on maturity, type, nutrient content and levels of contaminants. Contaminants include pests, pathogens, seeds of weed species, inert contaminants such as plastic in all its forms, metal and glass and heavy metals. If industrial waste or sewage sludge has been used to make the compost, heavy metal contaminants can include cadmium, arsenic and lead, which are toxic, and plant nutrients such as copper and zinc, that with repeated soil application could build to plant toxic levels.

The objective of compost manufacture is to either eliminate these risks or keep them to acceptable levels. Compost manufacturers therefore need to have demonstrable certified quality control processes in place.

**Compost maturity**
As a guide, with immature compost, temperatures in a moist undisturbed compost pile will be hot, relative to fully matured compost where temperatures will have stabilised around 20-25°C.

Feedstock and composting time largely determine compost maturity. The level of maturity is characterised by a succession of micro-organisms. For example, relatively immature composts are characterised by high levels of Actinomycete fungi and these composts are potentially more effective at disease suppression.

Immature composts are those that have not completed the thermophyllic phase and are best suited for use as mulches. They still have a relatively high nitrogen requirement and are likely to compete with crops for nitrogen, especially when incorporated in the soil. This is termed nitrogen draw-down, and the potential for it to occur can be determined by conducting a nitrogen draw-down index or NDI test in a laboratory. Note, that under the Australian Standard AS4454 for compost, these materials can be called compost, providing they have undergone adequate periods of temperatures above 50°C to control pests, pathogens and weeds.

For horticultural production the main consideration is whether the material is best suited to soil incorporation prior to crop establishment or application as mulch after the crop has been established. Current experience indicates that immature composts are best used as soil mulches and generally to established tree or vine crops.

**Compost type**
Compost from non-woody organic materials such as crop waste, straw and leafy materials has a fine granular appearance and takes the least amount of time to make. This is because the carbon in these materials is easily degraded. With the addition of clay in relatively small amounts, these composts develop a good crumb structure that is visibly soil like in appearance.

Composts made from lignified woody materials displays different characteristics and, unless coarse woody material is screened out, is best suited to use as surface mulches. (mainly because the carbon from these sources is difficult to degrade). These materials are
therefore effectively immature composts because they contain, depending on their age and coarseness, undecomposed woody material. Soil incorporation processes generally break up this woody material, increasing the amount of exposed, undecomposed woody material. This results in increasing microbial activity and decomposition which competes for available nitrogen and potentially reduces crop growth.

Composted mulches can still influence and enhance soil microbial activity and hence will generally outperform non-composted mulches. They are likely to become more available as local governments increasingly divert ‘green waste’ from landfill.

*Nutrient content and characteristics*

The nature and ratios of the materials or feedstocks used to make compost will influence the nutrient content of the compost produced.

Being derived largely from plant materials (typically 80% of the initial mix), compost nutrient contents and their ratios will be similar to those in most crops. Depending on the rate used, compost therefore has the potential to supply mulch of a crop’s nutrient needs.

Phosphorus and potassium are typically in the order of 1.5% to 3.5% and 1.0% to 2.5% respectively.

The critical factor is nitrogen. Nitrogen levels rarely exceed 1.5% (dry weight) in well-made reasonably mature composts. In mature compost, nitrogen is almost totally organic and is therefore largely contained within microorganisms. Their constant recycling means a slow release of nitrogen. However in most horticultural cropping situations, this nitrogen source alone is unlikely to be sufficient for crop requirements.

*Compost reduces leaching of nitrogen*

One of compost’s advantages is its ability to significantly reduce leaching, particularly of nitrate nitrogen. Compost retains nitrogen and releases it slowly. Overseas experience suggests that in initial years of compost application, 30% to 50% of the total nitrogen will be available to a crop within six months. However, this will vary with climate and soil type as well as compost type.

*Strategies for using compost*

Full benefits will only be obtained from regular, repeated compost applications. As the impact on soil organic matter cycles and microbial populations stabilises, significant reductions in fertiliser, irrigation and pesticide applications will be possible.

For vegetable production on sandy light soils, trial work suggests that rates in the order of 20 tonnes/ha are sufficient to achieve significant results. In the longer term, it is feasible that lower rates of 10-15 tonnes/year will be sufficient to maintain these benefits. However it must be stressed that these rates will be determined by our ability to adopt management practices that encourage the maintenance of effective soil organic cycles. These include the reduced cultivation, greater use of cover or break crops and selection of pesticides and fertilisers that are less disruptive to beneficial microbial populations.

*Spreading of compost*

Ideally, compost is applied using specialised compost spreading machines, which generally utilise conveyer belt feed and rotary spreading mechanisms. Large capacity Multi-spreaders™ or similar type fertiliser spreading units will do the job, but are ideal due to slower spreading rate and greater susceptibility to blockage.

The ease of spreading of different grades of compost varies with the composition (feed stock materials used) and moisture content. For ease of spreading, the compost needs to be moist but friable and crumbly in texture. Spreading is difficult if the product is wet and soggy.

*Cost considerations for using compost*

Estimated percentage savings in input costs needed to cover a range of compost prices and rates are presented in Table 2.9. These figures are based on typical fertiliser, pesticide and irrigation costs associated with major vegetable
crops grown on the sandy soils of the Swan Coastal Plain (Vegetable Budgeting Handbook for the Swan Coastal Plain, Peter Gartrell, (1998) Agriculture Western Australia Miscellaneous publication 13/98). These estimates indicate that as little as a one third reduction in the cost of these inputs will cover the cost of a 25 t/ha compost application. This break-even figure does not include any consideration of increases to marketable yield that have already been demonstrated for several crops. The rates of compost used in Table 2.9 have achieved yield increases in practice. The current costs of compost typically vary around $40 to $50 per tonne, depending on source and transport requirements. In future, factors such as landfill reduction targets, introduction of landfill levies and restrictions on the use of raw poultry manure are likely to result in some downward pressure on compost prices.

Table 2.9 Percentage input cost savings in fertiliser, pesticide and irrigation, required for economic compost application

<table>
<thead>
<tr>
<th>Rate of compost (tonnes/ha)</th>
<th>Percentage input cost savings required to cover cost, at compost price per tonne ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$20/tonne</td>
</tr>
<tr>
<td>12</td>
<td>8.1%</td>
</tr>
<tr>
<td>25</td>
<td>16.9%</td>
</tr>
<tr>
<td>50</td>
<td>33.8%</td>
</tr>
</tbody>
</table>

Some compost suppliers in the south west

Malatesta Green Organics, Bunbury.
08 9725 4144

Custom Composts, Mandurah.
08 9581 9582

Cost is around $30 per tonne depending on grade. Transport (back-loads) can be arranged through local hauliers. E.g. Kamman Bulk Haulage will deliver to orchards in Manjimup for around $18 per tonne for road train back-loads.

Claying of light sands
(Carter and Hetherington, 1999)

Light sands, especially white, grey and black sands often have attributes that cause environmental and production problems. They are often water repellent, which causes poor infiltration, uneven wetting and susceptibility to erosion at the break of season.

They also have a low Phosphorus Retention Index and a low reactive iron content that translates to a low holding capacity for nutrients, rendering the soil infertile and prone to nutrient export when fertilisers are applied.

The hydrophobic compounds (waxes, alkanes, long chained fatty acids) that are left behind in the breakdown of organic matter are a major cause of water repellence in non-wetting soils. Most of the water-repellent soils have clay content of less than one percent. Sands that have three to four percent clay content do not appear to have these water-repellent characteristics.

Water repellence generally exists only in the top 100mm cultivated layer. The soil below this depth wets up easily because of the lack of organic matter and hence the lack of hydrophobic compounds.

Research carried out by Agriculture Western Australia on cereal cropping/pasture land evaluated the application of clay subsoil to increase the ability of these soils to accept water. An amount of 100 t/ha of subsoil with a 30% clay content, mixed into the top 100 mm increases the clay content of the cultivated layer...
to three to four percent. This ameliorant is continuing to produce positive results even 8 years after the first application.

**Benefits of clay application**

- **Increased production.** Under claying, lupin yield increased by 700 kg/ha whilst pasture seed production increased by 100%.
- **Increased moisture infiltration.** Infiltration rates increased by three times, with the addition of the clay, and the water repellency rating of the soil was reduced from high severity to zero in the second year after application.
- **Even wetting of the soil.** The soil wets up evenly and even light rains are able to penetrate over the whole surface. The even wetting of the soil allows the majority of the weed seeds to germinate at the same time, allowing better herbicide activity and weed kill.
- **Wind erosion control.** The sand develops a crust after rainfall and enough strength to prevents wind erosion when undisturbed.
- **Nutrient retention.** Retention of phosphorus and potassium which is made available to the plants.
- **Increased microbial activity.** Longer period of soil wetness encourages longer soil microbial activity.

**What are suitable clay subsoils?**

A clay content of 30% or more is the most important attribute of subsoils for spreading. Doing a texture or ribboning test can assess this (Section 2.2 ‘Procedure for 10 soil tests’). Knowing the actual clay content can assist you in decreasing the amount of subsoil that needs to be spread and also the cost of spreading. Changes in the subsoil as the pit is excavated should be checked to make sure you are not spreading sub standard material.

The other important thing in the subsoil is its ability to slake (Section 2.2). If the subsoil does not slake it is not suitable.

Subsoils that have high clay content (>50%), slake quickly and are highly dispersive (Section 2.2) are even more suitable and could be spread at lower rates.

The pH of the subsoil should also be taken into account in determining the rate of subsoil to be spread. Most subsoils in Western Australia are slightly less acid than the topsoils and will not affect the pH of the topsoil markedly.

The amount of subsoil that is applied will determine the clay content in the top 100 mm of topsoil. If spreading larger quantities than 100 t/ha, incorporation to a greater depth will be necessary to avoid a hard setting problem in the topsoil.

**Location of suitable subsoil**

The greatest cost in clay spreading is the transport cost. The optimum cartage distance would be 300 metres or less. If suitable clay can be found in the centre of the paddock then that is the cheapest option, but this is not always possible. Other options include increasing the catchment on an existing dam, building a new dam and using the excavated subsoil or digging a silage pit.

The first step is to auger in the desired locations for suitable clay. Most clay/spreading machines require 50 metres of pit length to fill the bowl in one pass. Examine the area to make sure there is depth of subsoil and no sand seams or large rocks.

**Spreading the subsoil.**

It is best to aim for an even cover of clay/subsoil as this will require only one incorporation and can then be left until seeding time. This is however not possible with all machines. The Claymate™, RoadScraper™, Multi Spreader™, Lehmann™ and Landplaner™ have all been used to spread clay and can all do the job. The amount of ripping that is done in the pit prior to loading the machine determines the quality of the spreading job. The finer and drier the material that goes into the machine the better it will come out.
For vegetable and potato cropping, the recommended application rate is 200 tonnes per hectare of subsoil if the clay content is 30% (Heap, 1998). Proportionally lower rates can be applied if the clay content is higher.

The spreading rate should be verified on the ground with the use of catching trays or small tarp. If gaps are left between the clayed strips, that distance should be no more than 1.5 metres. This is about the maximum distance that can be comfortably smudged in two runs.

Smudging is performed by dragging a frame made from two railway irons across the trails of subsoil. The frame is pulled at speed diagonally across the trails twice, in opposite directions at 45 degrees to the strips to give an even spread. This operation will also incorporate the clay.

**Incorporation**

The subsoil spread on the surface should be incorporated soon after it is applied. If it is not and it rains, it will slake and form a solid mass, which will have to dry out before you can smudge and/or incorporate. This mass of subsoil will also shed water and restrict plant growth.

Incorporation of 200 t/ha for vegetables or potatoes should be to a depth of about 100 to 150 mm initially, so that about a quarter of the material is still on the surface. The material on the surface gets rained on and slakes but is not in a high enough concentration to seal the surface and shed water. Being in contact with the spread clay that is on the surface will also wet the material just below the surface.

The incorporation can be achieved with tines or offset discs. Cropping the paddock for two years helps the incorporation.

**Site specific soil management strategies**

(Refer to Section 2.2 of the Code of Practice)

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### 2.3 Manage soil and drainage to minimise export of nutrients and chemicals

**Export of nutrients and chemicals**

(Refer to Section 2.3 of the Code of Practice)

**Erosion**

(Refer to Section 2.3 of the Code of Practice)

**Leaching**

(Refer to Section 2.3 of the Code of Practice)

**Waterlogged sites**

(Rose, 2000; Bennett et al, 1999)

Winter waterlogging is a common problem in the high rainfall SW, as the heavy rainfall during the period May-September can saturate the soil profile for more than a week at a time on some sites. Sites that remain waterlogged in summer are generally not suitable for horticulture in high rainfall areas because:

- Most horticultural crops cannot grow in prolonged waterlogged conditions.
- Waterlogged soils are often unstable and likely to erode when cultivated

In situations where waterlogging is caused by seepage discharge which is fed continually by groundwater under pressure, the area is best excluded from horticulture paddocks. It should be fenced and vegetated with native swamp species. In some other situations waterlogging can be treated effectively but it is essential that correct drainage practice is conducted.

**Correct drainage practice**

- **Plan carefully before proceeding with drainage:**
  - A notification of intent (NOI)* may be required if the drainage will affect downstream users. The local catchment group and downstream neighbours must be consulted to ensure that planned drainage
is in accordance with the local water management plan.

* Contact the local Department of Agriculture Land Conservation Officer.

☐ Obtain expert help with drain design and surveying to ensure that the drainage is suitable for the soils, terrain and local drainage system. For drains in waterlogged areas:
  - The grade should generally not exceed 0.5%.
  - Spoon or W-shaped drains are most appropriate.

**Shallow, broad-based drains**  
(Department of Agriculture Western Australia, 1984)

To ensure that erosion of the beds and banks does not occur, all drains should be as wide and shallow as possible and the grade should be surveyed to be uniform. Flowing water becomes much more erosive as depth and speed increases. Grades of up to one percent are acceptable on stable soil types but on sandy soils, 0.5% is the recommended maximum. The depth should not exceed 0.3 metres. There are two types of drains that meet these criteria.

**W-drains**

A typical W-drain has an excavated channel on either side of a central spoil bank. Water moves easily into the drain from both sides but the spoil bank disrupts vehicle access. Where straight W-drains can be built, the spoil may be formed into a small road access across wet flats.

**Spoon or U-drains**

When building spoon drains, soil is spread alternatively on either side of the drain in as thin a layer as possible so that water can flow in easily. To spread soil adequately, a road grader is required. An advantage of this design is that vehicles or machinery can cross the drain. Note that the drain channel itself should never be cultivated.

**Survey**

The best time to peg W or spoon drains is after heavy rain when the depressions are easily seen and the lowest point of each can be easily located. A steel peg or wooden post can be hammered into the depressions and the relative levels measured with a laser level later. Once this has been done, a network of drains can be planned. Levels are taken on the high and low points. The levels can then be plotted on graph paper to find the overall grade and depth of cut necessary through the high points.

**Construction**

W-drains can be built with a road grader in clay soils at three to four hours per kilometre. As spoon drains require the soil to be spread, they may take four to six hours per kilometre.

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**Figure 2.6 Cross-sections of broad-based drains**

**Spoon drain**

3 to 4 metres

0.3 metres

**W-drain**

3 metres

0.3 metres

5 metres

3 metres
**Maintenance**

Re-grading will be required if the channels silt up on flat grades. Silting is an indication that erosion is occurring due to poor drain design or poor soil management, which should be rectified.

Keep the channels grassed, particularly where the grade exceeds 0.5%.

Major drains should be fenced off and vegetation established along the banks (Refer to Section 5.3 for details).

**Interceptor banks**

- **Graded interceptor banks are a way of reducing waterlogging on slopes with duplex soils.**

A grader is the best machine for constructing these, in the same way as grade diversion banks. The difference is that they may be deeper (up to 0.8 metre), to intersect the impermeable clay layer. They are designed to run water and are a good means of water harvesting.

**Sub-surface drainage**

Sub-surface drainage, by perforated drain coil pipe, mole drainage or tyre drains, is sometimes used to combat waterlogging and soil salinity (Section 2.4). However, it is not recommended for wet grey sands as these soils have a low capacity to retain nutrients and chemicals. Phosphorus and nitrogen may be leached from the soil into the drainage outflow where it may enter wetlands or waterways.

**2.4 Manage soil acidity, sodicity, salinity and other soil chemical problems**

**Soil acidity**

Horticultural cropping acidifies the soil at a faster rate than other agricultural activities because it removes more plant products and requires more fertiliser. Plant material is generally alkaline. When it is removed the soil becomes more acid, especially in the root zone at five to 20 cm depth. Significant yield reductions will occur for nearly all crops and pastures when the pH (in CaCl₂) falls below 4.5.

Managing soil acidity is an important activity for all horticultural growers. It is most crucial in acid sandy soils and soil types where acidity increases at depth.

- **Include pH and lime requirements in the soil test and nutrient management strategy before each vegetable crop.**

Soil acidity, expressed as soil pH, is an important component of the soil test. Get expert recommendations on the type of lime product and the rate at which lime should be applied to your soil. Application rates will depend on the soil pH, soil type and its pH buffering capacity. Less lime is required to raise the pH of sandy soils by one unit than would be required to have the same effect on heavier soils, which have a high buffering capacity due to high clay and/or organic carbon content.

- **Regular and substantial lime applications will be necessary to maintain productivity of sandy soils.**

Acidic, grey sands, such as those on the Scott Coastal Plain, need applications of lime to adjust soil pH, measured in calcium chloride, to between 5.0 and 5.5. Applications of lime should be applied at the break of season (May/June) prior to planting to maximise the opportunity for it to impact on the soils pH (Paulin, 1999).

Lime increases soil pH and therefore plays a key role in our farming systems. Lime has the added benefits of:

- Increasing rhizobium survival and nodulation of legumes, which generally survive poorly in low pH soils.
- Increasing plant availability of nitrogen, phosphorus, and molybdenum.
- Decreasing available aluminium levels.
- Lime can also have the adverse affect of increasing the incidence of take-all disease susceptible areas, and decreasing plant availability of copper, manganese, and zinc.
**Liming**  
(Leonard, 1995)

*How to start liming – soil monitoring*

Soil monitoring is an essential part of a lime management program and allows you to consider a lime rate and how often you should apply it.

The soil should be tested for pH in the topsoil (0-10 cm) and in the subsurface (10-20 cm). If you have a deep sandy soil you should also test for pH at the 20-30 cm depth.

Soils should be monitored every two to three years to track soil pH and lime movement.

**Initial soil pH**

As soil acidity increases (the lower the pH), more lime is needed to ameliorate acidity.

If soil pH is lower in the sub-surface soil compared to the topsoil, a liming program must commence immediately. It can take five years or more before you see any pH increases in the sub-surface after a topsoil application.

**Crops**

Different crop species have different tolerances to acidity. Plant growth is affected at a certain soil pH, which is known as the critical pH. Below the critical pH plant growth is severely retarded. When to commence liming will depend on the critical pH level of the most acid sensitive species you have in your rotation. Lime should be applied when the soil reaches a pH near but above the critical pH for the crops to be grown.

**Caution for potato growers**  
(McKay, 2002; Department of Agriculture NSW, 1983).

*Common scab disease of potatoes (Streptomyces scabies) is favoured by neutral to alkaline soil conditions. Raising soil pH to near 7 or above by the application of lime or wood ash will increase the risk of scab occurrence.*

If liming is required, the following methods, combined with soil pH testing prior to cropping to ensure that pH is not too high, will minimise risk of scab occurrence:

- Apply low rates (<2 tonnes per hectare) after the potato crop before the pasture phase, to allow adequate time for it to disperse in the soil.
- On acid sands that have very low pH, where higher rates of lime are required, incorporate the lime into the top 20 cm of soil. Where possible allow a year or more for it to disperse in the soil before cropping.

**Buffering capacity**

The pH buffering capacity of a soil is its ability to resist pH changes. The higher the organic carbon and/or clay in the soil, the greater its buffering capacity and its ability to resist pH change. More lime is needed to increase soil pH in a soil with a high buffering capacity.

*Table 2.10 Estimated pH increases with the addition of 1 t/ha of 100% NV product to soil types with a high, medium and low leaching intensity*

<table>
<thead>
<tr>
<th>Leaching factor of soil type</th>
<th>Increase in pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (sand)</td>
<td>0.5 – 0.7</td>
</tr>
<tr>
<td>Medium (loam)</td>
<td>0.3 – 0.5</td>
</tr>
<tr>
<td>Low (clay)</td>
<td>0.2 – 0.3</td>
</tr>
</tbody>
</table>

**Incorporation**

Lime has to be physically in contact with moist acid soil in order to neutralise acidity.

Lime dissolves slowly in the soil, therefore, incorporation in the top 10 cm of soil (or deeper if possible) is best to increase the rate of reaction and leaching of lime to a greater depth.

Incorporating lime will increase soil pH in the 0-10 cm soil depth within one to three years.

If lime is not incorporated it will take longer to increase soil pH.

**Rainfall**

Newly applied lime starts to react with the hydrogen ions only after the soil becomes moist. Higher rainfall means greater leaching and faster lime reaction.
**Lime quality**

Agricultural lime comes from either naturally occurring limestone or fine lime-sand. These are composed mostly of calcium carbonate with silica and/or magnesium carbonate. Deposits of lime-sand occur mainly along the south west coast, while deposits of limestone occur south of Perth. Lime sources are also found in the form of dolomite, which is a lake source, and in industrial by-products.

The quality, and therefore the effectiveness, of different lime products varies. Two measures of lime quality are neutralising value and fineness.

**Neutralising value (NV)**

The capacity of a liming material to correct soil acidity is expressed as neutralising value (NV). The higher the NV, the greater the ability of the product to neutralise the acidity. Pure lime or calcium carbonate is taken as the standard with NV of 100.

The neutralising values of all other sources of lime are graded relative to pure calcium carbonate. Therefore, a source of lime with a neutralising value of 80 means it is 80 per cent as effective as pure calcium carbonate in neutralising soil acidity, that is, it is 20 per cent less effective than pure calcium carbonate. A lime source with a neutralising value of 150 is 50 per cent more effective than pure calcium carbonate.

Liming products like pure hydrated or slaked lime and pure burnt or quick lime have NV of 130 and 170 respectively.

**Fineness**

The finer the lime, the more quickly it will react to neutralise acid in the soil. A lime with fine particles has a greater surface exposed to the acid and more particles distributed through the soil than an equal weight of coarser material.

The accepted measure of fineness in Western Australia is the percentage of particles that will pass through a 0.6 mm sieve.

In Western Australia all commercial liming products must be registered under the Fertiliser Act as one of two grades (see Table 2.11). Neutralising value will depend on the composition and particle size of the product. As the costs of cartage and spreading generally comprise more than 60% of liming costs, it is important to factor in neutralising value when comparing the cost of using different lime products.

---

**Table 2.11 Grade and neutralising value of lime**

<table>
<thead>
<tr>
<th>Grade of lime</th>
<th>Neutralising value (NV)</th>
<th>Material which passes a 0.6 mm sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>First grade</td>
<td>not less than 75%</td>
<td>at least 80%</td>
</tr>
<tr>
<td>Second grade</td>
<td>not less than 50%</td>
<td>at least 60%</td>
</tr>
</tbody>
</table>

To compare the cost of lime for your situation, use the following calculation:

Cost of product ($/t) = cost of lime at the pit + freight + spreading.

Pure lime equivalent ($/t) = cost of product multiplied by 100 divided by neutralising value (NV).

---

**Example**

**Lime A**

Cost of lime at pit $9/t; freight $0.10/km (200 km); spreading $10/t; NV95.

Cost of product ($/t) = $9 + $20 + $10 = $39

Cost of pure lime equivalent ($/t) = $39 multiplied by 100 divided by 95 = $41
**Lime B**

Cost of lime at pit $9/t; freight $0.10/km (180 km); spreading $10/t; NV80.

Cost of product ($/t) = $9 + $18 + $10 = $37

Cost of pure lime equivalent ($/t) = $37 \times 100 \div 80 = $46

This example shows that although Lime B’s cost of product is cheaper, its pure lime equivalent cost is more expensive. Lime A provides better value for money spent to neutralise soil acidity.

Applying good quality lime of neutralising value >95% and fineness, 90% passing through a 0.6 mm sieve, will save costs and ensure good results.

- *If lime or other soil amendments are needed, apply well before cropping.*

Lime moves into the soil slowly, so it may take over a year for top dressing to take effect. In horticulture this can be overcome by applying well before cultivation, so that it is incorporated into soil during cultivation and planting. If soil pH is lower in the sub-surface, a liming program must be adopted well before soils reach critical levels in the topsoil, because lime will take time to leach down.

**Other factors affecting soil pH**

- **On acid soils, use non-acidifying fertilisers, such as ammonia-free nitrogen sources and gypsum, in preference to acidifying fertilisers.**

Fertilisers that contain N in the form of ammonium, such as ammonium sulphate, ammonium nitrate and di-ammonium phosphate, generate acidity in the soil. They release H+ ions when ammonium is converted to nitrate in the soil. Elemental sulphur and to a lesser extent urea are other fertilisers which generate soil acidity, but to a lesser extent. The acidification is made worse if the fertiliser is leached below the root zone and not used by the plant. (Moore, 1998).

If possible avoid using these fertilisers on acid soils as from two to seven kg of lime would be required to neutralise every kilogram of fertiliser applied.

Contrary to common belief, superphosphate fertilisers do not contribute to soil acidification, though they may increase crop yield and therefore product removal. (Moore, 1998).

**Effect of organic matter on soil pH**

- **Mulch cropping and application of compost are good practices for acid sands because they increase the organic matter content of the topsoil, which buffers and increases soil pH.**

**Soil salinity**

**Identifying and managing saline land**

- **Identify land with saline subsoils and map it in the farm plan.**

The most cost effective and rapid method of surveying large areas for soil salinity is by using electromagnetic inductance instruments, either airborne, vehicle mounted or hand held. For some areas, aerial surveys have been conducted (inquire at the Department of Agriculture Western Australia). If you suspcet saline subsoils, it is worth hiring a hand-held EM 38 instrument which gives readings that can be directly converted to the average concentration of salts in the top one to two metres of soil. Examples of sites with saline subsoils are some poorly drained flats with clay at or near the surface, such as are found on parts of the eastern Swan Coastal Plain. These sites may become too saline for horticulture and are best planted to trees or perennial pastures.

**Measuring soil salinity**

Most ‘measures’ of salinity use electrical conductivity to estimate salinity of soil and water. These measures are cheap and easy to do, and can even be done (with some care) in the field.

Another, increasingly more common, estimate is with the EM 38 or EM 31 using electromagnetic induction. EM readings are useful to
compare within and between similar sites, but use EM readings with caution unless they are calibrated against soil salinities (ECe for preference) and other influencing factors. The EM38 instrument is quite expensive, but relatively easy to use in the field, and gives readings into the root zone.

Soil samples can be measured by the ‘EC 1:5 w/v’ method – one part by weight (g) air dried soil to five parts by volume (mL) distilled water, which is agitated then allowed to settle, then the solution is measured for electrical conductivity (EC). However, sand particles will not hold as much salt from the soil water as will clay. Therefore, sand will give apparently lower readings than clay, even though the soil water (which is the part affecting plant roots) is the same.

ECe or ECse – electrical conductivity of the extract or saturation extract- is a more accurate test that allows for the soil texture affect on soil salinity. The proper measurement of the ECe is a laboratory technique and relatively expensive.

The EC1:5 reading, (if less than 350 mS/m) can be converted to ECe by multiplying by the following factors depending on soil texture (approximate only):

- sand: 15
- sandy loam: 12
- loam: 10
- clay loam: 9
- light/medium clay: 8
- heavy clay: 6

Revegetating saline land

- Plant salt and/or waterlogging tolerant native vegetation on land where saline groundwater is within two metres of the surface. This will reduce capillary rise and reduce concentration of salts on the soil surface.

Saline discharge is often caused by excessive recharge on land above the seepage area. Planting high water use commercial tree species, such as lucerne and commercial tree species, on the recharge area above the seepage can reduce saline discharge. For this to be effective, over 50% of the catchment above the seep would need to be planted

- Planting high water use vegetation in recharge areas above saline seeps on the farm can reduce saline discharge.

Refer to Appendix 2.2 for a list of suitable high water use commercial tree species for planting on recharge areas.

Note that it is desirable to plant shrub species underneath the trees to increase wildlife habitat and windbreak values. (Section 2.1 under ‘Windbreaks’).

Refer to Section 8.1 for technical information on site preparation and tree planting.

Sub-surface drainage

(Bennett et al, 1999)

- In some cases, such as the south west irrigation area near Harvey, sub-surface drainage can help prevent the salinisation of land with saline subsoils.

Caution: Sub-surface drainage may increase nutrient export from sands with low Phosphorus Retention Index (PRI) and should not be conducted in these soil types.
### Sub-Surface Tyre Drains

| Description | Trench in which truck tyres are placed, fastened together to form a tube. Covered with geo-textile cloth and filled over with soil. If the drain is to be designed to run water in permeable soils, it needs to be lined with clay or plastic sheeting under the tyres. |
| Purpose | Disposing of surface and shallow sub-surface water in situations where trafficability (of light vehicles only) is required. |
| Suitable for (site, soil types) | Wet or seasonally waterlogged sites, or any site where a substantial trench can be dug on an even grade. Slopes up to 15%. |
| Gradient of earthworks | Variable depending on hill slope; needs to be even to prevent blockage. |
| Profile | Circular, 0.5-0.7 m in diameter. |
| Machinery required for construction | Excavator, manual labour. |
| Estimated cost | $20-50,000 per km. |
| Possible problems and limitations | May be susceptible to blockage – screened inlets required. Durability uncertain as the technique has not been tested over long periods. |

### Sub-Surface Drainage-Slotted Coil Drainage Tube

| Description | Slotted plastic agricultural drainage pipe, 80 or 100 mm in diameter. The trench is partly backfilled with 5-10mm bluemetall or similar aggregate to assist drainage and prevent blockage of the slots (this is essential). |
| Purpose | Draining waterlogged soils. |
| Suitable for (site, soil types) | Waterlogged flats, seepage areas at foot of slope. |
| Gradient of earthworks | The bottom of the trenches must be accurately surveyed to an even grade (0.1-1%) using laser controlled equipment. |
| Profile | Laid in trenches 160-200 mm wide and 800-1000 mm deep. |
| Machinery required for construction | Laser controlled pipe laying machine or trench digger. |
| Estimated cost | $2000/hectare at 50 metre spacings or $7-10,000 per km. |
| Possible problems and limitations | The slots in the pipe can be blocked by iron precipitates in the drainage water. It is wise to incorporate permanent access points at the ends of the pipelines for inspection and flushing. Pipelines should be no more than 300 m long. |
Mole drains

Mole drains can be constructed in loam or clay based soils using a mole plough. This is relatively inexpensive but the site needs to be carefully surveyed and a network of slotted pipe drains constructed at 50 m intervals for the mole drains to run into. This process is expensive, costing more than $2000 per hectare.

Irrigation salinity

(Refer to Section 4.3 for information about the salinity of irrigation water and how to manage it).

All horticultural farmers need to regularly monitor salinity and conduct management practices to prevent even small increases in the salinity of soil and irrigation water.

Most standard agricultural soil analyses include soil conductivity (EC), which is a measurement of soil salinity. Specify that EC be included in all of your soil tests. Keep records of these measurements to detect any increases in soil salinity.

Salinity risk factors

- Be aware of conditions and practices that increase the risk of irrigation salinity and avoid them.

If your horticulture paddocks have two or more of the following characteristics, there is a risk of salinity developing.

- Poorly drained soils
- Subsoils with high salt content
- Saline water table less than two metres from the surface. At the critical depth of around 1.8 m, saline water can reach the surface by capillary rise in medium textured or clay soils, in sufficient quantities to decrease wheat yields (Moore, 1998).
- Clay or fine textured topsoils. These soils are slower to drain and have the greatest capillary rise.

Practices to avoid

- Avoid irrigating with water containing high salt concentrations and where this cannot be avoided manage irrigation carefully (Section 4.3).
- Avoid cropping on or near wet areas such as groundwater discharge areas or on poorly drained soils.

Poorly drained or groundwater discharge areas are at high risk of becoming saline, more so where rainfall is less than 800 mm. These areas should not be cleared. In most cases where such sites have been cleared they are unlikely to be suitable for horticulture and are best fenced off and revegetated with suitable high water use perennial shrubs or trees.

Do not flood irrigate poorly drained soils.

Treat wet areas by revegetating before they become saline (see above).

- Avoid using potash as a potassium fertiliser.
  Use other sources such as potassium sulphate which do not increase soil salinity.

Avoid using fertilisers containing chloride such as potash (potassium chloride). It is cheap fertiliser that is often acceptable for fertilising pastures and cereal crops. However it is not recommended for horticulture because it can increase soil salinity by increasing the soil chloride ion concentration. Up to 10 times as much potassium is required for some horticultural crops than would be applied to pasture. This can be likened to adding another 300 kg of salt per hectare to the soil, in addition to that which comes from rainfall and irrigation water.

Chloride is a component of salt (sodium chloride) and is toxic to plants, particularly some vegetables, if it occurs in elevated concentrations in the soil.

Use potassium sulphate or potassium nitrate, as these do not contain chloride.

Although they are more expensive fertilisers, they provide additional sulphate or nitrogen. Note that these extra nutrients need to be
factored into the overall fertiliser strategy to avoid applying excess amounts.

**Cadmium and other heavy metals**
(CRC for Soil and Land Management and CSIRO, 1999)

- **Potato growers should always use low cadmium phosphate fertilisers and where there is risk of heavy metal contamination, monitor the metal concentrations in fertilisers, soil amendments, soil and tubers.**

Cadmium can be taken up by plant roots. It is most readily available in sandy or saline soils. Saline soils have high levels of chloride. Cadmium reacts with chloride to form a complex, which is more readily taken up by plant roots. Trials have shown that cadmium uptake in potato tubers increases significantly where the salinity of irrigation water exceeds 1000 ppm (200 mS/m). Uptake varies considerably between different plant species and between varieties or cultivars.

Cadmium levels may increase in the soil if sewage sludge or phosphatic fertilisers high in cadmium are applied. Sewage sludge is not often used in horticulture and most phosphatic fertilisers now come from low cadmium rock phosphate sources.

The only way to detect cadmium levels is by tissue testing by accredited laboratories. Western Potatoes routinely samples potatoes it sells and has them tested for cadmium.

**Cadmium risk factors for potatoes**
(CRC for Soil and Land Management and CSIRO, 1999; McKay, 2002)

**Saline irrigation water**

The maximum concentration of cadmium allowable (MC) in potato tubers is 0.1 mg cadmium per kg fresh weight. Surveys have shown that the probability of cadmium in potato tubers exceeding the MC is low when using irrigation water with conductivity less than 200 mS/m, but rises to over 50% as irrigation water conductivity rises above 300mS/m.

Potato growers are advised to use water with a conductivity of less than 200 mS/m.

Growers should test the salinity of their irrigation water regularly, especially before commencing irrigation and later in summer (Section 4.3 Measuring salinity).

If use of water with conductivity above 200 mS/m is unavoidable:

- Select potato varieties with low or medium susceptibility to cadmium uptake, including Wilwash, Russet Burbank, Lemhi, Russet, Ranger Russet, Winlock, Tarago, Pontiac, Atlantic, Desiree and Delaware.
- Use sulphate of potash rather than muriate of potash to supply potassium.*
- Confirm possible problems by in-crop tuber testing. When water conductivity remains constant, testing early in the season gives a good indication of potential problems.

*Note: Make sure the crop receives sufficient zinc applied before planting.

**Soil cadmium**

Research also indicated that the probability of cadmium levels reaching the MC was increased if the soil contained more than 15 µg/kg cadmium extracted in 0.01 M calcium chloride. Soil cadmium levels are likely to be high in paddocks with a history of heavy applications of phosphate fertiliser containing high levels of cadmium.

If possible, avoid growing potatoes on these soils.

**In-crop tuber sampling**

For each soil type, potato variety or management unit, take a representative sample of at least 25 healthy tubers, taken from at least 5 locations, about 50-70 days after planting. This will usually give a good indication of the tuber cadmium concentration in the mature tubers.

Brush off soil, put the tubers in a clean paper bag, keep them cool and send the sample to a laboratory within 3 days for analysis of cadmium concentration.
Sampling of plant tops to estimate cadmium concentrations is not recommended as levels vary with different stages in growth.

**Aluminium toxicity**

- If aluminium toxicity is suspected, ask the laboratory to include soluble aluminium in the soil tests.
- The treatment for aluminium toxicity is the same as for soil acidity, that is applying lime to raise the soil pH.

**Soil sodicity**

In Australia, soils are called sodic if they have an exchangeable sodium percentage (ESP) of 6 to 15 and highly sodic if their ESP is more than 15. Sodium adsorption ratio (SAR) may be used as an alternative test, particularly in saline soils. Most soil laboratories can do these tests.

Sodicity destroys soil structure and causes surface crusting.

Soil sodicity in general does not occur in the south west horticulture growing areas. However it may be a problem on clay or alkaline soils.

**Procedure to indicate whether a soil is sodic (gypsum responsive)**

(Department of Agriculture Western Australia, 1985)

- Test clay or alkaline soils for sodicity.

The following procedure should be repeated with samples from different parts of a suspected area, as soils can vary greatly even within a few metres.

1. Take a sample of the soil from the surface and another from 15 cm below the surface.
2. Place about 50 mL of distilled water or freshly collected rainwater into each of two clean jars, labelled surface and subsurface for easy identification.
3. Wet the soil sample with the distilled water until it is moist, easily manipulated but not sticky. Mould some of the soil into a sphere about 7 mm in diameter and gently drop into the appropriately labelled jar of water.
4. Leave the jars of water completely undisturbed for 24 hours. If after this time a milky cloud or halo has formed around either soil sphere then the soil is likely to be gypsum responsive.

- Sodic soils can be treated by applying gypsum to reduce the sodicity of the surface soil, adding organic matter and carefully applying best practices to maintain and improve soil structure.
  - To determine whether gypsum will be beneficial, test strips of gypsum can be applied at rates of 2.5, five and seven tonnes per hectare, to compare yield with untreated strips. Alternatively, take at least 20 small equal samples from the surface and 15 cm depth from the suspected area, bulk them in two lots and send them to a soil testing laboratory for sodicity testing. A soils consultant should be able to recommend a gypsum application rate given the test results and the crop type.
  - Apply gypsum before the soil is wet.
  - Only very light, shallow cultivation after application is required, to stop the gypsum from blowing away.
  - Minimum tillage practices should be adopted after gypsum application. This will ensure that the gypsum remains close to the surface and will also help build up organic matter, which improves soil structure.
  - The gypsum will supply more than crop requirements of sulphur, so no extra sulphur fertiliser should be required in the year of application.

- Crops that are more tolerant of alkaline, saline soils should be grown (where soils are sodic).
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Murphy, D. Soils researcher, 2001, pers comm. University of Western Australia.


Figure 2.7 Schematic diagram illustrating good practices for constructing acres tracks

<table>
<thead>
<tr>
<th>Track follows ridge line</th>
<th>Speed bumps divert water off track on hill slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where track runs across hill slope, it is located below a diversion bank</td>
<td>Built-up section of track on hill slope has diversion spreader drains every 50 m</td>
</tr>
</tbody>
</table>
### APPENDIX 2.1

#### Table A2.1 Salt and waterlogging tolerant vegetation
(Department of Agriculture WA, 1990)

<table>
<thead>
<tr>
<th>Species</th>
<th>Salt tolerance</th>
<th>Max. height breadth (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia saligna</em></td>
<td>High</td>
<td>5 * 3</td>
<td>Short lived</td>
</tr>
<tr>
<td><em>Acacia prainii</em></td>
<td>Mod</td>
<td>2*2</td>
<td>understory</td>
</tr>
<tr>
<td><em>Acacia collectoides</em></td>
<td>Mod</td>
<td>2*3</td>
<td></td>
</tr>
<tr>
<td><em>Casuarina obesa</em> (swamp sheoak)</td>
<td>High</td>
<td>10*5</td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus camaldulensis</em> (river red gum)</td>
<td>Mod</td>
<td>20*15</td>
<td>tree</td>
</tr>
<tr>
<td><em>Eucalyptus platypus var platypus</em> (moort)</td>
<td>Mod</td>
<td>5*6</td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus sargentii</em> (salt river gum)</td>
<td>High</td>
<td>10*8</td>
<td></td>
</tr>
<tr>
<td><em>E. spathulata</em> (swamp mallet)</td>
<td>Mod</td>
<td>8*6</td>
<td></td>
</tr>
<tr>
<td><em>Melaleuca acuminata</em> (broom bush)</td>
<td>Mod</td>
<td>2*2</td>
<td></td>
</tr>
<tr>
<td><em>M. brevifolia</em> (mallee honey myrtle)</td>
<td>Mod</td>
<td>4*4</td>
<td></td>
</tr>
<tr>
<td><em>M. cuticularis</em> (salt water paperbark)</td>
<td>High</td>
<td>8*6</td>
<td></td>
</tr>
<tr>
<td><em>Melaleuca hamulosa</em></td>
<td>Mod/high</td>
<td>3*4</td>
<td></td>
</tr>
<tr>
<td><em>Melaleuca thyoides</em></td>
<td>Mod</td>
<td>2*2</td>
<td></td>
</tr>
</tbody>
</table>

### APPENDIX 2.2

#### Table A2.2 Suitable high water use commercial tree species for planting on recharge areas
(Department of Agriculture, 1990. Department of Conservation and Land Management Plant Propagation Centre)

<table>
<thead>
<tr>
<th>Species</th>
<th>Max. height (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus globulus</em> (Tasmanian bluegum)</td>
<td>35</td>
<td>Fast growing, Timber, pulp, windbreak</td>
</tr>
<tr>
<td><em>E. saligna</em> (Sydney bluegum)</td>
<td>35</td>
<td>Fast growing, timber, windbreak</td>
</tr>
<tr>
<td><em>Eucalyptus botryoides</em> (bangalay)</td>
<td>30</td>
<td>Fast growing, timber, windbreak</td>
</tr>
<tr>
<td><em>Eucalyptus diversicolor</em> (karri)</td>
<td>40</td>
<td>Timber</td>
</tr>
<tr>
<td><em>Eucalyptus viminalis</em> (manna gum)</td>
<td>30</td>
<td>Timber, fast growing</td>
</tr>
<tr>
<td><em>Eucalyptus citroyodora</em></td>
<td>30</td>
<td>Fast growing, timber, ornamental</td>
</tr>
<tr>
<td><em>E. patens</em> (blackbutt)</td>
<td>30</td>
<td>WA native, timber</td>
</tr>
<tr>
<td><em>E. calophylla</em> (marri)</td>
<td>30</td>
<td>WA native, honey, wildlife</td>
</tr>
<tr>
<td><em>E. maculata</em> (spotted gum)</td>
<td>25</td>
<td>Fast growing, timber, honey, ornamental</td>
</tr>
<tr>
<td><em>E. camaldulensis</em> (river red gum)</td>
<td>25</td>
<td>Fast growing, timber, windbreak</td>
</tr>
<tr>
<td><em>E. gomphocephala</em> (tuart)</td>
<td>20</td>
<td>Windbreak, timber, limestone country</td>
</tr>
<tr>
<td><em>Pinus pinaster</em> (maritime pine)</td>
<td>25</td>
<td>Timber, windbreak, sands.</td>
</tr>
<tr>
<td><em>Pinus radiata</em></td>
<td>30</td>
<td>Timber, windbreak</td>
</tr>
</tbody>
</table>
APPENDIX 2.3
Compost production
(Paulin, 1999)

Compost is made from a wide range of organic materials including plant material, such as straw and other crop/garden/tree materials, along with manure, food waste and animal processing waste. Inorganic materials such as clay, fly ash (from power generation) and bauxite residue or ‘alkaloam’ can be included. These non-organic materials can potentially improve compost quality and its nutritional characteristics.

However, growers should request that composts containing industrial residues be analysed for heavy metals and should also have their soil and produce tested periodically.

To make compost, these raw ingredients or feed stocks are mixed to provide carbon to nitrogen ratios in the range of 1:25 to 1:40. There are a number of composting methods including open windrow, static pile and in-vessel processes. Regardless of method, composting requires process control to ensure that, within the composting mass:

• adequate oxygen levels are maintained
• moisture levels are maintained between 45 and 55%
• temperatures are maintained below 70°C and preferably below 60°C

Composting is an oxygen requiring process. This is achieved by either pumping air through the compost or by physical turning of the compost at regular intervals.

Moisture levels are equally important for microbial growth. Micro-organisms require moisture and their growth and activity will decline when moisture levels drop below 40%. As moisture content increases beyond 60%, the risk of low oxygen conditions developing increases rapidly and their activity will also decline.

The composting process involves two critical stages, which are characterised by the temperatures achieved within the composting pile or windrow.

1st Stage – Thermophilic (hot) phase
Temperature exceeds 50°C and must be maintained below 70°C by turning and aeration. This period typically lasts up to six weeks. Under carefully managed conditions, it can be much shorter and, with woody materials, it can also be much longer.

Providing temperatures above 50 – 55°C are maintained for four to five days, effective sterilisation occurs during this period. These temperatures kill pathogenic micro-organisms while the beneficial microbes that are responsible for organic matter breakdown survive temperatures up to 60-70°C.

2nd Stage – Mesophillic phase.
Temperatures are less than 50°C and fall over time, eventually stabilising at 20 to 25°C. This period is usually referred to as the maturation phase and generally takes another six to eight weeks.

Nitrogen is the fuel for microbial activity, which degrades or breaks down the carbon rich organic materials such as straw, crop waste, food waste and ‘green waste’. Nitrogen is usually derived from manure. However a number of fresh, green/leafy organic wastes have adequate carbon nitrogen ratios for them to compost without the addition of extra nitrogen.

When the carbon: nitrogen ratio is low, nitrogen levels are high relative to carbon levels. This accelerates microbial activity levels so that maintaining temperatures below 70°C becomes much more difficult. This situation also results in greater nitrogen losses.

If nitrogen levels are too low, the composting process will fail to achieve temperatures required to destroy disease organisms as well as other soil pests and weeds.
SECTION 3

Fertiliser Management
Fertiliser Management

Use of Best Environmental Management Practices in fertiliser management is crucial to preventing movement of nutrients off the site and into water bodies and groundwater.

This section outlines BEMPs for fertiliser management as follows:

- Soil sampling and testing
- Calculating fertiliser application rates
- Phosphorus fertiliser management
- Choosing the right fertiliser
- Correct storage and handling
- Accurate application
- Fertigation
- Minimising leaching of nitrogen and phosphorus
- Soil amendments

3.1 Optimise application of nutrients to plant and soil requirements

Today’s horticultural growers need to obtain expert analyses of soil test results for each soil type within each paddock. In this way, nutrient application can be matched as closely as possible to crop requirements for optimum production on the particular soil. The extra cost will be more than offset by the savings in fertiliser costs.

Soil sampling and testing

(WA Dept of Agriculture, 1984)

To get nutrient application right, it is necessary to conduct a soil sampling and testing program, aiming to test each main soil type (land management unit) in each paddock prior to each vegetable cropping phase. To gain an understanding of their soil nutrient requirements, it is recommended that growers hire an experienced, independent soil nutrient consultant to analyse soil test results and prescribe fertiliser application rates.

- Engage an experienced, independent soil nutrient consultant to analyse soil test results and prescribe fertiliser application rates.

Correct soil sampling technique is important. For vegetable and potato cropping, two soil test samples from the top 15 cm are required, one at 0-10 cm and the other at 10-15 cm. Take about 20 cores to 15 cm (using a two centimetre diameter corer) in a zigzag pattern (see Bulletin No 4328) from the area to be cropped. Bulk the 0-10 cm cores in one plastic bag and the 10-15 cm cores together in another plastic bag. Label the bags clearly with the soil type and core depth.

Take separate samples for different soil types and areas that have different paddock histories. Avoid unrepresentative areas such as sprinkler lines, fence lines and sheds that may have had higher rates of fertilisers through spillage, traffic etc. than the main area of the paddock.

- Use reputable laboratories for testing and interpretation

Have the soils tested at an accredited laboratory, e.g. CSBP, Chemistry Centre. Avoid using laboratories in other States or countries as they may use different chemical analyses and these will give different readings to the standard tests used in WA.

Calculating fertiliser application rates

(Agriculture Western Australia, 1999)

- Engage an experienced, independent soil nutrient consultant to analyse soil test results and prescribe fertiliser application rates.

To calculate how much of each nutrient to apply, nutrient consultants use the following information:

- Soil type and PRI (from soil test).
- Concentrations of the nutrients already in that soil as shown by a soil test.
- Crop replacement requirement, which is the
amount of nutrient that the crop or livestock will remove from the paddock. To calculate the consultant needs to know the concentration of nutrients in the plant or animal material (from tables) and the total quantity of plant or animal material per hectare expected to be removed from the paddock.

- Efficiency factor, which is a measure of the proportion of the nutrient applied to the soil that can be extracted from the soil by the plant. If a crop requires one unit of nutrient and it has an efficiency factor of 10 for that soil, then 10 units of nutrient must be present in the soil to provide one unit to the plant. Heavier, higher PRI soils have higher P efficiency factors, i.e. more P has to be present in the soil to supply the plant’s needs.

- Leaching factor, which allows for nutrient loss by leaching and erosion. It depends on the soil type and fertiliser type. In grey and white sandy soils, nutrients stay in soluble form so these soils have the highest leaching factors. If soil erosion occurs, more nutrients will be lost and the leaching factor will be even higher.

Calculating fertiliser application rates involves interpretation of tables of tissue nutrient concentrations for different crops and efficiency factors and leaching factors for different soil types. Other factors such as soil texture, reactive iron content and pH will also influence the soil nutrient requirements. For these reasons, it is best to hire an experienced soil nutrient consultant at least to gain initial understanding of the soil chemistry.

**Phosphorus management**

- **On all soil types, apply phosphorus according to soil phosphorus test levels.**

  Environmental best practice for phosphorus application on all soils is:

  1. Test the major soil types in a paddock before each vegetable or potato crop.
  2. Contract a qualified, independent soil consultant to calculate phosphorus requirements, according to soil PRI and available phosphorus test levels.

  3. Aim for 95% maximum yield. Attempting to gain a few percent in yield by applying phosphorus (or nitrogen) in excess of recommendations is damaging to the environment and not good practice.

To determine how much phosphorus fertiliser should be applied, it is essential to have the soil tested for phosphorus. The Colwell-extractable P and the PRI-100 tests are the standard soil tests that should be requested.

To get an accurate result, the proper sampling technique should be used (see ‘Taking soil samples for testing’ above).

*The Colwell soil test for phosphorus*

The Colwell-extractable P test is the standard soil P test used in WA. It measures the P in solution after extraction by a 0.5M sodium bicarbonate solution, at pH 8.5, shaken for 18 hours. The Colwell test measures phosphorus that is either adsorbed or in solution in the soil and is used as an indicator of phosphorus available to plants during a cropping period. Colwell-extractable P is expressed as mg/kg or parts per million (ppm).

*The PRI-100 test for phosphorus retention*

The capacity of a soil to retain phosphorus is measured by using the Phosphorus Retention Index (PRI) test, which can be done by most soil laboratories on request. In general, the light coloured sands have low reactive iron content and low clay content which means they will have a low PRI. White and grey sands have the lowest PRI’s. These soils have a very low capacity to hold on to the major nutrients phosphorus and sulphur.

**Phosphorus fertiliser management for sands**

(McPharlin, 2001; Rose, 2001)

Sands present moderate to high risk of phosphorus leaching. Particular care and attention needs to be paid to the rate and timing
of phosphorus application on sands as excess phosphorus is rapidly leached into groundwater, or into dams and wetlands that may be nearby. The rate of phosphorus application required varies greatly depending on the amount of residual phosphorus present in the soil. It is essential that sands are tested for residual phosphorus levels and Phosphorus Retention Index to determine how much phosphorus fertiliser will be required.

Appendix 3.1 shows indicative rates of phosphorus that would be required for autumn, winter or summer sown potatoes on the coastal sands. Rates for two soil types, for different soil test levels of phosphorus are shown. The soil groups are:

- Grey-white (Bassendean/Joel) and light yellow (Karrakatta) sands.
- Red-Orange, yellow (Spearwood or Tuart) sands.

Note that these rates are only indicative and accurate determination of requirements will depend on specific characteristics of the soil, such as PRI and texture that can only be determined by doing soil tests.

**Plant Analysis (potatoes)**

Collect samples of petioles (20 per time) after planting to monitor the phosphorus status of the crop. The % phosphorus should range from 0.8-0.9% when tubers are 10mm diameter to 0.2-0.25% at 120 to 130 days after sowing.

**Phosphorus fertiliser management for loamy or gravelly soil**

Phosphorus export by leaching much less on these soils. The moderate to high iron content ensures that most of the soil P is bound (adsorbed) to soil particles, that is the P is retained in the topsoil and not easily leached.

However excess P should not be applied to these soils because if erosion occurs, phosphorus rich topsoil is washed into dams and streams. Once in the water body, this adsorbed P can be even more damaging than dissolved P. The reason for this is that under warm, anaerobic conditions common in summer, the chemical conditions in the water change and the P adsorbed in sediments is released into the water. It is in these conditions that the water becomes nutrient enriched and algal blooms are likely to occur.

With marron and fish culture and tourism becoming important industries in the south west, algal blooms caused by nutrient export from farm land can have devastating economic as well as environmental consequences.

Trials conducted growing potatoes on jarrah-marri and karri soils in the Manjimup-Pemberton area (Hegney, Mc Pharlin et al, 1992) showed that:

- Phosphorus requirements for 99% yield varied greatly, from 25 kg of P to over 200 kg of P, depending on the soil P test levels and the soil PRI.
- Potatoes grown on jarrah-marri gravelly loams require relatively small phosphorus applications when Colwell P level is above 160 ppm before planting.
- To lift yield from 95% of maximum to 99% of maximum, phosphorus applied had to be increased by 60-75%, i.e. 110 to 150 kg more phosphorus per hectare (equivalent to about 1.5 tonnes of superphosphate). The extra phosphate produced no significant improvement in tuber quality.
- The indication is that 1.5 tonnes of superphosphate, costing about $300 would be required to achieve a four percent increase (about 2 tonnes per hectare) in yield. This equates to about $600 in production. In other words, to gain a few hundred dollars per hectare, the grower greatly increases the risk of damage to streams, dams and groundwater resources.

Refer to Appendix 3.2 for indicative rates of phosphorus application for potatoes on loams. Note that these rates are only indicative. Accurate determination of requirements will depend on specific characteristics of the soil, such as PRI and texture that can only be determined by doing soil tests.
Note also that patches of sands, often with low PRI are common in jarrah- marri and karri soils. It is most important that these soils be tested and fertilised separately from the high PRI brown and red soils. Much less phosphorus is required for these soils and it should be applied little and often, mainly after planting. (see above ‘Phosphorus management for potatoes on sands’ and Section 3.3 ‘Minimising leaching of phosphorus on light sands’).

Method of application of phosphorus
(Paulin, 2001)

The recommended application method for phosphorus fertiliser depends on the soil PRI and the crop grown. The following are guidelines:

1. Soil ‘PRI-100’ values are less than 2.0 to 3.0

Phosphorus is best applied in more than one application by:

Broadcasting three applications. Take care when broadcasting fertiliser to ensure accuracy and evenness of placement (see 3.2 ‘Broadcasting’).

Or

A light application pre-planting, with more than 75% of the phosphorus applied by fertigation during crop growth.

To accommodate progressive development of the crop root system, the total amount should be applied as follows

• 15 to 25% of the total application at planting. Apply the higher proportion when only two applications will be made. This application should be applied over the planting row.

• 30 to 40% of the total application, three to four weeks later and when three applications will be made.

• The remainder half way through the crop’s expected life or as late as is practicable in terms of minimising crop damage, such as with potatoes.

2. Soil ‘PRI-100’ values exceeding 15 to 20

When soil PRI-100 values exceed 15 to 20 and available phosphorus soil test levels are low, the total phosphorus application should be either banded or broadcast at planting, depending on crop (banded for potatoes).

Choosing the right fertilisers
(Rose, 2002; Ross, 2002)

The grower needs to determine, with the help of a nutrient consultant, suitable fertilisers in the correct proportions according to soil test and crop requirements. The nutrient content, and whether it is in slow or quick release form, needs to be carefully considered when selecting the fertilisers to be applied (refer to Table 3.1 below).

Standard blended products such as Potato E™, NPK Blue™, Super-Spud™ and AgraSt™ and some unblended products such as Superphos™ and potassium sulphate contain two or more nutrients in certain proportions. Some of these products are granulated, which has the advantage that the nutrients are mixed in fixed proportions in each granule, ensuring even distribution.

However, using standard-blended products on their own is often not the best practice because this will seldom supply all nutrients in the correct proportions. In order to apply enough of one nutrient there is likely to be too much of another.

It is necessary to calculate from the soil tests how much of each nutrient is required. Custom blends can then be made up for each paddock or soil type. Alternatively the nutrients can be applied in the correct proportions in separate fertiliser applications, whichever is most convenient for the grower.

Order custom blended fertilisers mixed in the proportions recommended by the soil test analysis, in preference to using only standard blended products.

The fertilisers applied may include some standard blend products, but the main thing is that the right balance of nutrients are applied according to the soil test, and this will vary according to paddock fertiliser history and soil type (see Table 3.2 overleaf for an example).
Post-plant applications should be recorded to ensure that total application is according to the soil test analysis and plant tissue testing results. Tissue testing provides a ‘double check’ that the crop is receiving adequate nutrition throughout crop growth.

Fertigation and boomsprayer application enables soluble nutrients to be applied in balanced amounts during crop growth. Note that some soluble fertilisers react together and should not be mixed in the fertigation tank (Section 3.1).

Slow release phosphorus and sulphur fertilisers are available at little extra cost and are worth considering as part of a strategy for light sands (Section 3.3).

Table 3.1 Nutrient content of some common fertilisers
(adapted from Moore, 1998)

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Phosphorous %</th>
<th>Sulphur %</th>
<th>Calcium %</th>
<th>Nitrogen %</th>
<th>Potassium %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single superphosphate</td>
<td>9.1</td>
<td>11.5</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Double Superphosphate</td>
<td>17.5</td>
<td>3.5</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Triple Superphosphate</td>
<td>20</td>
<td>0-1.5</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phosphate rock*</td>
<td>1-15</td>
<td>0</td>
<td>N/a</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>North Carolina Rock*</td>
<td>13.5</td>
<td>0</td>
<td>36</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wet process phosphoric acid</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Di-ammonium phosphate</td>
<td>20</td>
<td>0-1.0</td>
<td>0</td>
<td>17.5</td>
<td>0</td>
</tr>
<tr>
<td>Mono-ammonium phosphate</td>
<td>22.6</td>
<td>0-1</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>0</td>
<td>0.2</td>
<td>0.6</td>
<td>13</td>
<td>36.5</td>
</tr>
<tr>
<td>Potassium chloride (muriate of potash)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50- 51</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>Gypsum (CaSO4.2H2O)</td>
<td>0</td>
<td>17</td>
<td>22</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>Elemental sulphur*</td>
<td>0</td>
<td>90-100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Phosphorous</th>
<th>Sulphur</th>
<th>Calcium</th>
<th>Nitrogen</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato-ETM™</td>
<td>7</td>
<td>13</td>
<td>15</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Super-Spud™</td>
<td>12.4</td>
<td>5</td>
<td>N/a</td>
<td>11</td>
<td>12.2</td>
</tr>
<tr>
<td>Agras No 1™</td>
<td>7.6</td>
<td>17</td>
<td>0</td>
<td>17.5</td>
<td>0</td>
</tr>
<tr>
<td>Summit Topield™</td>
<td>20</td>
<td>1.7</td>
<td>0</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Summit Pasture™</td>
<td>18.6</td>
<td>10</td>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coastal Super™*</td>
<td>7.5</td>
<td>18.5</td>
<td>17.5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Slow release fertilisers
** Half of the S is slow release elemental sulphur
Table 3.2 Example – Calculating fertiliser application to supply nutrients according to soil test and crop replacement requirements.
(The nutrient contents of the fertilisers were derived from Table 3.4).

<table>
<thead>
<tr>
<th>Nutrient (application rate in kg per hectare)</th>
<th>Lime (5,000)</th>
<th>Double super (130)</th>
<th>Potassium sulphate (722)</th>
<th>Urea (574)</th>
<th>Mono ammonium phosphate (296 kg)</th>
<th>Totals</th>
<th>Recommendation according to soil test and crop replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>264</td>
<td>36</td>
<td>300</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>23</td>
<td>67</td>
<td>90</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>300</td>
<td></td>
<td>300</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>130</td>
<td></td>
<td>130</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>1600</td>
<td></td>
<td>1600</td>
<td>N/a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The important point to note from the example in Table 3.2 is that the rates of N and P fertilisers have been calculated so that the total N and P applications do not exceed the soil test recommendations for that soil and crop. This is important from an environmental perspective because it is these nutrients that have the most potential to pollute water resources.

Note also that the sulphur application exceeds the recommendations; but this does not matter as both sulphur and potassium are not serious environmental pollutants.

Calcium application is well in excess of crop requirements as this rate was needed to raise soil pH. Lime has no known detrimental off-site environmental effects.

Horticultural growers should have their soils tested periodically for trace elements. Trace elements can be applied to the soil or as foliar spray, according to soil consultants’ recommendations.

Manganese deficiency is a problem in many coastal and wheat belt soils. Manganese sulphate can be applied to the soil or as a foliar spray.

Molybdenum deficiency is most marked on the yellow sandy earth soils of the wheat belt. However, it can also occur on sandy gravelly soils and the red-brown soils of the lower south west hills horticultural areas. Molybdenum can be applied to the soil or as a foliar spray.

Copper has been shown to have good residual value and may only need to be applied at the recommended level every 25-30 years on cereal cropping land but may be required more frequently for vegetable cropping, depending on soil test results.

Zinc is now added to WA-made phosphatic fertilisers to maintain levels added to the soil. It can also be applied in foliar sprays.

Trace elements

☐ Include trace elements in the soil tests periodically
(Moore, 1998)

Most soils in WA are ancient and highly weathered. When newly cleared, they are often acutely deficient in the major nutrients, phosphorus and nitrogen and the trace elements copper, zinc and sometimes molybdenum and manganese. Profitable production on these soils has only been achieved by applying fertilisers.
3.2 Minimise loss of fertiliser to the environment

Storage and handling of fertilisers

❑ Store fertilisers in covered field bins or sheds that keep the product dry and prevent contact with the ground.

It is essential that storage facilities have the following characteristics:

- Sealed floor such as a concrete slab underlain with waterproof plastic membrane (slab as for dwellings is generally sufficient but would have to be thicker if vehicles are to be driven on it)

- Covered, to keep the product dry and prevent it being blown or washed outside the storage area by wind or water.

Bulk fertiliser can be stored in sheds and handled with a bucket loader, provided that the loading area is concreted to prevent fertiliser from spilling into the surrounding environment.

• Don’t dump fertilisers in heaps on the ground.

In the past, some growers have had fertiliser dumped on the ground where they transferred it into spreading equipment with a front-end loader. This practice was most common on new or leased land remote from storage facilities. It is no longer acceptable for any fertiliser, even on heavy soil types, as a few centimetres of soil contaminated with fertiliser are left over an area of about 10 by 10 metres. This amounts to between 100 and 1000 kg of fertiliser left on the soil surface, where it can be washed directly into drains and streams, either in solution or attached to soil particles, or leach downwards into water tables.

Storage bins

Covered metal field storage bins on legs, of the type hired by fertiliser companies, are adequate. Most covered truck mounted bins with augers or conveyor belts to transfer the product are acceptable provided the transfer mechanisms operate without spilling fertiliser.

One tonne fertiliser bins that can be stacked in a shed, handled with a fork-lift and placed on flat bed trucks are also available. All of these storage/handling methods are acceptable.

• Covered field bins should be ordered well in advance if fertiliser needs to be stored in the paddock.

Bagged fertiliser

Bagged fertiliser should be stored in a covered shed with a sealed floor as above. When transported, it should be adequately secured on the truck and covered in the event of rain.

Fertiliser bags should be completely emptied into the fertiliser box of the application implement and kept for recycling or proper disposal (Section 9.1, ‘Plastic and other solid wastes’).

Accurate application of fertilisers

Excess fertiliser applied in the wrong place, at the wrong time or in the wrong form can be easily leached or washed into groundwater and surface water bodies. In order to minimise the loss of fertiliser into the environment, the aim is to ensure that as much of the applied fertiliser as possible is taken up by the crop.

Most vegetable crops are fast growing, but do not have extensive root systems. To ensure that the crop makes maximum use of the fertiliser, application must be accurate in terms of rate and placement.

❑ Banding or dropping and incorporating of fertiliser close to the plants using an accurately calibrated fertilising or planting implement are the best practices for pre-plant fertiliser application on most soils except light sands.

Fertilising using an implement mounted on the planter, that meters fertiliser accurately and incorporates it into the seed-bed has been proved to be more effective than banding for brassica crops and is also being trialed for potatoes (see below).
Incorporation of fertiliser for cauliflower and broccoli crops
(Lancaster and Ross, 2002)

For brassica crops such as cauliflower and broccoli, fertiliser placement on loam and clay soils has traditionally been by banding. Two narrow bands of fertiliser are placed either side of the seedling transplant, so they are slightly below and off set from the seedlings. An alternative method for fertiliser placement for these crops is to apply the fertiliser to the soil surface in a strip (about 20 cm wide) and incorporate it into the soil to a maximum depth of 15 cm (strip incorporation). The cauliflower and broccoli seedlings are transplanted into this fertiliser strip.

The fertiliser is incorporated using small rotary tillers on the planting machinery. The number of rotary tillers required depends upon the number of rows of crop to be planted by each pass of the machine. One row of cauliflower is placed in each strip of incorporated fertiliser. Existing brassica planting machinery can be modified to fit the rotary tillers.

Experimental work and growers’ experience has shown that this strip incorporation method helps cauliflower and broccoli plants grow faster, particularly during the cooler winter months. Plant growth occurs immediately, as the plant roots are surrounded by the phosphorus fertiliser, which is mixed through the soil in the root zone.

For banded fertiliser, the plant roots first have to grow to the band to intercept the fertiliser and this delay in the plants obtaining nutrients can reduce early and subsequent growth.

Commercial producers have also reported other advantages that the strip incorporation method has over banding:
- A reduction in the number of harvests required to remove the crop.
- Less chance of ‘fertiliser burn’ of the roots of the transplanted seedling.

Fertiliser burn of the roots often occurs when fertiliser is banded, as the seedlings can be transplanted directly on top of the fertiliser band if there is a slight movement sideways of the transplanting machinery. With strip incorporation, the fertiliser is mixed evenly around the plant roots.

For strip incorporation on loam and clay soils, fertiliser containing a higher concentration of water-soluble phosphorus is more effective. The amount of water-soluble phosphorus can be determined by looking at the chemical analysis of the fertiliser written on the bag or asking for the analysis in the case of bulk supplies. The strip incorporation method can be successfully used with fertiliser that has a low water soluble phosphorus content, if the background level of phosphorus in the soil is high. This will be shown by soil testing.

Cropping sandy and loamy soil types separately, to enable application of fertilisers according to the different soil requirements is good practice.
Fertigation
(Refer to Section 4.1 for details of best practices for fertigation)

- Fertigation is a recommended means of post-planting fertiliser application if conducted according to best practice.

Table 3.6 Fertiliser solubility for estimating tank sizes
(Calder and Burt, 2001)

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Solubility kilograms per 100 litres at 20 °</th>
<th>Amount of fertiliser required (kilograms per hectare)</th>
<th>Water needed to dissolve that amount fertiliser (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium nitrate</td>
<td>32.0</td>
<td>80</td>
<td>250</td>
</tr>
<tr>
<td>Urea</td>
<td>105.0</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Potassium sulphate</td>
<td>11.0</td>
<td>80</td>
<td>730</td>
</tr>
</tbody>
</table>

Boomsprayer application
The use of fertigation is less suitable where the sprinkler layout gives a poor distribution uniformity. In this situation, a boomsprayer can apply soluble fertilisers more efficiently.

Apply sprinklers for two to five minutes after boomspraying to wash the fertilisers from the leaves and into the soil.

This method is used in preference to fertigation for crops such as lettuce in windy coastal plain areas where wind speeds often make it impossible to attain acceptable sprinkler distribution uniformity.

Boomsprayer application of all soluble fertilisers and chemicals is the standard method used by Department of Agriculture WA vegetable researchers in their trials, where maximal accuracy is required.

Mixing fertiliser for fertigation or boomspray application
When preparing fertiliser solutions for injection units, care must be taken with chemicals. Some will react together forming precipitates, which block and damage the equipment. Soluble fertilisers that must not be mixed together are:

- Calcium nitrate with any phosphates or sulphates.
- Magnesium sulphate with di- or mono-ammonium phosphate.
- Phosphoric acid with iron, zinc, copper and manganese sulphates.

Most materials used in fertigation are corrosive. The injector is also often used to inject acid into the irrigation system for regular maintenance. Therefore, all injector parts should be made of corrosion resistant materials.

Broadcasting
Broadcasting of fertiliser from super spreaders is the most inaccurate means of application and is generally not suitable for vegetable and potato cropping, except for acid grey sands with very low PRT. Banding, boomspray application, strip incorporation and fertigation are the preferred methods.

However, broadcasting is suitable for other rotations in the horticulture enterprise, such as establishing post-harvest cover crops and topdressing pastures.

- Top dress after break of season after germination (Do not top dress prior to break of season or in winter).
• Avoid top dressing fertilisers on bare ground.
• When top-dressing pastures or crops, the best time is after germination when the topsoil is moist.
• Do not apply fertilisers in wet paddocks.
• Do not apply fertilisers in or on the banks of streams or drains.

Erosion of soil fertility

- Applying best practices to minimise soil erosion is essential to prevent loss of nutrients from the topsoil. (Section 2)

3.3 Minimise leaching of nutrients

Minimising leaching of nitrogen (Lantztke, 1995)

High nitrogen concentration in the groundwater below horticultural properties is common on the south west coastal plains (Section 5.1 ‘Nitrates in groundwater’). This is important for three reasons:

• Health concerns from drinking water with high nitrate levels
• The growth of algae in surface water
• The amount of nitrogen applied to crops in irrigation water

Nitrogen application and tissue testing

- Apply no more nitrogen fertiliser than the crop needs for good growth. Refer to Department of Agriculture WA fertiliser recommendations for different crops.
- Apply nitrogen fertiliser in small, regular doses throughout the life of the crop. This is especially important on sandy soils.

Indicative rates of nitrogen application on sandy soil types can be found in Appendix 3.3

When plants are young, place nitrogen fertiliser with droppers immediately adjacent to plants. When crops develop more extensive roots they are better able to extract nutrients spread over the whole cropped area.

Once the crop’s water requirements are being provided by irrigation, both nitrogen and potassium can be applied by fertigation, boomspray or broadcasting in regular applications – at least weekly for nitrogen and at least fortnightly for potassium (Paulin, 2001).

Potatoes (processing)

- Around 20-30% of N is applied immediately prior to planting
- Two to three post-plant applications of 50 kg/ha up to 50 mm tuber size
- Weekly applications of 20, dropping to 10 kg/ha/wk to maintain leaf petiole nitrate levels above 8000 ppm
- Nitrogen rates for seed potatoes can be further reduced

Other vegetable crops

On all soils, apply nitrogen weekly. Rates for the first four weeks are 30% less than subsequent applications and these can be maintained until a week before harvest.

- Match nitrogen application rates with crop growth stage. When plants are young, place nitrogen fertiliser with droppers immediately adjacent to plants.

Plant tissue testing is recommended as the most accurate means of determining whether and when to apply more nitrogen and other nutrients during growth of vegetable and potato crops. Plant tissue samples need to be carefully collected to prevent contamination. Accredited laboratories conduct accurate nutrient analyses cost effectively with results generally being available within a few days. Alternatively, sap testing kits provide a quick method to determine the nitrogen status of a crop.

- Conduct tissue testing to determine whether the crop has sufficient nitrogen and adjust nitrogen applications.

Most vegetable crops have specific tissue testing requirements in terms of the part of the plant sampled and growth stage. For example:
• **Potatoes**

Petiole testing is the most reliable check on the nutrient state of a potato crop and should be carried out at least four times during the season. It is very important that the first test is taken when developing tubers reach 10 mm in length because our standards are based on this stage of potato plant development. To accurately judge this, begin checking tuber size at least weekly, five weeks from planting. Repeat petiole sampling at least four times, ideally every two weeks.

• **Carrots and onions**

Sample youngest mature leaf at mid growth period.

• **Corn**

At tasselling, sample the ear leaves.

Most manures, particularly poultry manure, and some composts are high in nitrogen. Growers need to know the nitrogen content of these products and factor it into the total nitrogen application.

- **Do not apply high rates of poultry manure, which will increase soil nitrogen levels far beyond what the plant can use and lead to nitrogen leaching.**

**Taking account of nutrients in groundwater** (Lantzke, 1995)

Groundwater may contain significant amounts of nitrogen leached from previous applications. The amount of nitrogen in groundwater can be significant—amounting to over 30% of the crop requirements on some sites. If the recommended amounts of nitrogen are continually applied without subtracting the nitrogen in irrigation water, the total nitrogen applied will be greatly in excess of crop requirements. The result will be further leaching of nitrogen into the groundwater aquifer, increasing the pollution of this resource.

- **Factor groundwater nitrogen into total nitrogen application.**

Refer to Appendix 3.4 to calculate nitrogen applied in irrigation water. Subtract the nitrogen to be applied in irrigation water over the life of a crop from the total nitrogen required for that crop when calculating fertiliser requirements.

Growers should test bore water to determine the concentration of nitrogen, potassium and, if the soils are grey or white sands, phosphorus (Section 5.1).

**Nitrogen**

The result should be expressed as ppm or mg/L of total nutrient. If test results express the nitrogen concentration as nitrate-nitrogen, divide by 4.5 to get the nitrogen concentration. This figure can be used, but will underestimate the total amount of nitrogen being applied, because additional small amounts of nitrogen are usually present in the groundwater as ammonia and organic nitrogen. For this reason it is best to ask the laboratory to do the analysis for total nitrogen.

**Potassium**

Potassium concentrations in the groundwater beneath horticultural properties may also build up to the point that irrigation with this water supplies a significant part of the crop’s requirement. A potassium analysis can be done at the same time as a nitrogen analysis. The results may indicate that potassium fertiliser applications can also be reduced.

**Phosphorus**

Phosphorus concentrations in groundwater under horticultural properties are unlikely to increase, since this nutrient is held tightly by most soils and not readily leached. However, levels may increase in the shallow groundwater below horticultural properties that are located on acid white or grey sands.

**Other ways to reduce nitrate leaching** (Lantzke, 1995)

- Do not over-water. Excessive applications of water infiltrate through the soil and leach nutrients away. Small, frequent waterings are
best on sandy soils, keeping the root zone moist without excessive water loss by deep drainage.

Never apply nitrogen when the soil is saturated

- Ensure that your irrigation system applies water evenly. Uneven application leads to over-watering in some areas in order to supply enough water to the drier spots. This excess water drains below the root zone, taking nutrients with it.
- Slow-release nitrogen fertilisers can reduce leaching, because they supply nitrogen at a steady rate over an extended period. This can result in efficient nitrogen use by crops, with less nutrients available for leaching. At present these forms of nitrogen are more expensive and uneconomic for broad scale application.

Consider applying soil amendments to light sandy soils (Refer to Section 2.2).

Minimising leaching of phosphorus on light sands

Phosphorus leaches rapidly from white or grey sands and particular attention needs to be paid to phosphorus management. These sands have a very low PRI (Section 3.1 Phosphorus management). This is due to low clay content of less than one percent. Without the clay particles onto which it can adsorb, the phosphorus is rapidly leached below the root zone where it is fixed by clays at greater depth or enters the water table.

Sands with low PRI require less phosphorus to be applied as fertiliser as it stays in the soluble form in which it is readily taken up by plant roots. However, the phosphorus must be applied little and often, or in slow release form. If single applications of soluble phosphorus, sulphur and to a lesser extent, potassium are applied to low PRI sands, these nutrients will rapidly leach vertically or wash laterally out of the root zone.

Section 3.1 explains why and how phosphorus should be carefully managed on sands. Appendices 3.1 and 3.3 give an indication of the applications required, according to soil phosphorus levels and soil PRI.

Apply phosphorus according to soil phosphorus test levels

Have the PRI test conducted on light sandy soils. The PRI test result is important to determine the fertiliser strategy for these soils

Over 70% of the total phosphorus fertiliser should be applied post-planting, ‘little and often’ on light sandy soils with PRI < 20

Another environmentally acceptable alternative is to use fewer applications of slow release sources of phosphorus such as reactive rock phosphate, and sulphur such as crushed rock gypsum. Organic manures are also suited to these conditions as they release nutrients more slowly than soluble fertilisers. However these should be in dried granulated forms as raw manures present fly breeding and odour hazards.

Consider using slow release sources of phosphorus and sulphur and dried granulated manures on light sands with low PRI.

Other post-plant fertiliser applications

Potassium and sulphur application on sandy soils

(Paulin, 1999)

Potassium and sulphur are, like nitrogen, quickly leached from the soil profile, particularly in sandy soils with PRI < 20.

Indicative rates of potassium application for vegetables on sandy soil types can be found in Appendix 3.3.

Sufficient sulphur for heavier soil types is supplied in soluble form with some phosphate fertilisers, such as superphosphate. If other sources of phosphate with little or no sulphur are used, or the soils are light sands, extra sulphur may need to be applied from other sources such as gypsum or potassium sulphate.
Tissue testing is the best way to ensure that the crop is receiving the right amount of each nutrient when it is needed. This is most important on sandy soils.

**Soil amendments**

- **Increase the organic matter and clay content of grey and white sands by:**
  - Turning in mulch crops
  - Applying compost
  - Claying

Organic matter in the soil minimises leaching by retaining soil nutrients and releasing them slowly as it decomposes and oxidises. Green mulching, incorporation of residues and composting (Section 2.2) to increase organic matter are therefore good practices for minimising leaching of nutrients.

In addition to increasing infiltration by overcoming water repellency and improving moisture retention on sands, clay is beneficial to the nutrition of these soils in that it:

- Retains phosphorus, potassium and sulphur in the topsoil where it is made available to the plants. It increases the Phosphorus Retention Index (PRI) of the topsoil.
- Retains soil moisture and encourages longer soil microbial activity, resulting in a controlled release of soil nutrients over a longer period.

See Section 2.2 for details of clay soil amendments.

**References**


McKay, A., 2002. *pers. comm.* Department of Agriculture Western Australia senior horticulture development officer.


Rose, B.J., 2002. *pers. comm.* Department of Agriculture Western Australia.

Ross, P., 2002. *pers. comm.* Department of Agriculture Western Australia.

**Further Reading**


APPENDIX 3.1

Indicative rates of phosphorus application for potatoes on sands

Table A3.1 Indicative phosphorus (P) or double superphosphate (DSP) required for potatoes (based on Delaware) on coastal sands according to Colwell soil test P

<table>
<thead>
<tr>
<th>Soil test result 0-15 cm (mg/kg)</th>
<th>Light yellow (Karrakatta) sands &amp; grey-white sands Kg P/ ha</th>
<th>Red-orange (Spearwood) sands &amp; Yellow (Tuart) sands Kg P/ ha</th>
<th>(kg DSP/ha)*</th>
<th>(kg DSP/ha)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;11</td>
<td>162</td>
<td>926</td>
<td>285</td>
<td>1629</td>
</tr>
<tr>
<td>11-20</td>
<td>147</td>
<td>840</td>
<td>278</td>
<td>1589</td>
</tr>
<tr>
<td>21-30</td>
<td>111</td>
<td>634</td>
<td>261</td>
<td>1495</td>
</tr>
<tr>
<td>31-40</td>
<td>75</td>
<td>428</td>
<td>225</td>
<td>1286</td>
</tr>
<tr>
<td>41-50</td>
<td>40</td>
<td>228</td>
<td>189</td>
<td>1080</td>
</tr>
<tr>
<td>51-60</td>
<td>27</td>
<td>156</td>
<td>154</td>
<td>880</td>
</tr>
<tr>
<td>61-70</td>
<td>26</td>
<td>150</td>
<td>119</td>
<td>680</td>
</tr>
<tr>
<td>71-80</td>
<td>26</td>
<td>150</td>
<td>85</td>
<td>486</td>
</tr>
<tr>
<td>81-90</td>
<td>26</td>
<td>150</td>
<td>48</td>
<td>274</td>
</tr>
<tr>
<td>&gt;90</td>
<td>26</td>
<td>150</td>
<td>26</td>
<td>150</td>
</tr>
</tbody>
</table>

Note:
Application rates of different fertilisers can be calculated from the P rate in the table:
• double superphosphate (DSP) from CSBP contains 17.5% P
• triple superphosphate (TSP) from Summit has 20.5% P
• superphosphate (super) from CSBP has 9.5 % P.

Example: What the rate of TSP should be applied on a Spearwood sand with a soil test result of 45 mg/kg of phosphorus?

TSP rate is 100/20.5 times the P rate from the table.

TSP rate = 100/20.5 * 189

= 922 kg/hectare

Plant analysis (potatoes)

Collect samples of petioles (20 per time) after planting to monitor the P status of the crop. The %P for maximum yield ranges from 0.8-0.9% (tubers 10 mm diameter) to 0.2-0.25% at 120 to 130 days after sowing.

Disclaimer

Further, but without detracting from the disclaimer applying to this manual, the figures in Table A3.1 are only indicative, for the stated Swan Coastal Plain soil types, to give 95% maximum yield. It is recommended that growers have their soils tested and obtain advice from qualified soils consultants to interpret the tests and make fertiliser recommendations.
APPENDIX 3.2

Indicative rates of phosphorus application for potatoes on loams
(McPharlin, 2001)

These recommendations are for the management of P for late winter, spring and early summer-sown potatoes on the loams (includes the gravelly jarrah/marri sandy loams, loams, loamy sands and karri loams) in the Manjimup-Pemberton area. These soils generally retain phosphorus and are termed ‘high P-sorbing soils’. This means that most of the soil phosphorus will be either adsorbed (loosely bound) or fixed (permanently bound) to soil particles (Peverill et al, 1999).

The redder, finer textured soils generally have higher iron content, higher PRI and higher phosphorus sorbing and fixing capacity.

Soil testing

To determine how much P to apply pre-planting, both the Colwell P and the PRI-100 test are required (see soil testing above).

For gravelly jarrah-marri and karri loams, the Colwell test is used to predict if the soil will respond to applied P and the PRI-100 is used to determine the amount of P to apply.

Estimating phosphorus application rate

If the Colwell test is greater than 160 ppm then soil P is substantially adequate for crop growth and it is only necessary to apply 33 kg of phosphorus (191 kg of DSP) per hectare.

If the Colwell soil test is less than 160 ppm (the critical level for potatoes) then phosphorus should be applied according to the soil PRI-100 test result as shown in Table A3.2 below. The higher the PRI-100 test, the higher the P application required. This is because high PRI soils fix much of the P applied, making it unavailable for uptake by the plant roots.

Table A3.2 Indicative phosphorus (P) or double superphosphate (DSP) required for potatoes (based on Delaware) on loams according to the PRI-100 soil test

<table>
<thead>
<tr>
<th>PRI-100 reading range</th>
<th>P (kg/ha)</th>
<th>DSP equivalent (kg/ha)</th>
<th>PRI-100 reading range</th>
<th>P (kg/ha)</th>
<th>DSP equivalent (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>33</td>
<td>191</td>
<td>171-180</td>
<td>144</td>
<td>823</td>
</tr>
<tr>
<td>51-60</td>
<td>46</td>
<td>265</td>
<td>181-190</td>
<td>149</td>
<td>850</td>
</tr>
<tr>
<td>61-70</td>
<td>58</td>
<td>334</td>
<td>191-200</td>
<td>153</td>
<td>875</td>
</tr>
<tr>
<td>71-80</td>
<td>69</td>
<td>397</td>
<td>201-220</td>
<td>161</td>
<td>920</td>
</tr>
<tr>
<td>81-90</td>
<td>80</td>
<td>456</td>
<td>221-240</td>
<td>168</td>
<td>958</td>
</tr>
<tr>
<td>91-100</td>
<td>89</td>
<td>510</td>
<td>241-260</td>
<td>174</td>
<td>991</td>
</tr>
<tr>
<td>101-110</td>
<td>98</td>
<td>561</td>
<td>261-280</td>
<td>179</td>
<td>1020</td>
</tr>
<tr>
<td>111-120</td>
<td>106</td>
<td>607</td>
<td>281-300</td>
<td>184</td>
<td>1044</td>
</tr>
<tr>
<td>121-130</td>
<td>114</td>
<td>650</td>
<td>300-350</td>
<td>190</td>
<td>1090</td>
</tr>
<tr>
<td>131-140</td>
<td>121</td>
<td>690</td>
<td>351-400</td>
<td>195</td>
<td>1122</td>
</tr>
<tr>
<td>141-150</td>
<td>127</td>
<td>727</td>
<td>400-450</td>
<td>200</td>
<td>1143</td>
</tr>
<tr>
<td>151-160</td>
<td>133</td>
<td>762</td>
<td>451-500</td>
<td>203</td>
<td>1158</td>
</tr>
<tr>
<td>161-170</td>
<td>139</td>
<td>793</td>
<td>&gt;500</td>
<td>208</td>
<td>1190</td>
</tr>
</tbody>
</table>

Note: Application rates of different fertilisers can be calculated from the P rate as described under Table A3.1
Disclaimer

Further, but without detracting from the foregoing disclaimer applying to this manual, the figures in Table A3.2 are only indicative, for the stated soil types of the Manjimup-Pemberton area (not the Busselton area), to give 95% maximum yield. It is recommended that growers have their soils tested and obtain advice from qualified soils consultants to interpret the tests and make fertiliser recommendations.

APPENDIX 3.3

Fertiliser management for vegetables on sandy soils of the high rainfall south west coastal plain (Paulin, 2001)

The nutrient application rates given in Table A3.3 are only indications and actual requirements will depend on the soil test levels. Fertiliser programs need to be continually monitored and developed with the aid of soil testing and tissue analysis. Over time as sites are re-planted to successive horticultural crops, it will also become increasingly important to take account of the cropping history.

Table A3.3 Indicative nutrient application rates for vegetable crops on soils of the south west coastal plains

<table>
<thead>
<tr>
<th>Soil</th>
<th>Nutrient</th>
<th>Crop nutrient application rate (kg/ha)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Potato</td>
<td>Carrot</td>
</tr>
<tr>
<td>Orange-brown sand</td>
<td>Phosphorus</td>
<td>200 – 250</td>
<td>200</td>
</tr>
<tr>
<td>Grey sand</td>
<td></td>
<td>90 – 100</td>
<td>100</td>
</tr>
<tr>
<td>Orange-brown sand</td>
<td>Nitrogen</td>
<td>320</td>
<td>250</td>
</tr>
<tr>
<td>Grey sand</td>
<td></td>
<td>360</td>
<td>250</td>
</tr>
<tr>
<td>Orange-brown sand</td>
<td>Potassium</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>Grey sand</td>
<td></td>
<td>350</td>
<td>300</td>
</tr>
</tbody>
</table>

Further, but without detracting from the foregoing disclaimer applying to this manual, the figures in this Table 3.3 are only indicative, for the stated soil types. It is recommended that growers have their soils tested and obtain advice from qualified soils consultants to interpret the tests and make fertiliser recommendations.
APPENDIX 3.4

Calculating nitrogen applied in irrigation water
(Lantzke, 1995)

Step 1
Have a sample of your bore water analysed to determine its total nitrogen content. Take a sample of at least 100 mL of water in a clean bottle with a tight lid. Keep the sample cool in an ice pack or Esky® and deliver it to the laboratory (Chemistry Centre WA or private laboratory) within a few hours. Frozen samples will last up to four weeks (fill the bottle only two-thirds full, to allow for expansion during freezing).

Step 2
Calculate the volume of irrigation water (m³) applied per hour over one hectare:

Output of one sprinkler (L/h) multiplied by 10 divided by distance (m) between sprinklers along each lateral multiplied by distance (m) between laterals.

Another way to do this is, if you know the rate that water being applied in mm per hour:

Volume of water applied, in cubic metres = 10 times the depth of water applied in millimetres

Step 3
Calculate how many kilograms of nitrogen are applied per hectare per hour in the irrigation water:

Nitrogen analysis results (Step 1) multiplied by volume of water per hectare per hour (Step 2) divided by 1000.

Step 4
Calculate how many kilograms of nitrogen are applied per hectare over the crop’s life. Hours of watering will vary with time of year, crop stage and rainfall:

Kg of nitrogen per hectare per hour (Step 3) multiplied by total number of hours of watering over the crop’s life.

The figure obtained in Step 4 is the extra nitrogen that is applied to the crop per hectare from the nitrogen in the groundwater.

Example
If the nitrogen concentration of bore water used in a market garden is 15 ppm, how much nitrogen is being applied through the irrigation system over one crop’s lifetime?

Assume the following:

• output of a Pope Premier sprinkler (size 12 nozzle) at a pressure of 300 kPa = 1452 L/h (24.2 L/min);
• sprinklers 12 m apart along the laterals;
• laterals 13 m apart;
• crop watered 1.5 hours per day (on average); and
• the crop is a cabbage crop that takes 72 days to mature.

Step 1
The nitrogen content of water is 15 ppm (which is the same as 15 mg/L).

Step 2
Calculate the volume of irrigation water (m³) applied per hour over one hectare:

Output of one sprinkler (L/h) multiplied by 10 divided by distance (m) between sprinklers along each lateral multiplied by distance (m) between laterals.

That is: 1452 multiplied by 10 divided by 12 multiplied by 13 = 93 m³/ha/h

Step 3
Calculate how many kilograms of nitrogen are applied per hectare per hour in the irrigation water:

Nitrogen analysis results (Step 1) multiplied by volume of water per hectare per hour (Step 2) divided by 1000.

That is: 15 multiplied by 93 divided by 1000 = 1.40 kg of nitrogen per hectare per hour.
Step 4

Calculate how many kilograms of nitrogen are applied per hectare over the crop’s life:

\[
\text{Kg of nitrogen/ha/hour (Step 3) multiplied by total number of hours of watering over the crop’s life.}
\]

That is: \(1.40 \times 108\) (1.5 hours/day multiplied by 72 days) hours = 151 kg of nitrogen/ha/crop.

A cabbage crop generally requires about 400 kg per hectare of nitrogen for optimum growth. This grower only needs to apply 249 kg of nitrogen per hectare (400 kg minus 151 kg) because of the contribution from the irrigation water.

In this example, nitrogen applied in the groundwater is 38% of the crop’s nitrogen requirements!
Excessive application of phosphorus and nitrogen fertiliser is a major cause of algal blooms and excessive weed growth in wetlands and waterways.

Spreading compost.
SECTION 4

Irrigation Management
Irrigation Management

As outlined in Section 4 of the Code of Practice, efficient irrigation is of prime importance for environmentally sustainable vegetable and potato production.

In accordance with the Code, this section aims to provide sufficient technical information to enable growers to:

1. When installing a new system, choose the right type for their soil, site and climatic conditions and crop requirements.
2. Test the efficiency of irrigation systems.
3. Carry out checks and maintenance of the irrigation system.
4. Conduct fertigation (application of fertilisers and chemicals through the irrigation system), according to best practice.
5. Schedule irrigation effectively to avoid over-watering or under-watering.
6. Manage salinity of irrigation water.

Designing an irrigation system requires specialist knowledge and growers should, in addition to acquiring as much knowledge as they can, employ a Certified Irrigation Designer.

4.1 Use an efficient, properly maintained irrigation system

The aim in designing an irrigation system is to deliver a uniform coverage of water. A uniformity coefficient of 85-90% with a distribution uniformity of 80% or greater is recommended.

The design and specification of the reticulation system is crucial. Uniformity of any sprinkler system depends largely on the combination of sprinkler type, nozzle size, operating pressure and spacing.

Uniformity indicators defined (Gupta, 2001)

Some of the indicators that help evaluate the performance of a sprinkler system are Distribution Uniformity (DU), Christiansen’s Coefficient of Uniformity (CU) and Scheduling Coefficient (SC).

Distribution Uniformity (DU)

Distribution uniformity is defined as the percentage of the average of the lowest 25% of the application rate to that of the mean application rate of the entire pattern. The internationally accepted standard for DU is a minimum of 75%.

\[
DU = \frac{d_{avg25}}{d} \times 100
\]

where,

- \(d_{avg25}\) = average of the lowest 25 percent of the application rates in the sprinkler pattern
- \(d\) = mean application rate of entire pattern

Coefficient of Uniformity (CU)

The uniformity coefficient is an estimate of the uniformity of the sprinkler pattern based on an average of the entire area. The industry standard for agricultural applications requires the CU to be above 85%. The drawback in using the CU to rate sprinkler system performance is that it treats over- and under-watered areas in the same way because of using the absolute value of the deviation from the mean. Since it is an average, it gives no indication of how bad the coverage might be in localised areas. Therefore, it is best to use DU and SC to evaluate sprinkler uniformity.

Scheduling Coefficient (SC)

The scheduling coefficient is a fraction used to determine the length of time that a sprinkler system should be run to account for sprinkler uniformity at the driest area. For example, a system operating at 100% uniformity has a scheduling coefficient of 1.0. A system with a SC of 1.5 means that we have to run the system for an extra 50% to achieve the same precipitation (as in the above case 100% uniformity) to bring the driest area up to the average. There is no critical limit defined for SC.
in the irrigation industry, however a SC of 1.4 would be a good measure of the system uniformity.

\[
SC = \frac{d}{d_{\text{lowest}}}
\]

where:

- \(d\) = mean application rate of the entire area
- \(d_{\text{lowest}}\) = average lowest application rate in the five percent window size of the entire area or a minimum of four catch cans.

**Selecting the right type of system**

When selecting an irrigation system, topography, soils and climate and possible environmental impacts must be considered to ensure that the system is the most efficient and appropriate for the site conditions.

- Consider the environmental risks when selecting the system type and design best suited to the soil, terrain and wind conditions.

The following information should already be part of the farm plan and should be used in selecting the irrigation system.

- Map of the property’s boundaries and size of the property.
- Location in relation to other land uses, particularly sensitive land uses such as residential areas, conservation wetlands and public drinking water supply areas where spray drift and leaching may be issues.
- Climatic data – temperature, rainfall and evaporation graphs or tables, wind intensity and frequency.
- Soils map of the property and soil profile descriptions, including texture, wetting properties and infiltration rate.
- Depth to summer and winter water table, with areas where this is less than two metres mapped.
- Topographic survey map of the property. If there is to be large investment in permanent irrigation systems, the area should be mapped to one metre contours.
- Location, quantity, quality and availability of the water source.
- Types of crops, spacing, estimated rate and frequency of irrigation.
- The location and availability of the energy source.

**Soils**

The first step in preparing a sound irrigation plan is to carry out a soil survey and prepare a soil map. A soil map allows the designer to map crop management units as a basis for the irrigation design. Irrigation section boundaries should then be designed to coincide as closely as possible with these units.

Soil profile information for the main soil types is essential for the designer to ensure that watering application rates are always less than the minimum soil infiltration rates for each station. Soil texture, gravel content and infiltration rate should be measured over at least one metre profiles.

**Topography**

When the elevation variation across a property is more than two metres, this will significantly affect pressure heads in the irrigation lines. The pressure differentials must be taken into account when designing the irrigation layout. Appropriate pipe diameters and pressure compensation devices are crucial to ensure acceptable uniformity coefficients over all irrigation sectors.

Some types of irrigation systems present problems on steep terrain or land prone to waterlogging (see overleaf).

**Systems suitable for various site and soil types**

Some advantages and disadvantages of commonly used types of irrigation systems are described below:

1. **Dripper or micro-sprinkler systems** use much less water than conventional sprinkler systems and are the best option for minimising leaching on sands. These systems can be adapted to any site. They are used for growing melons, pumpkins and cucurbits but are not
widely used for growing other vegetable crops, such as lettuce which require cooling of the leaves in hot conditions. However, micro-sprinklers are an option for most vegetable crops and use less water than conventional sprinklers. Micro-sprinkler systems are similar to dripper systems in that they are low pressure, have low application rates and are connected to small-diameter polyethylene reticulation tubing.

Disposal of large quantities of used plastic tubing is an issue. The life of the tubing, and whether it can be recycled, should be considered when selecting the system. Depending on the quality of the tube and drippers and the application, it may only last a year or two. Landfill is not a good way to dispose of polyethylene plastics as these do not break down for hundreds of years. It is best to select systems that can be re-used at least for several years, and dispose of old tubing through plastic recycling facilities.

2. **Permanent sprinkler systems** with buried PVC reticulation are often used in more intensive operations where land is limited. Time and labour savings offset the high capital cost where there is frequent cropping of vegetables, but not where there are long pasture phases in the crop rotation.

3. **Semi-permanent sprinkler systems** with detachable coupled aluminium pipes or poly pipe are suited to and widely used in situations where there is a pasture or dry-land crop phase. These systems need regular checking and maintenance to minimise leakage and ‘blow-outs’ at the pipe couplings.

4. **Centre pivot irrigators** have many benefits but can present particular problems. Once set up they can water a large area with very little labour input. Another advantage is that there are no pipes and sprinkler spacings to consider when constructing surface water control earthworks.

The large circular shape of the irrigated area (400-750 m in diameter, 20- 40 hectares) means that hill country they are likely to traverse some land that is unsuitable for intensive cultivation, e.g. drainage lines, waterlogged areas or steep slopes over 15% gradient. The temptation is to cultivate and plant through those areas and if this is done, erosion is likely.

Another problem with centre pivots is that excessive run-off and erosion can occur when the sprinklers are aligned running up a steep slope. Erosion will also often occur in the wheel ruts of centre pivot irrigators. In these conditions low rate sprinklers and high travel speeds should be used.

For centre pivot systems it is essential to plan surface water control earthworks, which need to be in place at all times during cropping to prevent erosion. A good surface water control layout is permanent grassed waterways every 50 – 100 m running up and down the slope with temporary grade furrows running into them, intercepting the wheel ruts and thus disposing of excess water safely (Section 2.1).

*Irrigation systems 5 and 6 are generally less suitable for vegetable and potato growing.*

5. **Flood irrigation** is a cheap way of irrigating pasture flats. However its relative inefficiency and the high risks of nutrient and chemical export are disadvantages when using it for cultivated cropping.

6. ‘**Rain gun**’ type travelling irrigators. Large travelling irrigators can cause soil erosion in some situations. Models that apply water at a high rate with large droplet sizes can cause erosion, especially in the wheel ruts. Travelling irrigators are generally not recommended on long (>100 m) and or steep (>5%) slopes.

**System components and layout**

(Agriculture Western Australia, 1992)

Selecting the right type of irrigation system and design it properly is probably the most important decision that vegetable and potato growers make.

Designing an irrigation system involves selecting the right components and integrating them in an
effective layout. This is a specialised task and requires the input of a qualified consultant.

- When selecting and designing an irrigation system, employ a Certified Irrigation Designer (CID) accredited consultant.
  - Where possible, all stations should carry similar flows and operate against similar heads.
  - Dividing the plot into several equal operating shifts will enable the pump size to be reduced.
- Ensure the system has an effective means of controlling the time and duration of water application.

Some modern systems are automated to switch on and off according to pre-set times or soil moisture levels, as detected by electronic soil moisture monitoring systems. Some benefits of automation are:
  - Reduced labour costs
  - Easier night-time operation

Fertigation in trickle systems can also be automated.

- Select the system components to best suit the crop conditions, with consideration of environmental risks.

From an environmental perspective, aim for a system that:
  - Has an irrigation uniformity coefficient of >85%.
  - Is not prone to leakage, pipe failure or blockages, i.e. utilises appropriate fittings, pipe classes, pressure regulators and filters.
  - Has minimal spray pattern distortion and spray drift under windy conditions.
  - Waters at a rate not exceeding the infiltration rate of the soil.
  - Has effective means of controlling application, to minimise infiltration of water past the root zone.

The following guidelines are to help growers to recognise an efficient, environmentally sound irrigation system and to improve their systems.

Attention needs to be paid to all of the sub-headings in this section, which serve as a checklist for growers.

**Selecting the right sprinkler**
(Calder, T. 1992; Gupta et al, 2001)

Most irrigation of vegetable and potato crops in the south west of Western Australia is by sprinklers. In addition to their regular use for crop irrigation, sprinklers are sometimes used for frost control, crop cooling, and minimising the damage caused by sand blasting.

The efficiency of a sprinkler system is measured by the amount of water available to the plants, after evaporation, as a percentage of the water applied. Observations of market garden sprinkler systems in and around Perth have indicated that many systems are inefficient. The sandy soils and hot windy summer conditions on the Swan Coastal Plain pose particular problems for sprinkler irrigation.

Sprinkler design and delivery rate is crucial. In order to select the most suitable type, growers need information on the water application rates and operating pressures for each sprinkler type.

- The application rate of the sprinklers or emitters should not exceed the infiltration rate of the heaviest soil type in the block.

If water runs off the surface during irrigation, then the rate of application is too high. Run-off during irrigation wastes water, exports nutrients and erodes soil.

There is wide variation between types and brands in cost, uniformity of water application and durability. Several new sprinkler designs have appeared on the market in the last 10 years, many of them constructed of plastics for corrosion resistance and low cost.

The following guidelines are to help the grower purchase the most suitable type and best performing brand of sprinkler.

- First ensure that it has the right delivery rate and operation rate for your irrigation plan.
- Look at the cost and compare it with the expected life of the sprinkler.
- Find out what parts are likely to wear. How much will it cost to replace them? - Will it be cheaper to replace the whole sprinkler?
- Will the sprinkler be prone to blockages or corrosion?
- Does it comply with Australian design standards?
- How does it perform in windy conditions?
- What is the application rate? Is it suitable for the soil types?
- Can nozzles be changed easily if required?

**Medium rate continuous throw rotator sprinklers** such as the Nelson Rotator™ or Netafim™. These are the least likely of the larger sprinklers to cause run-off and erosion and are therefore recommended especially for steep slopes and water-repellent or loamy soils. Application rate about four mm per hour, about half the rate of most standard impulse sprinklers. They generally do not throw as far, although spacings of up to 14 m are possible with some models.

**Impulse double jet** sprinklers such as Pope Rainmaker or Premier models are traditionally the most commonly used. When larger jet sizes are used, irrigation rate may exceed infiltration rate on loamy soils or soil profiles with low water holding capacity, e.g. duplex sand/ gravel over clay. This can cause run-off, nutrient export and erosion. On these sites, care is needed in selecting smaller nozzles and not irrigating for too long.

**Micro-sprinklers**. Micro-irrigation is an efficient way of supplying water to a plant. The systems operate above 90 per cent efficiency. On sandy soils, pulsing with a micro-irrigation system can save about 40 per cent of the total water used by sprinklers, due to less leaching and less evaporation losses. Micro-irrigation systems have lower pressure requirements and are cheaper to operate. Wind conditions need to be considered when planning spacings.

The wetting pattern and distribution uniformity of all sprinklers is greatly affected by wind conditions. It is crucial to check the prevailing wind velocities and plan appropriate sprinkler spacings, pressures and nozzle sizes before installing the system. (see ‘Sprinkler system design for windy conditions’ in this section).

Application rate and droplet size can be altered within a limited range for each sprinkler type by nozzle selection.

**Sprinkler head design factors affecting distribution uniformity**
(Solomon, 1990)

The following are three general design factors that influence sprinkler distribution uniformity:

**Rotation speed of the jet**

Rapidly rotating jets have less chance to develop an envelope of moving air, so will always encounter maximum drag and will undergo most break-up. Thus rapidly rotating sprinklers are generally more affected by wind than lower rotation speeds.

**Jet trajectory**

The maximum throw in still air is achieved at around 30 degrees trajectory. However, in the presence of wind, high trajectory angles suffer the disadvantage that the water is in the air longer and hence more affected by wind. For sprinklers to be used in moderate to high wind conditions, lower trajectory angles are advised; 23, 21 and even 18 degree trajectory angles are available for use in successively higher wind conditions.

**Single or double nozzles**

The single nozzle is preferred in windy conditions because the second, spreader nozzle usually has a much finer and more diffuse spray than the main nozzle and is more affected by wind.
<table>
<thead>
<tr>
<th>Sprinkler type</th>
<th>Material</th>
<th>Application rate</th>
<th>Wetted area diameter</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-sprinklers</td>
<td>Plastic</td>
<td>Low</td>
<td>1-4 metres</td>
<td>Water efficient, low pressure. Can be used for some vegetable crops. Good performance in wind if located close to the ground.</td>
</tr>
<tr>
<td>Continuous throw, single nozzle rotator types</td>
<td>Plastic</td>
<td>Medium</td>
<td>6-12 metres</td>
<td>Generally good performance in wind if spaced correctly. Lower application rate than impact sprinklers makes them generally more suitable on hill slopes.</td>
</tr>
<tr>
<td>Butterfly types</td>
<td>Metal or plastic</td>
<td>Medium</td>
<td>6- 7 metres</td>
<td>Generally good performance in wind if spaced correctly.</td>
</tr>
<tr>
<td>Impulse or ‘knocker’ sprinklers</td>
<td>Metal or plastic</td>
<td>Medium to high</td>
<td>10-18 metres</td>
<td>Performance in wind is variable depending on model and nozzle size. Care needed to select nozzle size to keep application rate below soil infiltration rate.</td>
</tr>
<tr>
<td>Large gun type impulse sprinklers</td>
<td>Metal</td>
<td>High</td>
<td>20- 50 metres</td>
<td>Can cause surface run-off and be susceptible to spray drift in windy conditions. Care needed to select the right model and jet size for the soil and wind conditions. Generally not suitable for some situations such a steep slopes and heavy soils.</td>
</tr>
</tbody>
</table>
Sprinkler pressure and jet size

Sprinkler pressures above the recommended range create misting, resulting in wastage of water by evaporation and spray drift and poor distribution uniformity in windy conditions. Sprinkler pressures lower than the recommended range will give a typical ‘donut’ pattern and poor distribution uniformity.

- Restrict operating pressures to the manufacturer’s recommended range.

Check the pump operating pressure and keep it within the system limits. Always fit pressure relief valves. Pressure compensating devices should be specified on hilly land where laterals cannot be positioned on the contour.

Table 4.2 Recommended pressures for a range of sprinkler jet sizes

<table>
<thead>
<tr>
<th>Jet size (millimetres)</th>
<th>Pressure needed (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4- 4.8</td>
<td>240- 345</td>
</tr>
<tr>
<td>4.8-6.3</td>
<td>310- 415</td>
</tr>
<tr>
<td>6.3- 9.5</td>
<td>345- 480</td>
</tr>
</tbody>
</table>

- Do not use sprinklers of different types, precipitation rates or operating pressures within any sector of an irrigation system, unless specified by a CID accredited design for the site.

Sprinkler system design for windy conditions (Gupta et al, 2001; Calder, 1992)

Shallow-rooted vegetable crops are often grown on sandy soils in hot, windy summer weather. These conditions pose a difficult watering problem for many Western Australian vegetable growers.

During summer, regular and uniform water applications are needed to maintain growth. Irrigation systems should be able to cope with higher water requirements when hot, windy conditions occur.

A survey of vegetable properties on the Swan Coastal Plain showed that only 10% of sprinkler irrigation systems operated at the internationally accepted level of uniformity. On the Coastal Plain, wind speeds exceed 16 km/hr for 75% of the time during the main irrigation season. Irregularities in wetting patterns are common, largely because of variations in sprinkler spacing and capacities.

Wind speed and direction (Appendix 4.3) is a major factor causing distortion in the uniformity of irrigation. Besides increasing water loss by evaporation, wind distorts sprinkler distribution patterns. Any sprinkler system operating under windy conditions must be designed to take into consideration the effect of wind speed on its performance.

Choose sprinklers and jet sizes, and design the sprinkler layout to counteract the effect of wind velocities. The following are some guidelines for designing irrigation systems for windy conditions.

- Sprinklers that produce coarser droplets minimise evaporation losses and are less susceptible to wind drift.
  - A combination of smaller spacing and lower operating pressures is desirable. Tests have shown that raising the operating pressure of the system does not improve uniformity if the sprinkler spacing is too large. Increased operating pressure also produces finer droplets, which lead to higher evaporation and wind drift.

  - Where possible, run banks of sprinklers operating together at right angles to the prevailing summer wind direction.

  - Use square spacings, as the problem of dry spots in the centre of adjacent sprinklers in windy conditions is worse under rectangular spacings.

  - Use windbreaks to reduce wind speed.

Sprinkler spacing

Proper spacing of the sprinklers is of paramount importance to achieve an acceptable level of distribution uniformity under windy conditions. For example, on a site with a prevalent wind speed of 13 km/hr, a system with sprinklers spaced 16 m x 16 m would have to be run 30% longer to apply the same minimum depth of
Irrigation water as 14 m x 14 m spaced sprinklers. This would cause over- and under-irrigation in some spots within the paddock leading to poor quality produce and leaching of fertilisers.

The sprinkler’s wetting radius quoted by the manufacturer is based on the indoor (zero wind speed) testing of the product at recommended operating pressures and discharge rates. There is little information available from the manufacturer / supplier as to how much extra overlap and which configuration (square, rectangle or triangle) would maximise sprinkler uniformity under windy conditions.

- **Space sprinklers to achieve a coefficient of uniformity (CU) greater than 85 per cent (internationally accepted levels).**

Exceeding recommended spacing greatly reduces the uniformity of application in windy conditions. Table 4.3 shows the sprinkler spacing needed with various wind velocities.

<table>
<thead>
<tr>
<th>Wind velocity</th>
<th>Spacing requirement, as a percentage of the spray diameter (diameter of the circle wetted in calm conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No wind</td>
<td>65%</td>
</tr>
<tr>
<td>0-8 km/hr</td>
<td>60%</td>
</tr>
<tr>
<td>9-16 km/hr</td>
<td>50%</td>
</tr>
<tr>
<td>Above 17 km/hr</td>
<td>22-30%</td>
</tr>
</tbody>
</table>

Refer to Appendix 4.4 for an example of how wind affects distribution uniformity for a particular sprinkler type.

There is great variation in performance between different sprinkler models in windy conditions. Department of Agriculture WA researchers (Gupta, 2001) are currently conducting extensive testing of many brands of sprinklers in a range of wind conditions. This work will be published and available to growers in 2002. It will help system designers, equipment sellers and growers to select the proper sprinkler and its spacing for a new system under windy conditions. It will also be useful when modifying existing systems to improve distribution uniformity if the prevailing wind speeds for the site are known.

**Sprinkler system design for high and moderate wind areas**

From the wind velocity tables in Appendices 4.3 (Jandakot, typical of the south west Coastal Plain) and 4.4 (Manjimup, typical of the south west Hills) the following general comments can be made about sprinkler system design for those areas.

The SW Coastal Plain is a windy area. Wind speeds in excess of 20 km/ hr occur over 40% of the time in the morning, rising to 70- 80% of the time in the afternoon during summer. The efficiency of sprinkler irrigation is likely to be inefficient for much of the time unless special consideration is given to the design and operation of the system.

The prevailing SE-E and NW-W wind directions should be taken out in designing the layout. Windbreaks should be planted at right angles to the prevailing winds, ie. a NE-SW orientation, to reduce wind speeds in the irrigation area. Wind resistant sprinkler heads with continuous jets and low trajectory angles should be used. An alternative is to consider changing to dripper or micro-sprinkler systems, which are more efficient in windy conditions.

The south west hills areas are less windy and are more suited to sprinkler irrigation. Wind conditions in the mornings are from one to 10 km/ hr for 50 to 60% of the time. Winds are is in excess of 20 km/h only five to 10% of the time in the mornings and up to 17% in the afternoons. The loamy soils of this area generally require less frequent watering than the sands of the Coastal Plain so it is more feasible to avoid watering in windy conditions. However, there is still a significant amount of wind in excess of 16 km/h and performance in windy conditions should be considered when selecting sprinklers and designing the layout. Wind conditions vary in hilly topography and some sites will benefit from strategically placed windbreaks.
Pipe sizing
(Calder, 1992)

Economical pipe sizes often have a friction loss ranging from 0.4 m to 1.2 metres per 100 metres of pipe. The most economical pipe size will vary with the pipe longevity, hours of pumping, pipe friction, energy cost and the current cost of pipe.

- Water velocities in pipes should not exceed 1.5 m/sec in mainlines or two m/sec in laterals. Water velocities lower than 0.6 m/sec allow air to accumulate at high points in the pipe.
- The use of air release valves at high points should always be considered.

* Saving money by purchasing smaller diameter pipes may lead to problems in efficiency and increased operating expenses due to flow turbulence. Turbulent flows result in high friction losses and reduce the pipes’ operating life. Pipe size should be adequate to ensure laminar (smooth) flow.

For further details on pipe selection and sizing, see Farmnote 65/87 ‘Selecting pipes for the farm’, or consult a Certified Irrigation Designer.

Mainlines – specification and layout
(Calder, 1992)

- The mainline should be a minimum of Class 9 or one class higher than that specified for the operating pressure. This will cater for the extra pressure caused by possible water hammer.
- Pipe strength decreases as temperatures increase. Temperature rating should conform to recommendations found in Farmnote 65/87 ‘Selecting pipes for the farm’.
- Mainlines located in the centre of the property are more economical than edge mainlines, since they create shorter laterals, which in turn reduce the friction losses.
- On steep slopes, the mainline is generally designed to go up and down the hill.

Laterals – layout
(Calder, 1992)

- Pressure variations in a valve section should not exceed 20 per cent of the sprinkler or emitter operating pressure. This will give a flow variation of approximately 10%.
- When rectangular sprinkler spacing is used, the laterals should be oriented so that the prevailing winds flow across them. This will improve the application uniformity. In Western Australia, a north-south direction is desirable to compensate for the easterly winds which dominate in summer. However, in undulating terrain, topography dictates the direction of the laterals.
- On steep sloping land, laterals are positioned to go across the slope or approximately on the contour, except where special management requires otherwise. If the laterals are positioned downslope from the mainline, increased pressure can compensate for extra friction loss and pipe sizes can be reduced.
- For future reference, obtain and keep a plan of the pipe network and operating specifications as designed by the consultant.

Pump selection
(Calder, 1992)

Many types of pumps are available but usually only one will best match a design. Using an oversized pump will ultimately result in higher operating costs. It is usually more economical in the long term to spend a little more on the most efficient pump, see Farmnote 17/84 ‘Pumping water on the farm’.

- Above 30m static lift, a submersible pump is cheaper than a turbine pump.
- Suction lift for centrifugal pumps should be kept to an absolute minimum and should be in accordance with manufacturers’ performance guidelines.
- The distance from an elbow to the suction valve of the pump should be at least three to five times the diameter of the pipe.
• The suction line inlet should be three to five times the pipe diameter below the water surface.
• With increasing age, pumps tend to decline in operating efficiency. This situation can cost growers a considerable amount of money in operating costs. Inspection of the impeller may show cavitation damage and that for the minimal cost of a new impeller the original efficiency can be restored. If cavitation has occurred, the cause should be determined. Unless there is an operating problem such as air ingress or suction blockage, the cause is likely to be poor design, which should be corrected.
• An ammeter installed on the motor will also show any dramatic change in energy use and indicate a potential problem.
• Install a pressure gauge at the pump outlet to enable regular checking of the pump’s performance. For accurate reading, the distance from a pressure gauge to a valve should be at least three to five times the diameter of the pipe. Flow meters are also useful but are less common owing to their relatively high cost.

Reliability of irrigation fittings
(Rose, 1997)
Failure of irrigation fittings is a common cause of system leakage and ‘blow-outs’. Neither event is acceptable. Blow-outs are likely to cause severe soil erosion, and leakage of any kind wastes water and can decrease the efficiency of the system by reducing pressure. Choosing the right types of fittings for the purpose will greatly improve the reliability of the system and reduce the amount of maintenance that will be required. Some fittings are prone to failure, especially in semi-permanent sprinkler systems.

Do not use unsuitable or failure-prone irrigation fittings.

Common causes of failures in irrigation systems are:
• Some types of aluminium pipe fittings. The latch type of joiner (e.g.Pope Mainline) is far more reliable than the twist type (e.g.Flexolite), which can loosen and twist undone during use if laid on uneven ground.
• Leakage due to worn coupling seals. The rubber sealing rings in all types of aluminium pipe couplings should be regularly checked and replaced when worn.
• Some PVC plastic fittings can become brittle after prolonged exposure to sunlight.
• Avoid coupling plastic components to metal components, especially where the components may be subject to mechanical stresses. The join will be a weak point, due to the large difference in strength of the metal and plastic.
• Ensure that the grade of pipe used is adequate for the system pressures.
• Water hammer can be a cause of burst pipes.
Ensure that suitable air release valves are fitted to the mainline to reduce the possibility of water hammer.

- Flexible riser tubes for low rate plastic sprinklers are joined via coupling grommets into polyethylene pipe laterals. These can occasionally pop out of the grommets. However, these systems have been improved and are generally less prone to major blowouts than aluminium semi-permanent systems.

**Fertigation**

Fertigation is the injection of soluble fertilisers into water flowing through an irrigation distribution system for application to land or crops or both. It has potential benefits, including savings on labour and fuel costs and convenience for frequent applications at low rates.

However, if fertigation is to be used, it must be conducted properly, as outlined below, to minimise risks of nutrient pollution by spillage, back-flow, leaching and spray drift.

To be efficient and environmentally acceptable, fertigation should ensure the following:

- Back-flow of nutrients into the water resource can not occur.
- Accurate application.
- Minimal risk of spillage.
- Containment and clean-up in the event of spillage.
- Minimal spray drift.

Accurate fertigation relies on an irrigation system that can apply water and fertiliser uniformly over the crop, (distribution uniformity > 90%) with minimal spray drift. Dripper systems are more likely to be capable of achieving these criteria, as they place water accurately on the crop plants and are not susceptible to spray drift. (Calameri, 2002).

Non-uniform application of plant nutrients results in uneven crop growth. In over-watered areas, fertiliser or chemical may leach past the root zone, resulting in higher fertiliser costs and possible groundwater pollution. Spray drift can pollute surrounding natural and human environments.

Fertigation by sprinklers is an inefficient means of applying fertilisers or chemicals in many situations. For example, the large leaves of crops such as brassicas funnel water in to the base of the plants. Sandy soils can quickly become saturated around the base of the plants during fertigation, with the result that much of the fertiliser is leached downwards beyond the root zone. When such crops are grown on sandy soils, it is best to apply fertilisers by boomspray or broadcasting rather than fertigation once the crop has developed substantial leaf cover (Calder, T. pers. comm).

- If fertigation is to be practiced, ensure that the irrigation system has a high coefficient of uniformity and low spray drift.

- Do not conduct fertigation in wind conditions exceeding 10 km/hr, or in temperature inversion conditions (Section 10.1 ‘Weather conditions’).

The greatest environmental risk associated with fertigation is accidental back-flow of fertilisers into the water resource. For this reason, it is essential that the equipment have safety devices to prevent back-flow. Traditionally, some growers injected fertilisers into the suction pipe below the pump, near the water resource (suction injection). This method presents the highest risk of pollution of the water resource and must not be used. The injection system should be located along the mainline, away from the water source.

- Anti-siphon devices and check valves should be fitted and operating according to the manufacturer’s approved design specification, to prevent back-flow of fertilisers and pollution of the water resource.

- Do not inject fertilisers into irrigation systems at or near dams, bores or any other water resource.

- Suction injection (location of the injection point on the irrigation suction pipe below the pump) must be avoided.
the pump) is not acceptable, as it presents a high risk of water resource pollution.

Chemigation

Chemigation is the injection of pesticides through the irrigation system to control pests. It is an inefficient method of applying pesticides, and can lead to off-target drift and water body contamination.

This method of application is allowed by law, except where the pesticide label prohibits its use. Always read the pesticide label to ensure that chemigation is allowed, (for example, on the metham sodium label, chemigation is prohibited).

There is continuing discussion by WA government agencies about the practice of chemigation, in view of the environmental risks. Meanwhile, if chemigation must be used, all of the practices outlined above for fertigation should be practiced, with additional safeguards. Back-flow devices as prescribed in new Victorian legislation (see below: Timebase Victorian Legislation, 2002) should be used to prevent contamination of water resources:

A person must not use chemigation equipment unless that equipment complies with the following specifications:

- A check valve or vacuum release valve must be installed between the irrigation water supply and the point of injection of the agricultural chemical product to prevent back-flow to the water source.*
- A check valve must be installed between the injection pump and main line to prevent flow of water into the chemical tank if the injection pump has failed.
- Interlocking or electronic control mechanisms must be used to prevent continued injection of an agricultural chemical product once the water pump has stopped.
- Any spray nozzle must produce droplets the volume median diameter of which is greater than 1400 micron.

- A person using chemigation equipment must calibrate and inspect the equipment at the commencement of each chemigation treatment and at intervals not exceeding 3 months unless the equipment has not been in use during the whole of the period.

Operators should be properly trained to set up and operate the equipment, and to handle and use chemicals safely.

The point of injection of concentrated chemicals is a high spill risk area. There should be a spill kit at the site at all times. Chemigation equipment should be surrounded by in a dished, waterproof spill containment trough or slab.

Fertiliser injection methods
(Calder et al, 1991)

There are two types of fertigation:

- Proportional fertigation delivers a constant ratio of nutrients applied to flow rate.
- Quantitative fertigation is the application of the plant nutrients in predetermined concentrations to the irrigation system.

The type of fertigation chosen depends on the crop grown and the farm management system. It is important to select a fertiliser injection method that best suits the irrigation system and the crop to be grown. Each fertiliser injector is designed for a specified pressure and flow range. Care must be taken in selecting a fertigation system that suits your requirements.

It is important to decide on the required fertiliser injection rate, the flow rate and pressure of the system and whether a pressure loss in the system is acceptable. Not all injection systems can be applied to both types of fertigation.

There are four principal methods used in fertiliser injection, some of which present higher environmental risks than others. They are:

- metering pumps;
- pressure differential;
- the venturi (vacuum); and
- suction injection.
Suction injection is not acceptable because it presents an unacceptable risk of pollution of the water source. The other systems are acceptable if installed properly and not located at the irrigation pump near the water source.

**Metering pumps**

The metering pump method uses a pump to inject the fertiliser solution from a supply tank into the mainline. The metering pump may be driven by an electric or diesel motor or by water pressure. The pump must develop a pressure greater than that of the pipeline to force the solution into the pipe.

**Advantages:**
- Simple to install and operate.
- Suitable for proportional or quantitative fertigation.
- Easily adjustable injection rate.
- No pressure loss in the mainline.
- Suitable for automation.

**Disadvantages:**
- Pumps and piping must withstand irrigation mainline pressure.
- Needs electricity or motor if not hydraulically driven.

A metering pump is often the most trouble-free choice. The metering pump system is flexible and simple to install and operate.

**Pressure differential**

The pressure differential method creates a pressure difference through the use of a regulating valve between the tank inlet and outlet. The difference in pressure is sufficient to cause water to flow through the tank.

There are two systems that use a pressure differential method. In one, a nutrient bag containing the fertiliser solution is in the tank, allowing the water pressure to force the solution out and into the system. In the other system, water enters the tank and mixes with the fertiliser solution before flowing into the system.

**Advantages:**
- Simple and inexpensive to operate.
- Easy to maintain.
- Easy to alter the type of fertiliser.
- Suitable for powder formulations, if used without a bag.
- No electricity or fuel needed.

**Disadvantages:**
- Requires pressure loss in the mainline, or a booster pump.
- If used without a bag, the concentration of the fertiliser solution decreases over time.

A pressure differential tank is best when fertigation is done on an irregular basis, and where stock solutions are not proportional.

**Venturi (vacuum)**

The venturi (vacuum) injection method uses a venturi device to cause a reduced pressure (vacuum) that sucks the fertiliser solution into the line.

**Advantages:**
- Easy to maintain.
- Easily adjustable injection rate.
- Suitable for very low injection rates.
- Injection rates can be controlled with a metering valve.
- Suitable for proportional and quantitative fertigation.

**Disadvantages:**
- Requires pressure loss in the mainline, or booster pump.
- Quantitative fertigation is difficult.
- Not environmentally acceptable when used on pumps near water bodies.

As the venturi system works on velocity to force the solution into the line, it depends upon a sound irrigation system, which can deliver a constant flow, in order to maintain a constant flow.
supply of plant nutrient. A metering pump may be a better option if the irrigation system is unsuitable.

_Suction Injection_

Suction injection is a method in which the fertiliser tank is connected by pipe to the suction line of a centrifugal pump. There is a the risk of contamination of the water source from fertilisers or chemicals draining through the suction hose to the water supply and other problems such less accuracy, less suitability for automation and the likelihood of air entering the system. For these reasons, this method should not be used and it is recommended that growers select one of the other methods described above.

_Warning when mixing fertilisers_

When preparing fertiliser solutions for injection units, care must be taken with chemicals. Some fertilisers that must not be mixed together are listed below.

- Calcium nitrate with any phosphates or sulphates.
- Magnesium sulphate with di-or mono-ammonium phosphate.
- Phosphoric acid with iron, zinc, copper and manganese sulphates.

Most materials used in fertigation are corrosive. The injector is also often used to inject acid into the irrigation system for regular maintenance. Therefore, all injector parts should be made of corrosion resistant materials.

_System checks and maintenance_ (Luke, 1990)

To get the best results from an irrigation system you need to check its efficiency periodically.

- **Check and maintain the irrigation system regularly.**

To evaluate your system, measurements must be taken on the property, under actual working conditions. It is important to test both old and new systems – new ones because they should be operating to design specifications and old ones because their efficiency deteriorates with use.

There are three things you must know about your system:

- The rate of application of water.
- The variation in delivery rate from place to place.
- Whether sprinklers spread the water evenly or not.

_Items that need to be routinely checked or measured_

1. Pump operating pressure and the operation of all pressure relief valves.
2. Draw-down of bore water supplies.
3. System pressures and pressure variation.
4. Pressures at the sprinkler.
5. Leaking pipes and sealing rings.
6. The flow and operation of each sprinkler or water distributor.
7. Depth of water applied.
8. Sprinkler system uniformity.

During lengthy non-watering periods, test run each segment of the system for a very short period about once every ten days to keep the water supply, electronics and sprinklers operational.

_Equipment needed for evaluating your irrigation system_

- A current irrigation design of your property.
- A good quality, accurate pressure gauge with a range of 0 to 400 kilopascals (kPa).
- A Pitot tube for taking pressures of over-canopy sprinklers and large low-level sprinklers.
- A threaded T-piece and fittings for taking pressures of small low-level sprinklers.
- Three to four metres of flexible plastic tubing to measure outputs. The tubing should be of a size that will allow it to fit over the sprinkler nozzles.
- A 13 mm (or other) threaded T for inserting the pressure gauge in various parts of trickle laterals.

- Barbed 13 mm (or other) joiners to repair laterals once pressure readings have been taken.

- A bucket or drum large enough to collect the flow from a sprinkler for 30 seconds.

- A watch that measures in seconds.

- A large metric measuring jug.

- A small measuring cylinder or rain gauge.

- At least 30 tin cans with a minimum height of 100 mm, to measure the distribution of sprinkler.

- A tape measure 30 to 50 m long.

**Pump operating pressure and the operation of all pressure relief valves**

Pumps and motors wear out with use. Most growers accept this as fact but do little about it until the unit fails. Many irrigators are unaware of how well the pump is performing, its operating pressure or the efficiency of pumping. Nor do they have a chart of the pump performance curve to show the flow at which the optimum efficiency of the pump set is obtained.

Measurement of pump performance and corrective action where necessary is the essential first step in evaluating your sprinkler system. All pumps should have a pressure gauge and flow meter near the pump outlet. Experienced personnel such as local qualified dealers or consultants can measure pump efficiency. Alternatively, you can do it yourself as follows:

- Determine the head, which is the height of the pipe outlet above the water level of the dam or bore.

- Determine the power of the pump from the pump manual. Record the pressure and flow gauge readings with the pump operating at the measured head and specified power.

The efficiency of the pump can be calculated by the following formula:

\[
\text{Efficiency (\%) } = 100 \left( \frac{\text{power of pump in kw}}{9.8 \times (\text{flow in litres per second}) \times (\text{head in metres})} \right)
\]

The efficiency of the pump should be the same as that stated in the pump manual.

**Draw-down of bore water supplies**

If drawing from a bore, check the standing level and draw-down level of the groundwater supply during operation. This is particularly important during late summer when the aquifer level is low and water inflow into the bore is likely to decrease.

**System pressure and pressure variation**

When checking pressures, first adjust any sub-main or internal valves to the pressure shown on the irrigation plan. Do this at the start of each irrigation season by carefully adjusting each valve several times until steady, correct pressure is achieved.

If the system is working properly, the valves will be adjusted so that the average pressure over the whole unit is as close as possible to the design pressure stated on the irrigation plan. None of the sprinklers or emitters should be operating at more than 10 per cent above or 10 per cent below this average pressure.

**Leaking pipes and sealing rings**

Inspecting water distribution lines when they are under pressure will help find leaks in the pipes. Rubber sealing rings in aluminium pipe couplings should be routinely checked for leaks and worn seals replaced.

**Pressures at the sprinkler**

After the internal pressures are set according to the design, measure the operating pressures at 10 or more locations spread across each irrigation unit. These must include the points nearest the valve, at the start and ends of laterals, and at
points of high and low elevation. The technique for doing this depends upon the type of system.

Over-canopy and large low-level sprinklers

Attach a Pitot tube to the gauge and then place it with the end of the tube held into the water stream, about 3 mm away from the nozzle. The reading may fluctuate, but the correct reading will be the highest registered on the gauge with the Pitot tube in this position.

Small low-level sprinklers

Attach a threaded tee piece to the gauge. Then select a sprinkler and choke off the water by crimping back the connector tube. Remove the sprinkler and replace it with the T piece, finally screwing the sprinkler on top of the assembly. Release the connector tube and record the pressure.

From the reading taken at 10 or more sprinklers, calculate the average pressure by adding all the pressures together, and dividing them by the number of sprinklers used in the test. The result should be close to the sprinkler pressure stated on the irrigation plan. If the variation is greater than 10 per cent above or below this, try to reduce it by adjusting any internal valves installed in the system.

If the variation cannot be reduced to within the ten per cent tolerance level, discuss the problem with an irrigation designer.

Trickle irrigation systems

The pressure at 10 different places in a trickle system should also be taken. These can be at the end of laterals, or at the start, high and low points, as for sprinkler tests. For these mid-lateral readings, cut the line and insert the threaded takeoff. After the reading is completed, repair the lateral with the barbed joiner.

Pressure compensating system

If the design uses pressure compensating sprinklers or emitters, then pressure variations from the irrigation plan greater than 10 per cent may be found. Providing the pressures fall within the manufacturer’s specified range for optimum performance, the system should be operating satisfactorily.

Spot-check and record the precipitation rate of each distributor line two or three times each summer. Variations could mean a potential problem, such as system wear, water loss, water inlet blockage, pipe sludge accumulation, pipe damage or distributor blockage.

Flow and operation of each sprinkler or water distributor

Checking for worn sprinkler components

Watch your sprinklers and emitters during an irrigation to see if they are working properly. Look for:

- Excessive leakage of water around the sprinklers
- ‘Dumping’ of water around the sprinklers
- Uneven rotation (seen as ‘fluttering’ in small sprinklers)
- Loss of throw, leading to dry or under-watered areas
- Sprinkler parts distorted by the sun, for example, the bridge of micro-sprinklers
- Sprinklers or emitters not working, or stopping during an irrigation
- Emitters spurting water.

During winter, dismantle some sprinklers and check for wear of parts. This includes wear of the spindle, spinner and nozzles of micro-sprinklers, and the base, connector tube, seals, washers, springs, arms, spindles and nozzles of over-canopy sprinklers.

Replacement of worn sprinklers and parts during winter will prevent problems arising from sprinkler failure during the irrigation season.

Blocked or partially blocked trickle emitters indicate possible filtration problems, but may be treatable. For more information on these treatment techniques see Farmnote No. 43/92 ‘Iron in water for micro-irrigation’ and Farmnote No. 41/90 ‘Removing blockages from trickle irrigation lines’.
Checking nozzle and emitter sizes

All outlets should be the size stated on the irrigation plan to ensure an even depth of water is applied across the irrigation unit. It is usual for outlet sizes to be uniform throughout, although sometimes the size varies to accommodate differences in pressure or spacing. Study the irrigation plan carefully, and check the sizes across the unit.

Most outlets are marked with their size in millimetres, fractions of an inch, output in litres per hour, or in the case of plastic nozzles, by colour coding.

Unmarked nozzles with round openings can have their size checked by carefully inserting the shank of an unused steel drill bit into the nozzle. The bit with a snug fit indicates the nozzle size. This method can also be used to check for nozzle wear. A sloppily fitting drill bit of the same size as that stamped on the nozzle indicates substantial wear, and the nozzle should be replaced.

Measuring the discharge from outlets

Since outlets are affected by wear, it is essential to periodically measure discharge and compare this with the manufacturer’s performance chart. Collect the discharge from a sprinkler or emitter in a bucket for 30 seconds and measure the water collected in litres, using a measuring jug.

In the case of small low-level sprinklers, hold back the arm or spinner and direct the stream into the bucket for the 30 seconds. With larger sprinklers, place the end of three to four metres of plastic tubing over the nozzle, and direct the stream into a bucket for 30 seconds. Where the sprinkler has a rear nozzle, repeat the test on the second nozzle to determine the total discharge. Trickle emitters can be held over the collecting container.

Discharge, L/h = (litres collected in 30 seconds) multiplied by 120

Repeat the test on at least 10 outlets across the irrigation unit. The discharges of individual sprinklers on any one lateral should not vary by more than 15 per cent.

Compare the discharge measured over your block with the manufacturer’s specifications for the given operating pressure. If yours are on average more than about 15 per cent higher, it is likely that substantial nozzle wear has occurred, and you should consult your supplier about nozzle replacement.

Depth of water applied

The depth of water applied is the amount of water that would be collected in a rain gauge or measuring cylinder placed at the soil surface during irrigation.

To irrigate efficiently, you must know what depth of water your system is applying. This will ensure enough water is applied and will minimise the amount lost to drainage.

Two simple techniques can be used to measure the depth of water being applied.

1. First, if there is a meter, record the reading (usually in kilolitres) at the start and finish of the irrigation. Subtracting the reading at the start from the reading at the finish will give you the kilolitres used. From your irrigation plan, measure the area that was irrigated.

Depth in mm = \( \frac{\text{kL reading at finish} - \text{kL reading at start}}{\text{area irrigated (hectares)}} \times 10 \)

2. The second technique uses the discharge of an individual sprinkler or trickle emitter, and the area over which it applies the water. Using the manufacturer’s performance chart, read off the discharge for the combination of nozzle or emitter size and pressure. Then work out the area being irrigated by each outlet by measuring the distance between irrigation rows and the distance between outlets down the row.

Sprinkler system uniformity

If the sprinklers distribute the water unevenly, some areas will receive too little water and others too much. Under-watered areas of crop may become water stressed and in the over watered areas, large amounts of water will be wasted and nutrients leached. Similarly, plant
nutrients will be unevenly distributed if fertigation is practised.

The rate and uniformity of precipitation of sprinklers over the irrigated area should be tested annually or if there have been any changes to the system.

Check how even the distribution is by placing a grid pattern of empty tin cans between sprinklers. At least 30 cans of the same size should be used. Ensure the cans are upright, and not under low hanging foliage. The can layout will depend on the value of crop, and the type of sprinkler system installed. For sprinklers arranged in staggered lines, 14 m apart, arrange the sprinklers in a 2 m grid.

For low-level sprinklers, the cans should be dug into the ground with about 25 mm showing above the surface. This will ensure that the cans are below the throw of the sprinkler.

Sketch a plan showing the position of the cans. Turn the sprinklers on and operate them normally for at least a full irrigation. Record the direction and strength of the wind during the test.

After the sprinklers have been turned off, measure volume of water in each can using a measuring cylinder or rain gauge, and the depth using an accurate ruler. Record the results on the sketch plan.

Repeat the test to determine the evenness of the distribution over a range of wind conditions. As well, carry out the test at several locations in the irrigation unit.

Calculating distribution uniformity

From the sketch plan, firstly average the contents of the cans by dividing the total amount of water by the number of cans. Then circle the lowest amount, the next lowest, and so on, until you have circled a quarter of the values on the plan.

The next step is to average this ‘lowest quarter’ of the readings. Distribution uniformity as a percentage (DU%) is calculated by dividing the low quarter average by the average of all the readings, and multiplying by 100.

\[
DU\% = \frac{\text{low quarter average}}{\text{average of all readings}} \times 100
\]

A DU of 75 per cent or higher indicates acceptable uniformity, while values less than 67 per cent indicate that the sprinkler distribution is non-uniform.

Operation of fertigation and chemigation equipment

Injection lines should be regularly inspected and, if they have deteriorated, replaced with lines of approved standard. Fertigation equipment should not be accessible to stock or unauthorised personnel that may interfere with its operation. Flow rates should be periodically measured to maintain accurate rates of fertiliser application.

Correcting faults

Where faults are found in the irrigation system, the necessary changes should be worked out with your Certified Irrigation Designer. When designing or re-designing a sprinkler system, full account should be taken of the effects of wind, temperature and humidity. System pressure, sprinkler type and delivery rate and sprinkler spacings need to be selected accordingly.

After evaluating the sprinkler system and correcting any faults, the grower can irrigate, knowing how much water is being applied, and that application is uniform and efficient.

Better crop yields, savings in pumping costs and less water used will more than repay the cost of maintaining and/or improving the irrigation system.
4.2 Apply irrigation in accordance with crop demand and evaporation

The grower needs to consider many variables to ensure efficient watering. The following factors should be taken into account to determine the quantity and frequency of water application:

1. Type of crop and growth stage. This will determine the percentage of soil cover and the leaf area, which affect crop water use.

2. Evaporation rate. This will be affected by:
   - Relative humidity
   - Wind speed
   - Daily solar radiation (UV)
   - Air temperature

3. Soil moisture content. This will be affected by the soil’s:
   - Water retention capacity
   - Infiltration rate
   - Wetting properties

4. Type of sprinkler or emitter used. For example, drippers generally have less evaporation loss than sprinklers.

Irrigation scheduling

(WA Dept. of Agriculture, 1990)

The efficiency of water application is dependent on the design of the irrigation system, and the way in which the watering program is scheduled.

Irrigation scheduling is deciding time and frequency of irrigation and how much water to apply.

The aims of irrigation scheduling are to:

1. Replace the water used (transpired) by a crop and that which is lost by evaporation during application.
2. Minimise evaporation losses during application.
3. Maintain adequate soil moisture in the root zone during growth (day-time), so that optimum crop yield is achieved.

4. Avoid applying more water than the crop requires, thus minimising loss of water and nutrients by drainage through the soil below the root zone.

Why reliance on experience is not acceptable

Many growers still rely on years of experience to develop irrigation schedules that produce good crops.

However, trials done by the Department of Agriculture Western Australia have shown that many of these schedules, which were developed to maximise yields rather than save water, tend to over-water. Introducing best practices in irrigation scheduling has resulted in water savings of up to 70 per cent.

Over-watering causes many problems including:

- Inefficient use of applied nutrients by plants.
- Leaching of nutrients into the groundwater and wetlands adjacent to sandy soils.
- Waterlogging and yield losses on heavy soils.
- Wasted water and unnecessarily high pumping costs.

The Environmental Protection Authority requires that new horticultural enterprises be non-polluting and to ensure this, more reliable scheduling techniques must be used.

The need to upgrade the scheduling of irrigation systems therefore stems from the joint needs to conserve water, reduce costs, and preserve the environment.

For effective scheduling of irrigation, it is important to monitor and record both:

- evaporation
  and
- soil moisture

Evaporation records enable the grower to estimate how much water to apply (replacement rate).

Soil moisture monitoring provides a ‘double check’ as to accuracy of the replacement rate and tells the grower when to apply water and for how long.
By using both evaporation and soil moisture records, growers can become very efficient at irrigation scheduling. Neither is sufficient on its own, but in combination they provide essential cross checks.

Monitoring evaporation rate

For accurate irrigation scheduling, the grower needs a local record of evaporation, i.e. daily recordings from an evaporimeter on the property, or at least in the local area.

Monitor pan evaporation rate and factor it into the daily estimation of the quantity and frequency of water application that will be required.

Average daily evaporation figures are available (Appendix 4.2; Bureau of Meteorology). These averages are only useful as a starting point for estimating evaporation replacement. The actual daily figures can be more than 60% above or below the average, (see Appendix 4.1, which shows highest and average evaporation figures for Perth). It is important to measure and record evaporation rate on or near the property rather than use an average daily figure.

In addition to daily temperature and wind conditions evaporation varies according to site-specific influences such as exposure and windbreaks.

Evaporimeter

Evaporation is measured by an evaporimeter and is essentially millimetres of water lost from the surface of an open water body. Electronic evaporimeters can be purchased or simple pan evaporimeters constructed.

A simple evaporimeter can be made from any container that has a diameter of at least 30 cm and a depth of at least 20 cm. A gauge (plastic ruler) is attached to determine the amount of evaporation in millimetres. A ‘V’ notch cut in the upper edge assures a constant water level when filling. Poultry netting should be used to protect the evaporimeter from birds and animals. The home-made evaporimeter may not be sensitive enough for daily readings. Check local evaporation figures for these areas to see how they compare with the home-made evaporimeter. More sensitive electronic evaporimeters can be purchased

Use of the evaporimeter

For crops grown on sandy soils, read the evaporimeter throughout the year. Drought sensitive crops such as avocados could suffer from water stress, even in winter, after four or five rain-free days.

On heavier soils, start reading the evaporimeter in late October. A useful guide is to start irrigating after a loss of 25 mm in a week. Each week from then on, the evaporimeter should be read and then refilled.

If a pan evaporimeter is used, rainfall will be included in the evaporimeter readings and there is no need to allow for a reduction in irrigation requirements.

Evaporation rate and replacement rate

The replacement rate, (depth of water required to be applied each day in millimetres), is based on daily evaporation rate. The daily replacement rate is calculated by adjusting the daily evaporation rate by the following factors:

- A crop factor that takes account of the crop type and growth stage.
- An efficiency factor, which accounts for evaporation losses during irrigation (for sprinkler irrigation). The efficiency factor depends on wind conditions (Table 4.4).
- If the irrigation water has salt levels above 90 mS/m, (500 ppm), an extra leaching fraction may need to be applied (Section 4.3).

Crop factor

For best growth in the Perth region, the crop factor is about 80 to 150 per cent of the measured evaporation rates, depending on the crop type and growth stage. For example, corn needs (on average) 100 per cent, but this varies by about 20% each way depending on growth stage. Application needs to increases as leaf area
increases. Leaf crops such as cabbage need (on average) 120 per cent, and lettuce needs 150 per cent of evaporation rate for optimum yield (Calder, 1992). Growers should obtain crop factor tables for the particular vegetables they are growing and use them when calculating irrigation replacement.

**Irrigation efficiency factor – sprinkler irrigation**

Sprinkler irrigation is not 100% efficient because a significant percentage of the water is lost by evaporation during application.

Drippers have much higher irrigation efficiency than sprinkler irrigation in some situations, such as when they are located under the soil surface or under mulch, but in other situations, may not be much different to sprinkler irrigation.

Evaporation is greater during windy conditions. The wind effect is reduced with micro-sprinklers and negligible with drippers.

Table 4.4 shows that on a normal day, even when relatively calm, only 67 per cent of water leaving the sprinkler reaches the ground. This percentage may improve as humidity builds up during watering, but losses remain high. Since the interaction of wind velocity, temperature and humidity changes constantly, these figures are only approximations.

Table 4.4 does not take account of extreme conditions. Tests on a cool morning with no wind and high humidity showed water losses as low as 4 per cent (irrigation efficiency would be 96%).

In severe wind conditions on a hot day, evaporation losses could be 50 per cent (irrigation efficiency would be 50%). In these conditions, to supply 8 mm of water, up to 16 mm of water must be pumped out through the sprinkler system.

**Irrigation efficiency factor, trickle irrigation** (Calder, 2002)

Trickle irrigation efficiency is also variable, from 70-90%, (usually around 80-85%) depending on such factors as temperature, shading and soil type, but is not significantly affected by windy conditions.

Another reason that dripper systems use less water than sprinkler systems is sprinklers irrigate the whole area including laneways, while drippers only irrigate the beds. For the same replacement rate over the same plot, drippers would use less water because they would not be watering unproductive parts of the plot.

<table>
<thead>
<tr>
<th>Wind velocity</th>
<th>0 to 8 km/h</th>
<th>9 to 16 km/h</th>
<th>17 km/h and above</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of water applied</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>25 mm</td>
<td>67</td>
<td>63</td>
<td>62</td>
</tr>
<tr>
<td>50 mm</td>
<td>69</td>
<td>67</td>
<td>65</td>
</tr>
</tbody>
</table>
Salinity (leaching fraction)

If the salt level in the irrigation water is over 90 mS/m (500 ppm) and irrigation is by sprinklers, an extra amount of water (leaching fraction) may need to be applied to flush water from the root zone. Refer to Section 4.3 ‘Precautions for the irrigation use of salty water’ for more details, or refer to detailed handbooks.

For trickle irrigation, a leaching fraction is generally not required as long as an adequate wetting pattern is established and maintained. If watering is irregular and the wetted zone around the roots is allowed to contract inwards, salts will also move into the root zone.

Calculating irrigation replacement rate and time required for irrigation
(Luke, 1990)

Most vegetables are very water-sensitive plants because they have poorly developed and shallow roots. On the sands of the coastal plains, which have very poor water holding capacity, vegetables normally need to be watered every day in summer (except when rainfall is more than evaporation).

Vegetables are very sensitive to heat stress. In heat wave conditions they may require more watering than is indicated. When a cool week is followed by a very hot week, extra water should be applied.

Sprinkler irrigation

Evaporation losses from sprinklers during irrigation must be factored in. The irrigation efficiency, expressed as a percentage of the irrigation water remaining for plant use after evaporation loss, is approximately as follows:

- Night watering 90%
- Average day 65-85%
- Very hot windy day 50-60%

Estimates of evaporation losses for different wind speeds are shown below in Table 4.4.

Calculating the time required for sprinkler irrigation

1. Calculate the precipitation rate (PR).
   \[
   \text{P.R. (mm/min)} = \left( \text{litres/minute/sprinkler} \right) \text{divided by (sprinkler spacing, m lateral spacing, m)}
   \]

2. Measure the evaporation for the previous day from the evaporimeter.

3. Decide on the replacement rate by applying the following factors to the evaporation rate.
   - Multiply by the crop factor
   - Multiply by 100/ irrigation efficiency (%) in prevailing wind conditions (Table 4.4 above).
   - Allow extra for salinity if necessary (Section 4.3 ‘Leaching fraction’).

4. Work out the hours or minutes of watering, which is the replacement rate divided by the precipitation rate.

Example

1. Calculate the precipitation rate (PR):
   - Sprinkler spacing 6 m
   - Lateral spacing between pipes 6 m
   - Litres/minute/sprinkler = 15
   - \[
   \text{PR} = 15 \text{ divided by (6 multiplied by 6)} = 0.42 \text{ mm/minute}.
   \]

2. Evaporation for day = 9.2 mm (January)

3. Replacement rate:
   - Crop factor is 140 per cent (lettuces, more than 25% growth stage)
   - \[
   = 1.4 \times 9.2= 12.9 \text{ mm}
   \]
   - Wind efficiency factor, expected winds 8 km/hour= 67%
   - \[
   100/67 \times 12.9= 19.25 \text{ mm}.
   \]
   The water is less than 90 mS/m conductivity so there is no adjustment required for salinity
   - Replacement rate = 19.25 mm

4. Minutes of watering = replacement rate / precipitation rate=19.25 / 0.42
   - = 46 minutes
Trickle irrigation

Calculating the replacement rate for drippers is done in the same way as the sprinkler calculations. However, different efficiency factors will be applied:

- The efficiency factor will usually be higher (around 80%) and there need not be allowance for windy conditions.
- A leaching fraction need not be added when trickle irrigating using water of higher salt content.

Calculation of precipitation rate differs slightly:

- Count up the number of drippers per wetted hectare *.
- Precipitation rate (PR) in millimetres per hour (mm/h) = (No. of drippers/hectare multiplied by number of litres/dripper/hour) divided by 10,000.

* Note that, unlike sprinklers, which irrigate the whole area including laneways, dripper systems only irrigate the beds. For example, a 1.0 hectare vegetable plot has 10,000 drippers, watering 0.8 hectares of beds and there are 0.2 hectares of laneways that are not watered. This plot has 10,000/0.8 = 12,500 drippers per wetted hectare.

On heavy soils, if the dripper irrigation periods are less than eight hours per day, it is better to double the time and water every second day. This is because less than eight hours watering may not produce a uniform wetting pattern in these soil types. On sandy soils, which hold less water, irrigation will have to be for shorter periods but more frequent and this will be indicated by the tensiometers.

Minimising evaporation losses

- To minimise evaporative losses apply water during the coolest time of the day and at times when there is least wind.
- Water early in the morning if using sprinklers.

This results in the target area being better serviced by the reticulation system and decreases water loss through evaporation. Ideally, the first irrigation on hotter days should be between 5.30 a.m. and 6.30 a.m. Watering before 8 a.m. can also take advantage of off-peak electricity rates.

From the tables in Appendix 4.3 (Jandakot and Manjimup wind velocities), some comments can be made about the timing of sprinkler irrigation in these areas.

On the Swan Coastal Plain about 20-25% of wind is above 20 km/h at 6 a.m. rising to over 40% at 9 a.m. and 70-85% at 3 p.m. These wind conditions greatly reduce the efficiency of sprinkler irrigation and are a major consideration for the grower. The best times to water are from pre-dawn to before mid-morning. Higher wind velocities in the afternoon mean that watering with sprinklers is inefficient at that time and that more water would have to be applied. However tensiometer readings usually indicate that most crops on the sandy soil types require afternoon watering because of the low moisture retention capacity of the sands. Alternatives to consider are night watering and changing to drippers.

Summer wind velocities in the south west hills areas are much lower, with only five to ten percent of the winds being over 20 km/hour in the mornings and up to 17% in the afternoons. This climate is more suitable for sprinkler irrigation. The best time to water is early to mid-morning. Tensiometer readings will indicate whether more than one watering is required on sandy soil types.

Watering at night presents higher risks of nutrient leaching occurring particularly on the sandy soils of the Swan Coastal Plain. Plants use little water at night and as these soils do not hold water well, excess water applied will drain rapidly beyond the root zone.

However, it is recognised that it is often too hot or windy to apply sufficient water during the day. Watering at night may also be necessary for frost control.
If watering at night on sandy soils:

- Water lightly (less than 5 mm) and as close to dawn as possible.

Or

- Have an efficient automated soil monitoring system that switches the pump off when the soil becomes saturated.

Monitoring soil moisture

(WA Dept of Agriculture, 1998)

The physical structure of the soil dictates the reserve of water available to the plants. Watering should aim to provide water to the root mass, most of which is located in the upper 200 millimetres of soil. Water that penetrates below this depth is effectively wasted and increases the problem of nutrient leaching.

Using the methods described above, the grower estimates how much water a crop requires (the replacement rate). However it is also important to know how much water is in the soil. This enables the grower to:

- Double-check whether the right amount of irrigation has been applied and adjust the replacement rate if necessary.
- Determine when to switch the irrigation on and when to switch it off. For example, soil moisture monitoring will show whether a single daily application or two or three shorter applications are necessary to provide the replacement rate required by the crop on the particular soil type.

To determine the amount of water a crop is using and whether the frequency of irrigation is right, it is necessary to measure the soil moisture content on a regular basis.

Install moisture-detecting sensors within and below root depth to determine when irrigation is required and gain an understanding of the soil moisture profile.

The maximum time of continuous watering depends upon the soil type and the root depth of the crop. On sandy soils, prolonged watering periods result in water draining below the root zone. It may be necessary to break up the irrigation into several shorter periods.

For example, sandy soils requiring 50 mm of water replacement in a week may need four waterings each of 13 mm during the week.

There are a number of methods used for monitoring soil moisture levels in vegetable and potato crops:

1. Feel
2. Tensiometers
3. Capacitance probes
4. Neutron probes

Soil moisture monitoring, using one of methods 2-4 should be an integral part of every grower’s operation. Monitoring soil moisture by feel alone is neither accurate nor efficient enough for modern growing operations.

The large benefits in water, fuel and fertiliser savings, and in yield increases, more than justify the time and effort needed to set up a soil moisture monitoring program. The tensiometers and capacitance probes can be set to record automatically, and to trigger irrigation. These records can also be stored and analysed on a computer for record keeping or predicting future watering needs.

Feel

Feeling the soil is the oldest method. Holes are dug regularly to determine whether the last irrigation has penetrated to the correct depth. However, the technique is not accurate and cannot be relied upon as a guide to how much water is in the soil, or when the next watering should occur.

Tensiometers


Tensiometers consist of a water-filled hollow tube that acts like an artificial plant root. At one end, buried in the soil, is a porous cup. On the other is a pressure gauge. The tube between the gauge and the cup is filled with water and sealed with a cap.
As the soil dries out, water is sucked from the tube, through the cup. This causes a partial vacuum in the tube and increases the pressure reading on the gauge. The higher the reading, the less water in the soil, and the harder it is for the plant to extract water. After irrigation, water enters the cup and the vacuum pressure falls.

Tensiometers are relatively cheap, are easy to set up, and are valuable tools for irrigators. They are used in groups, with two or three instruments installed at different depths making up a ‘station’ or ‘nest’. At each station or nest the tensiometers are installed at the top, middle and/or bottom of the root zone. For vines and tree crops this is commonly at 30, 60 and 90 cm respectively. For vegetable crops tensiometers are commonly installed at 30 and 45 cm.

Initially, buy several sets of two or three, and see the benefits and cost savings. Then install further sets in each soil type on your property. This will ensure overall watering efficiency, better plant health, and increased crop yield.

Tensiometers should only be used as an indicator of when to water. Because of the time it takes for water to move through some heavier clay soils, even after the correct amount of water has been applied, it may take up to 24 hours for the water to soak down to the cup. In these soils, if watering continued until the gauge readings started to decline, over-watering would occur.

Note: For sandy soils, it is essential to use special sand tensiometers that have the blue (sensitive) tips. These can detect the very small difference in tension (pressure) between wet sand and sand that is too dry for the plant to extract water.

Preparing for installation

When tensiometers are bought, they must be prepared for installation. Unprepared tensiometers will not give true readings. The preparation varies slightly depending on the brand. Follow the instructions supplied to ensure correct filling, removal of air, and calibration.

Quick draw tensiometers

One other tensiometer on the market is the Quick Draw® type. This is not left inserted in one place but is moved around the field. After the device is set up and adjusted, it is moved to any site where a reading is required. Full details of the technique for setting up Quick Draw tensiometers come from the manufacturer with the device. Note that this technique is not recommended for gravel soils, which will damage the instrument when it is continually reinserted.

Where to install tensiometers

If a tensiometer is to give useful information about the availability of water in the soil, it must be put in a representative position and installed properly.

Use the following guide to select the right site:

- Determine the greatest area of similar soil for the crop. It may be necessary for you to have a soil survey made of the property, to identify the various soil types.

- Select an area where the plants have average vigour. A second station should be placed elsewhere in the planting as a check.

- Choose a place to install the station. For shallow-rooted vegetable crops the tensiometer station should be placed in the active root zone of the plant, directly under the stem of the plant. When the crop is young, one shallow tensiometer is adequate; as the plant grows, place a deeper tensiometer at the bottom of the root zone.

- Ensure that the positions selected receive an average water application. You must check the operating pressures, water output and water distribution of sprinklers in order to choose the best possible sites (Farmnote No. 35/90). Do not place tensiometers in localised hollows or excess water may build up around them.

Installation and maintenance

Installation of tensiometers is best done when the soil is moist, preferably two or three days
after irrigation. Refer to Appendix 4.5 for installation and maintenance of tensiometers.

Interpreting tensiometer readings

A tensiometer measures how hard the root system of a plant must work to extract water for its needs. It directly measures the ‘soil matric potential’, which is the physical force that the root system must overcome to free the water from the grip of the soil particles.

All tensiometers read in centibars (cb). One hundred centibars equals one bar. The higher the reading on the gauge, for example 40 cb, the harder it is for the plant to extract water from the soil. The lower the reading, for example 10 cb, the easier it is for the plant to extract water from the soil.

Most of the water in the soil available for plant growth occurs as a thin film on the soil particles or as droplets within the soil pores. The amount of water held in pores one to two days after an irrigation is known as field capacity.

At field capacity, tensiometer readings can range from six cb to 10 cb for sandy soils, and 10 cb or more for the heavy-textured soils. Readings less than field capacity indicate that the soil is saturated.

Because soils vary widely, a tensiometer reading between 25 cb (in light-textured soils) and 60 cb (in heavy-textured soils) tells you that it is time to irrigate. High tensiometer readings such as these show that the soil moisture has been depleted to a level where the crop could be stressed and needs water.

When to take readings

Ideally, take tensiometer readings at the same time each day, in the early morning. The frequency of readings depends on the soil type.

- In heavy soils, read tensiometers just before an irrigation and one or two days after the irrigation. In addition, read the tensiometers as necessary between irrigations, to help in deciding the timing of the next irrigation.
- In light soils, take daily readings.

In spring, summer and autumn, crop water use is relatively high, and the soil dries out more quickly. During these seasons, take tensiometer readings more often. For example, for sprinkler-irrigated tree crops in sandy soils, take readings each day. For vines on loamy soils, readings taken two or three times a week are usually enough.

Weekly reading of the tensiometers during winter is a way of detecting waterlogging. Consistently low readings would indicate that there may be a waterlogging problem and a need for drainage or other remedial action.

How to record the readings

Enter tensiometer readings in a notebook or diary with the rainfall and irrigation amounts and dates.

It is important to identify the location of tensiometer stations or nests, by recording a valve or site number, the depth of the tensiometer being read, and the date and time of taking the reading.

Plot tensiometer readings on graph paper. A graph provides the best picture of the changes in soil moisture levels.

Tensiometer records

The tensiometer readings (in centibars) with the date and time should be recorded in a notebook. These readings can be graphed, to help in the interpretation of the data.

The vertical scale of the graph represents the range of tensiometer readings from 0 to 80 cb. The horizontal scale represents time in days.

Record the date of each irrigation with an arrow above the graph. Also record above the arrow the time in hours and the amount of water applied during, or the amount of rainfall.

Draw in horizontal lines to show the desirable range of tensiometer readings, about 10-40 centibars. Irrigating to keep the readings between these lines will maintain the plants in an unstressed or minimal stress condition.
Refer to Appendix 4.6 for an example of graphing and interpreting tensiometer readings.

**Points to remember**

- The tensiometer with the readings that rise the most rapidly (usually the shallow one) determines when the next irrigation is due.

- The deepest tensiometer helps to determine the correct depth of irrigation. If this tensiometer indicates that the soil is wet below the root zone, too much water is being applied.

- Do not change your irrigation practice drastically. Monitor the readings for a period; dig holes with a shovel or a 100 mm auger, and follow your irrigation through the soil until you gain confidence in the tensiometer readings. This may take several irrigation cycles.

- It is not possible to set out instructions on when to irrigate for all crops, soils, methods of irrigation and climatic conditions. However, by plotting your tensiometer readings and keeping them within the desirable range you will gain confidence in using these instruments and will be able to decide when to irrigate and how much water to apply.

- Soils with water infiltration or hard pan problems can present difficulties in interpreting tensiometer readings. A grower might apply sufficient water to wet the soil to the porous cup and yet there could be no change to a tensiometer reading.

It is possible that the water did not enter the soil (poor infiltration), ran off to a non-target area or, if it soaked in, was held up by a subsoil compaction pan. Investigation of the problem would be needed.

**Neutron probes**

A neutron probe is a radioactive source and receiver lowered down monitoring holes in the field. The radioactive source emits neutrons, which are reflected off water in the soil, back to a receiver. This produces a digital count readout, which is converted to a moisture content by calibrating the site.

This technique is widely used for irrigation scheduling. It has been used as a research tool for many years, but has been developed into an on-farm system only in the last few years. The major disadvantages of the system are the radiation hazard, the insensitivity of the method near the soil surface, and a cost of $10,000 to $14,000 for the equipment. It is generally not used for potatoes as tubers close to the probe can cause erroneous readings.

Although quite a few growers have purchased units, many now rely on an irrigation scheduling service that uses a neutron probe. These are relatively cheap, and in recent years the numbers have grown rapidly. Such a service removes the need for the grower to buy a machine, get a licence to own and operate it, and learn how to operate the system.

**Capacitance probes**

Recent developments of capacitance probes, a fairly old system, offer good potential. These devices, like gypsum blocks, use electrical measurements to estimate water content. Unlike gypsum blocks they are not affected by soil salts and do not dissolve with time. Some systems use several of these probes, wired to a data logger or central computer. This technique is in use in commercial crops around Australia, but it is still not perfected for use on vegetable crops on sandy soils in Western Australia.

**Avoiding over-irrigating**

Over-irrigating is a major potential cause of nutrient leaching on sands. The hydraulic conductivity of sands increases 20-fold when the sand is completely wet and at this point, excess water applied leaches rapidly beyond the root zone. (Calder, T, 2002)

- Use an efficient and accurate method of soil moisture monitoring, particularly on sandy soils.

- Ensure that irrigation is stopped before water infiltrates past the root zone.

At least two probes should be installed at each station at different depths to give an
understanding of the soil moisture profile. The probe location should be based on the depth of the root system and include monitoring just below the root zone. The effect of moisture on the vegetable quality can also be assessed by factors such as appearance (wilting).

Over-irrigating on heavy soils may saturate the topsoil and cause run-off, nutrient loss and erosion. Run-off during irrigation may also be an indication that the application rate of the sprinkler system is too high for the soil type.

❑ Ensure that irrigation is stopped before water runs off the soil surface.

Rainfall should be deducted from the amount of water applied and, on some occasions, the irrigation system may be switched off. Soil moisture monitoring will be necessary to determine when the watering should be restarted. This can save water (and money), reduce the leaching of nutrients to the environment and improve the growing conditions for the vegetables.

❑ Deduct rainfall from the amount of water applied.

4.3 Manage salinity of irrigation water

The total amount of minerals in solution in water, the total soluble salts (TSS), mainly determines the suitability of water for crop irrigation. Other criteria are generally of secondary importance.

Measuring salinity

(Department of Agriculture Western Australia, 1990)

TSS mainly determines the suitability of water for irrigation. The types of salts in water are common salt (sodium chloride), calcium and magnesium bicarbonates, chlorides and sulphates. Sodium chloride is usually about 75% of the total, a ratio similar to sea water.

TSS is most easily measured by the electrical conductivity of the water, quoted as units of millisiemens per metre (mS/m). Multiply the conductivity (mS/m) by 5.5 to convert approximately to milligrams per litre (mg/L) concentration. Multiply the conductivity by 0.385 to convert approximately to the old unit, grains per gallon.

Samples for analysis of salt content

Samples of 500 mL can be sent in glass or plastic bottles to laboratories or the Department of Agriculture WA to be analysed for a small fee. Use a clean screw cap, cork or stopper to seal the bottle, and mark the bottle itself with the sender’s name and address, and the date of sampling.

Alternatively growers can purchase a pocket conductivity meter from instrument companies such as Perth Scientific™ for around $200. They can do EC testing of samples themselves, but the results will only be as accurate as the calibration of the meter.

Iron

Many groundwaters contain iron. It blocks trickle irrigation lines and pumps with deposits of reddish brown hydrated iron oxide. For small scale uses, iron can be removed by aeration and settling.

Corrosion

Metallic corrosion increases with the TSS and acidity of the water. To assess the corrosiveness of water, particularly undergroundwater, special techniques are required to make sure the sample is obtained without loss of dissolved gases. Before taking samples, seek advice from the Chemistry Centre of WA.

The only method to reduce corrosion by groundwater is to use resistant materials such as plastic piping and protective coatings on tanks and bronze or stainless steel for pumps.

Water quality for irrigation

(Lantzke and Calder, Agriculture Western Australia, 1999)

Irrigating crops with water of salinity higher than the plant can tolerate will result in yield loss and may decrease crop quality. Salty
irrigation water can affect plant growth in two ways:

- Osmotic effect – Salts concentrate in the topsoil due to evapo-concentration. This creates osmotic stress, which makes it more difficult for the plant roots to extract water from the soil.

- Chloride and sodium toxicity – These ions can be taken up either by the roots or by direct contact with the leaves and can be toxic to plants.

Generally, 635 mS/m (or 3500 mg/L) of total salts is regarded as the maximum for safe watering of any plants. With this salt content, drainage must be excellent and each watering should apply enough water to leach accumulated salts below the roots of plants. Most vegetables will suffer yield losses when the salt levels in the irrigation water reach 100-200 mS/m.

Test the irrigation water at the end of summer and select crops that can tolerate the salt levels without unacceptable yield loss.

The suitability of water for irrigation is influenced not only by the total soluble salts and their composition, but also by:

- type of soil and drainage.
- climate (rainfall and evaporation), the crop type.
- method and management of irrigation.

In general when sprinkler irrigating with water of salinity > 90 mS/m (groups B and C in Table 4.5), growers need to take specific management precautions (see ‘Precautions for the irrigation use of saline water’ below).

Salt tolerance of vegetables

Most vegetables are moderately to highly salt sensitive so irrigation water of good quality is required. Seedlings are more sensitive to salt than mature plants.

Table 4.5 below lists the salt tolerance of vegetable crops according to water conductivity group. These figures are estimates only (plus or minus 10%), based on sprinkler irrigation on a well-drained sandy loam to loam soil, with about 15% of the water applied percolating below the root zone.

The guidelines are too restrictive for drip irrigation, which is applied for longer periods, reducing salt concentration in the root zone. In addition, increases in salinity due to evaporation are generally less with drip irrigation.
Table 4.5  Tolerance of vegetables to total salts in irrigation water
(adapted from Lantzke and Calder, 1999)

<table>
<thead>
<tr>
<th>Water group and conductivity (EC) in (mS/m)</th>
<th>Precautions for irrigation use</th>
<th>Group</th>
<th>Suggested plants</th>
<th>EC (mS/m) causing 10% yield reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 0-90</td>
<td>Avoid wetting leaves on hot dry days.</td>
<td>Highly salt sensitive</td>
<td>bean, parsnip, lettuce, onion, carrot, radish capsicum</td>
<td>100, 90, 140, 120, 130, 150</td>
</tr>
<tr>
<td>B. 90-270</td>
<td>Avoid wetting leaves during daytime, avoid light frequent waterings and water quickly using continuous wetting sprinklers. Application of additional water (leaching fraction) may be needed.</td>
<td>Mildly salt sensitive</td>
<td>cucumber, sweetcorn, rock melon, potato, cabbage, water melon, broccoli, cauliflower, pumpkin, tomato, spinach</td>
<td>220, 170, 270, 170, 190, 240, 260, 270, 270, 230, 230</td>
</tr>
<tr>
<td>C. 270-635</td>
<td>Avoid wetting of leaves of most plants where possible. Adequate leaching necessary. Only irrigate on well-drained soils. Application of additional water (leaching fraction) will probably be needed.</td>
<td>Slightly salt sensitive</td>
<td>asparagus, kale, garden beets</td>
<td>340</td>
</tr>
</tbody>
</table>

Note: Multiply mS/m by 5.5 to give parts per million (ppm) or milligrams per litre (mg/L)
Precautions for the irrigation use of salty water
(Lantzke, 1999)

- When the irrigation water has conductivity 90 – 635 mS/m and there is no fresher water supply:
  - Maximising irrigation efficiency by minimising evaporation is of prime importance.
  - Dripper systems under plastic mulch are the best irrigation option when using salty water.
  - Avoid irrigating on heavy or poorly drained soils.
  - Application of more water may be necessary to flush salts from the root zone.

It is important to reduce evaporation if using salty water for sprinkler irrigation. Water just before dawn, early in the morning or late evening when the air is more humid. Watering in the heat of the day concentrates the salts, due to the high evaporation. Watering during high winds also concentrates salts.

- If using sprinklers, water using continuous wetting sprinklers and avoid light, frequent watering during hot weather.
- Keep the water off the leaves to avoid burning.

Avoid wetting leaves during daytime and do not use sprinklers that produce fine droplets. Low pressure systems – drippers and low-pressure micro-sprinklers – are generally the best for minimising evaporation. Avoid intermittent sprinklers if possible, especially slow revolution sprinklers, which allow drying periods, causing salt to build up on the leaves.

When watering with saline water, closely observe the growth and condition of plants or herbage. Saline water can cause considerable yield loss before symptoms of leaf burn become obvious.

- Monitor the soil conductivity in and beneath the root zone and take action before salt accumulation becomes a problem.

To do this it will be necessary to dig holes at different locations, and take soil samples down the profiles, the deepest sample being taken below the root zone. The heavier soil types in the paddock are likely to show salt accumulation first and it is these that should be sampled. The soil can be tested quickly in the field using the EC 1:5 method (Section 2.4 ‘Measuring soil salinity’), using a pocket EC meter and rainwater.

The more salty waters can be used more successfully on a well-drained light soil than on a poorly drained heavy soil, and also in districts where high seasonal rainfall leaches the salts accumulated in the soil. In well drained, sandy soils irrigation water can readily flush salts out of the root zone.

Leaching fraction

The stringent use of water to prevent waste and leaching may cause a salt build up in the soil when sprinkler irrigating with salty water. Extra irrigation may be necessary when using irrigation water of conductivity groups B and C (90-635 mS/m). The amount of extra water required to leach salt from the root zone is called the leaching fraction. The amount of leaching required to maintain acceptable growth depends on:

- The salt content of the irrigation water
- The salt tolerance of the crop
- Climatic conditions
- Soil type
- Irrigation method and management

For example, a leaching fraction of 20% or more may be required for heavier soils when irrigating with sprinklers, using water with salt levels in the higher range (Group C in Table 4.5).

A leaching fraction is not required for drippers, as long as an adequate wetting pattern is established and maintained. Hence it is better practice to irrigate by drippers rather than sprinklers when using water that has high salt content. (Calder, 2002).
Caution re leaching
(BEMP Manual Editorial Committee, 2002).

Applying extra irrigation to increase leaching of salts will also increase the risk of leaching of fertilisers. It is the grower’s responsibility to minimise leaching of nitrogen and phosphorus into groundwater and surface water resources. In areas where this may be a problem, growers need to take special care to:

- Avoid using water with higher salt levels where possible and thus avoid the need to increase the leaching fraction.

- Use trickle irrigation where possible.

- Manage irrigation efficiently (as described in Section 4.2).

- Manage fertilisers efficiently (as described in Section 3).

Corrosion of pumps and metallic components
Metallic corrosion increases with the total salt content and acidity of the water. To assess the corrosiveness of water, particularly groundwater, special techniques are required to make sure that the sample is obtained without loss of dissolved gases. Contact the Chemistry Centre of Western Australia (telephone 9325 5544) for details.

The only method to reduce corrosion by groundwater is to use resistant materials, such as plastic piping and protective coatings on tanks, and bronze or stainless steel for pumps.

References
Agriculture Western Australia, 1995. Watering requirements of vegetables grown on sandy soils. Farmnote No. 66/95.


Bureau of Meteorology, 2002. Wind and evaporation records supplied on request.


Calder, T., 2002. Pers. comm. Irrigation research officer, Department of Agriculture Western Australia.

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http://www.atinet.org/newcati/cit/rese

APPENDIX 4.1

Average daily evaporation rates

Table 3. Evaporation (mm) from a Class A pan evaporimeter at Perth, in relation to average and high wind speeds.

<table>
<thead>
<tr>
<th>Wind velocity</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average for month</td>
<td>273</td>
<td>249</td>
<td>210</td>
<td>119</td>
<td>80</td>
<td>61</td>
<td>60</td>
<td>70</td>
<td>100</td>
<td>149</td>
<td>197</td>
<td>261</td>
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<tr>
<td>Highest for month</td>
<td>326</td>
<td>262</td>
<td>242</td>
<td>133</td>
<td>96</td>
<td>59</td>
<td>64</td>
<td>82</td>
<td>121</td>
<td>172</td>
<td>240</td>
<td>290</td>
</tr>
<tr>
<td>Average daily</td>
<td>8.8</td>
<td>8.9</td>
<td>6.8</td>
<td>4.0</td>
<td>2.6</td>
<td>2.0</td>
<td>1.9</td>
<td>2.3</td>
<td>3.3</td>
<td>4.8</td>
<td>6.6</td>
<td>8.4</td>
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<tr>
<td>Highest day</td>
<td>13.7</td>
<td>12.4</td>
<td>10.6</td>
<td>7.7</td>
<td>6.8</td>
<td>5.9</td>
<td>3.7</td>
<td>4.8</td>
<td>7.4</td>
<td>9.4</td>
<td>11.6</td>
<td>10.6</td>
</tr>
</tbody>
</table>
**APPENDIX 4.2**

**Average daily evaporation rates for vegetable growing areas in WA**
(Bureau of Meteorology, 2002)

**Average daily evaporation mm**

<table>
<thead>
<tr>
<th>Month</th>
<th>Kununurra</th>
<th>Carnarvon</th>
<th>Geraldton</th>
<th>Gingin</th>
<th>Upper Swan</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>11.5</td>
<td>11.6</td>
<td>10.5</td>
<td>10.6</td>
<td>10.5</td>
<td>Jan</td>
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<td>Feb</td>
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<td>12</td>
<td>10.6</td>
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<td>Feb</td>
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<tr>
<td>Mar</td>
<td>9.9</td>
<td>10.1</td>
<td>8.4</td>
<td>8.4</td>
<td>7.8</td>
<td>Mar</td>
</tr>
<tr>
<td>Apr</td>
<td>7</td>
<td>6.9</td>
<td>5</td>
<td>5</td>
<td>4.5</td>
<td>Apr</td>
</tr>
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<td>May</td>
<td>5.4</td>
<td>4.9</td>
<td>3.1</td>
<td>3.1</td>
<td>2.9</td>
<td>May</td>
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<tr>
<td>Jun</td>
<td>3.9</td>
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<td>Jun</td>
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<td>Jul</td>
<td>4</td>
<td>2.9</td>
<td>2</td>
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<td>1.9</td>
<td>Jul</td>
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<tr>
<td>Aug</td>
<td>4.8</td>
<td>3.6</td>
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<tr>
<td>Sep</td>
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<tr>
<td>Oct</td>
<td>8.2</td>
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<td>Dec</td>
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<td>11.8</td>
<td>10.4</td>
<td>10.4</td>
<td>9.8</td>
<td>Dec</td>
</tr>
</tbody>
</table>

**Average daily evaporation mm**

<table>
<thead>
<tr>
<th>Month</th>
<th>Perth</th>
<th>Medina</th>
<th>Donnybrook</th>
<th>Manjimup</th>
<th>Pemberton</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>8.5</td>
<td>8.8</td>
<td>7.1</td>
<td>6.8</td>
<td>5.8</td>
<td>Jan</td>
</tr>
<tr>
<td>Feb</td>
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<td>8.8</td>
<td>6.7</td>
<td>6.2</td>
<td>5.5</td>
<td>Feb</td>
</tr>
<tr>
<td>Mar</td>
<td>6.5</td>
<td>6.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.3</td>
<td>Mar</td>
</tr>
<tr>
<td>Apr</td>
<td>4</td>
<td>4</td>
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<td>2.9</td>
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<td>Apr</td>
</tr>
<tr>
<td>May</td>
<td>2.5</td>
<td>2.6</td>
<td>2</td>
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<td>Jun</td>
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<td>2</td>
<td>1.6</td>
<td>1.6</td>
<td>1.7</td>
<td>Jun</td>
</tr>
<tr>
<td>Jul</td>
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<td>Jul</td>
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<td>Aug</td>
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<td>2.2</td>
<td>2</td>
<td>1.9</td>
<td>1.9</td>
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</tr>
<tr>
<td>Sep</td>
<td>3</td>
<td>3.3</td>
<td>2.4</td>
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APPENDIX 4.3

Table A4.3a. Wind velocities for Jandakot
(Bureau of Meteorology, 2002)

Percent of the time that the wind speeds occur

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<th>Wind velocity</th>
<th>Jan</th>
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<th>Apr</th>
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<th>Nov</th>
<th>Dec</th>
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## APPENDIX 4.3

Table A4.3b Wind velocities for Manjimup  
(Bureau of Meteorology, 2002)

### Percent of the time that the wind speeds occur

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</table>
APPENDIX 4.4

Effect of wind on sprinkler distribution uniformity

Figure A4.5 below shows the performance of sprinkler HR46C double nozzle (4.76mm x 3.2mm) under increasing wind conditions. This sprinkler is suitable for spacings of 12m x 12m and 14m x 14m in square configuration, as the distribution uniformity (DU) is still greater than 75% at a wind speed of 15 km/hr. This configuration would be suitable for most properties located in windy areas. The sprinkler spacing of 15m x 15m may be used with caution only. As wind speed increases above 11.0 km/hr the DU drops below 75%. The distribution uniformity at 16m x 16m spacing (dotted line) is only acceptable at wind speeds up to 10.0 km/hr.

Fig. 4.1 Effect of wind speed on distribution uniformity (DU %) and scheduling coefficient (SC)
APPENDIX 4.5

Installation and maintenance of tensiometers

Equipment needed for installation

Obtain the following items to ensure the tensiometers are installed correctly:

- sets of Irrometers (or equivalent) to give measurements at the top, middle and bottom of the root zone (usually 30, 60 and 90 cm)
- a service kit that includes a hand vacuum pump and instruction booklet
- boiled rainwater
- cloth for wrapping the cup
- a 13 mm hand auger, made by welding a 13 mm coring bit on to a piece of steel rod
- a coring tool made from a one metre length of 13 mm water pipe
- a white painted post to mark the position of the station, so that tractor operators and pickers can see it
- Rain gauges.

Installation

Using the auger, start digging at a slight angle. Keep checking the depth by placing the tensiometer in the hole. Stop digging when there is about 10 cm between the bottom of the gauge and the soil surface.

Having augered to the required depth, carefully insert the coring tool into the hole, centre it, and then hammer it down a further seven cm. Remove the coring tool containing the soil core.

Place the cup of the tensiometer in the mouth of the cored hole. Force the cup into the hole by pushing directly down on the cap. Do not wobble or rotate the tensiometer shaft and do not push on the gauge. When the cup of the tensiometer is properly positioned there must be at least three centimetres between the bottom of the gauge and the soil surface. If there is less than three centimetres or if the tensiometer can be easily rotated, the installation should be started again in a fresh hole.

When you are satisfied with positioning the cup, place a small amount of water into the bottom of the hole and allow it to soak in. This helps the cup to make contact with the soil.

In gravelly soils it may be necessary to make a larger hole. Soil from this larger hole should be laid on the plastic sheet in the order in which it is removed.

Remove all gravel stones from the soil. If the stones are not removed, they will jam against the side of the tensiometer, causing air pockets to form. These air pockets can cause air to enter the porous cup, or hold more water than the surrounding soil, leading to false readings.

The coring tool can still be used to finish the hole, which is again watered before the tensiometer is inserted and soil replaced.

Start replacing the soil around the tensiometer using material from the bottom of the hole first. Every few handfuls, tap down the soil with the flat top of the coring tool or some other suitable tool. Continue repacking to the surface, finishing with the topsoil to ensure that the original order of soil layer is maintained.

Remove the cap and insert the hand vacuum pump. Apply a suction of about 60 centibars on the gauge, for at least 15 to 20 seconds, while tapping the side of the tensiometer. This removes air bubbles trapped in the instrument.

Slowly release the lip of the vacuum pump and replace the cap and stopper. Screw the cap down until the rubber stopper just touches the base of the reservoir, then apply another quarter of a turn.

Install the white marker post near the tensiometers so that the site is clearly visible.

Install a rain gauge with every set of tensiometers in sprinkler irrigated crops to record water application. Ensure that the rain gauge does not ‘shade out’ the tensiometers.
Maintenance

Under normal use, air bubbles form in the water column just below the stopper, resulting in incorrect gauge readings. To remove them, service tensiometers about every two weeks in summer and every month in winter.

- Remove the cap and stopper by holding the reservoir and gauge in one hand and unscrewing the cap with the other. This procedure stops the tensiometer from rotating in the soil.
- Jet-Fill tensiometers can be topped-up by pushing the plunger on the top of the reservoir.
- Top-up the water reservoir with boiled rainwater that has cooled.
- Remove air bubbles with the hand vacuum pump by applying and holding the suction at about 60 centibars on the gauge for at least 15 to 20 seconds, while tapping the side of the tensiometer.
- Slowly release the lip of the vacuum pump.
- Before replacing the cap check that its rubber stopper has not become flattened or perished. If so, replace it. Then replace the cap.

APPENDIX 4.6

Graph and interpretation of tensiometer readings

The graphs in Figure A4.6 - Plotting tensiometer readings show typical changes in tensiometer readings. A tensiometer station or nest normally consists of three tensiometers, but for easier interpretation, the readings from only two have been plotted.

The following interpretations were made on the changes in the readings that lie below the labels such as ‘Comment 1’ on the graph. Look at the graph first, then read the relevant comment in the text overleaf.

Figure A4.6  Plotting tensiometer readings
Comment 1

Tensiometer readings were increasing right up to when the 10 hour irrigation (in this case, 65 mm) started. Note how quickly the tensiometer readings fell when water reached the porous cup of both the deep and the shallow tensiometers. This indicates that the entire root zone was wetted.

In some soils, such as at Carnarvon, it may take more than 24 hours for the water to reach the deeper cup. The actual time for the water to reach the deeper cup and the amount of water applied will vary from property to property.

Comment 2

A 10 hour irrigation was applied. This was completely unnecessary, since the tensiometer readings were still low, showing that topsoil and subsoil were wet enough for plants to obtain water.

Comment 3

Rainfall at this time slowed the rate of increase in tensiometer readings and delayed the need for irrigation.

Comment 4

The readings of the shallow tensiometer began to increase rapidly and a short (five hour) irrigation was applied to re-wet the upper root zone but not the deeper root zone, which was still wet enough. The irrigation did not penetrate deep into the root zone and the water did not reach the deep tensiometer, so its readings continued to rise.

Comment 5

The readings of the shallow and the deep tensiometers have increased, showing that a 10 hour irrigation was needed to re-wet the entire root zone. Immediately after the irrigation, both tensiometer readings fell, showing that the irrigation was adequate but not excessive.

Comment 6

By observing the slope of the line produced by joining the plotted tensiometer readings, and referring to earlier irrigation cycles, it is quite easy to project ahead the number of days before the next irrigation is needed (see the dotted lines).

Of course, hot weather or a sudden rainfall will alter the projected trend. In these cases, the decision when to irrigate will have to be based on further tensiometer readings.
This plastic ‘rotator’ sprinkler type used at close spacing delivers a good combination of low application rate and acceptable performance in moderate wind conditions.

Centre pivot irrigators are cost efficient and suitable for large areas of even terrain.
SECTION 5

Water Resource Management
This section contains information and best environmental practices relating to:

1. Protecting the water quality and biodiversity values of surface water resources:
   - How to manage riparian areas.
   - How to establish vegetated buffer strips around surface waters to trap sediments.
   - Factors that influence risk of chemical contamination of water resources, including a table listing risk factor values for various common pesticides.

2. Protecting the quality of groundwater resources:
   - Nitrates in groundwater.
   - How to monitor the quality of bore water.

It refers to other sections of the BEMP Manual for fuel and chemical storage, soil, irrigation, and biodiversity management techniques, which are also crucial to maintaining good water quality.

5.1 Minimise nutrients entering surface and groundwaters

Sources of nutrients and chemicals

Export of nutrients and/or chemicals is the process by which they move through (leach) and over soils dissolved in water or attached to soil particles, and contaminate water resources. On vegetable and potato cropping sites, nutrients and chemicals are mainly exported from diffuse (extensive, non-concentrated) sources. The main diffuse sources of nutrients and chemicals are (Moore, 1998):

- Fertilisers applied to crops are the source of the majority of nutrients exported from most operations.
- Animal wastes (if livestock are run on the property), particularly if streams are not fenced and stock can defecate and urinate in the water.
- Leguminous pastures, such as clovers are a diffuse source of nitrogen.
- Chemicals sprayed onto crops (Section 5.5).

Point sources, where high concentrations are generated at a particular point, can also account for a significant portion of the nutrients and/or chemicals exported. Manure heaps, waste heaps, fertiliser storage areas, waste from processing and septic tanks can be point sources of nutrients (Sections 3.2 and 9.1). Potential point sources of chemical pollution are storage facilities and accidental spills (Section 5.5).

Export of nutrients can be minimised by:

- Minimising leaching (Section 3.1)
- Minimising soil erosion (Section 2.1)
- Minimising nutrients in drainage (Section 2.3)
- Accurate placement of fertilisers (Sections 3.2, 4.1- Fertigation, 4.2).

Minimising leaching

Applying too much fertiliser, inaccurate placement of fertiliser and poor timing of application are major causes of leaching.

☐ Conducting best practice to avoid applying fertiliser in excess of crop and soil requirements is of prime importance in minimising leaching (Section 3.1).

If irrigation water is applied at a faster rate than the crop uptake and evaporation it will either run off the surface and into waterways, or infiltrate past the root zone to the water table, carrying dissolved nitrogen and other nutrients.

☐ Irrigate according to crop needs and evaporation (Section 4.2).

Unacceptably high concentrations of nitrogen and phosphorus have been measured in subcatchments with wet grey sandy soils in the Ellen Brook, Peel and Scott River catchments. Poor fertiliser practice associated with cultivated horticulture has proved to be a major contributing cause of this.
When cropping wet sandy sites, take special care in planning a fertiliser strategy (Sections 3.1 and 3.2).

Soil amendments such as clays and red mud ‘alkaloam’ reduce leaching of nutrients by improving soil nutrient retention and reducing water repellence.

Consider applying soil amendments to light sandy soils (Section 2.2).

There are also risks of nutrient leaching from activities and facilities that concentrate nutrient rich materials such as manure heaps, septic tanks and fertiliser storage.

In relation to the design and location of nutrient producing activities and infrastructure:

- Always locate them away from waterways and wetlands.
- Avoid sites that are prone to waterlogging.
- Design storage facilities to include weather proof cover and waterproof barrier underneath to prevent downward leaching.
- Ensure that leach drains are surrounded by clay or iron rich soils that trap nutrients.

Nitrates in groundwater (Lantzke, 1995)

Nitrates from nitrogen fertiliser are readily leached from all soils. Leaching is particularly rapid on sandy soils because of their limited capacity for holding nutrients and moisture.

High nitrate concentrations in the groundwater below horticultural properties are common on the Swan coastal plain. This is of interest for three reasons:

1. Health concerns from drinking water with high nitrate levels
2. The growth of algae in surface water
3. The amount of nitrogen applied to crops in irrigation water.

Health concerns

Drinking groundwater that has high levels of nitrates is dangerous to health, especially that of children.

In 1991, just under half the bores sampled (40 market gardeners’ bores) contained concentrations in excess of the World Health Organisation Guideline of 10 mg/L nitrate-nitrogen. Drinking water with nitrate levels exceeding this limit is especially serious in infants. It is important that people who drink groundwater from farm bores have it tested. The Chemistry Centre (WA) or a private laboratory can analyse water samples for nitrate content.

If the domestic bore is located near a septic tank or poultry manure heap, also have a sample analysed for harmful bacteria that can cause gastroenteritis. Samples taken by local health surveyors can be analysed by State Health Laboratory Services.

The growth of algae in surface water

In saline estuaries and shallow coastal waters, nitrates can cause the growth of algae and phytoplankton. Algal blooms choke waterways, give off foul odours and may kill seagrass, fish and birds.

Groundwater flowing from agricultural and urban areas can carry nitrates, which may ultimately reach estuaries or the ocean and contribute to algal blooms.

Nitrogen applied to crops in irrigation water

Irrigation with nitrogen rich groundwater can add a considerable proportion of a crop’s nitrogen requirement. Calculate the amount of nitrogen applied in the irrigation water and adjust fertiliser programs accordingly. See Section 3.3 for how to do this.

Nitrogen in the groundwater can be so high that the crop suffers nitrogen toxicity. In this case, use no further nitrogen fertiliser, or mix the water that is high in nitrogen with a different, uncontaminated source before irrigating.
SECTION 5

Monitoring the quality of groundwater

It is recommended that growers using bore water monitor the quality of the groundwater regularly. Monitoring provides an ongoing indication on the trend in groundwater quality and a check for the grower as to whether his water management practices are effective.

Refer to Appendix 5.2 for details of how groundwater monitoring bores should be installed.

The water should be tested for EC (salinity), nitrogen and phosphorus. If the water is used for drinking, tests for hydrocarbons and pathogen bacteria should be included.

Nitrogen levels in the groundwater are likely to be higher in areas where horticulture has been practised for a long time and where the groundwater source is shallow. It is important to regularly check the nitrogen concentration in bores and to readjust fertiliser programs if nitrogen concentrations change.

Growers using bore water or nutrient rich surface water should:

- Have the water tested twice yearly for nitrogen concentration.
- Take into account the nitrogen in the irrigation water when calculating the nitrogen fertiliser application required for crops.

Take a sample of bore water and have it analysed to determine its nitrogen content (also ask for potassium and phosphorus analyses). Take a sample of at least 100 mL of water in a clean bottle with a tight lid. Keep the sample cool in an ice pack or Esky® and deliver it to the laboratory (Chemistry Centre WA or private laboratory) within a few hours. Frozen samples will last up to four weeks (fill the bottle only two-thirds full, to allow for expansion during freezing).

The results of these analyses can be used to calculate nitrogen applied in bore water (Section 3.3). The nitrogen required as fertiliser can be significantly reduced when bore water high in nitrogen is used.

Best fertiliser management practices for reducing nitrogen leaching can be found in Section 3.3 ‘Minimise leaching of nitrogen’ and best irrigation management practices for minimising leaching are outlined in Section 4.2.

Minimising erosion

To minimise export of nutrients and chemicals, conduct best practices to minimise soil erosion (refer to Section 2.1).

Minimising nutrients in drainage

Poorly designed, inappropriate or unprotected drains are major causes of nutrients and chemicals entering streams and water bodies. In planning, consideration needs to be given to where drainage water from the farming property would flow to and the drainage route it would follow. In catchments with wetlands or estuaries with natural conservation values, there are strict requirements for limiting nutrient concentrations in the water.

Conduct best drainage practice (refer to Section 2.3).

Fence streams and major drains and establish vegetated buffers (Section 5.3 below).

Water re-use

Tailwater dams are recommended downstream of vegetable and potato growing sites where practicable, to collect and re-use nutrient rich run-off.

Irrigating vegetated land with nutrient-rich wastewater

(Water and Rivers Commission, 2002; NHMRC et al, 1996)

These notes apply to the irrigation of treated effluent from intensive animal industries, recycled run-off from agricultural land, and treated municipal wastewater, which is applied to land to promote the growth of healthy vegetation.
Detailed note assessments and more stringent requirements are required for sensitive areas, i.e. in Public Drinking Water Source Areas (PDWSAs), within 200 metres of conservation value wetlands and managed estuaries, or where the depth to groundwater is less than 2 metres. PDWSAs include Underground Water Pollution Control Areas, Water Reserves and Public Water Supply Catchment Areas declared in accordance with the Metropolitan Water Supply Sewerage and Drainage Act 1909, or the Country Areas Water Supply Act 1947.

The following requirements reflect the Water and Rivers Commission’s current position. They are recommendations only and may be varied at the discretion of the Commission.

Irrigation of wastewater with inadequate planning has the potential to cause the following impacts:

- Soil erosion and turbidity in water resources
- Leaching of nutrients into water resources which can produce eutrophication and toxic effects
- Salinisation and water logging to land.

Site selection

Proponents intending to irrigate wastewater to land should design systems suited to the infiltration capacity and the nutrient retention ability of the soil.

NB: PRI means Phosphorus Retention Index, a scientifically determined measure of the phosphorus retention capacity of surface and near surface soils.

Soil characteristics will influence the rate and frequency of irrigation, and should be taken into account to minimise waterlogging and the leaching of excess nutrients into waterways and sub-surface aquifers.

**Irrigation rates**

Irrigation schemes should be managed to avoid build-up of salts in the soil. Ideally wet season rainfall should flush accumulated salt away from the site prior to the commencement of the seasonal irrigation scheme.

Irrigation rates should take into consideration seasonal evapo-transpiration (ET) rates and the water requirements of the selected vegetation.

Watering requirements can be calculated at 60-80% of pan evaporation depending on application method. Rates will also vary according to the intended cropping and species uptake rates. Factors including soil type, soil moisture content, irrigation method, land slopes and depth to water table will also influence application rates.

For clay soils irrigation rates up to 5 mm/hour are reasonable, while sandy sites may accept 15 mm/hour without run-off. Irrigated areas should ideally have a slope of 0.5 – 10% to avoid ponding or erosion. Irrigated water should always be applied evenly and the irrigated area allowed to dry out for 24 hours between applications during hot, dry weather and 3 days to 7 days during cool, wet weather.

<table>
<thead>
<tr>
<th>Vulnerability</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Coarse sandy soil/gravel draining to surface water with <strong>moderate/high</strong> eutrophication risk.</td>
</tr>
<tr>
<td>Category B</td>
<td>Coarse sandy soil/gravel draining to water with a <strong>low</strong> risk of eutrophication.</td>
</tr>
<tr>
<td>Category C</td>
<td>Loam/clay soil (PRI &gt;10) draining to water with <strong>moderate/high</strong> eutrophication risk.</td>
</tr>
<tr>
<td>Category D</td>
<td>Loam/clay soil (PRI &gt; 10) draining to water with a <strong>low</strong> risk of eutrophication.</td>
</tr>
</tbody>
</table>

*Table 5.1: Soils and receiving environments have been divided into four vulnerability categories as follows:*
Soil nutrient status

Wastewater should not be applied to sites where there has been extended application of nutrients such as annual applications of superphosphate/urea or long term grazing of animals, unless the soil nutrient status has been determined and considered in the site irrigation management plan.

Application criteria

Wastewater containing volatile (degradable) organic matter should not be applied at rates exceeding 30 kilograms/hectare/day, expressed as Biochemical Oxygen Demand (BOD), to avoid offensive odours. For wastewater with BOD concentrations exceeding 150 mg/L, further biological stabilisation methods should be used prior to irrigation. Heavy metals in wastewater should not exceed the irrigation water quality criteria in ANZECC’s Australian Water Quality Guidelines for Fresh and Marine Waters (1992).

Irrigated areas should normally be at least two metres above the highest seasonal groundwater table and have no ponded irrigation water present on the site.

Table 5.2: Recommended maximum nutrient (nitrogen as N and phosphorus as P) application criteria for irrigation water:

<table>
<thead>
<tr>
<th>Vulnerability Category</th>
<th>Nitrogen (N)</th>
<th>Phosphorus (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Application rate kg/hectare/year</td>
<td>concentration (mg/L)</td>
</tr>
<tr>
<td>A</td>
<td>140</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>180</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>300</td>
<td>19</td>
</tr>
<tr>
<td>D</td>
<td>480</td>
<td>30</td>
</tr>
</tbody>
</table>

Nutrient concentrations in Table 5.2 are based on an average of 50 mm (500 kL/ha) of water applied/week over 32 weeks /annum and no other nutrient sources. Facilities for the storage of wastewater should be available over the wet season, or when precipitation meets the water needs of the vegetation.

Application criterion is based on these quantities of N and P being available to promote viable vegetation growth and needed by the selected plant species.

Nutrients should be applied to coincide with the seasonal needs of the selected vegetation species. If nutrients are applied at times when plants cannot uptake them, leaching of nutrients to water resources is likely to result.

Biological contaminants

Advice should be sought from the Health Department concerning irrigation constraints to minimise the incidence of disease-causing organisms, i.e. bacteria, intestinal worms, protozoa and viruses.

Salts, metals, foaming substances, petroleum derivatives, pesticides and radioactive substances

All these materials at various concentrations may be harmful to vegetation or other aspects of the receiving environment. Irrigation scheme planners and operators should determine concentrations of contaminants which may be present in waters to be irrigated.

The Commission uses the Australian Water Quality Guidelines for Fresh and Marine Waters published by ANZECC (1992) as a guide to the quality requirements in water resources that may receive run-off or leachates from irrigated land. This document contains tables which state criteria for various uses of water resources.
Assistance should be sought from qualified and experienced people who are able to assess the likely fate of these contaminants when they move in the environment after application to land.

The Water and Rivers Commission employs environmental modelling techniques and risk assessment procedures to judge whether such contaminants are in sufficient concentrations to cause harm.

**Monitoring and reporting**

The Health Department and Water and Rivers Commission normally require chemical and microbiological monitoring of reclaimed water quality depending upon the extent of application and access afforded to the public.

Monitoring must be able to assess water quality at three stages: the point of supply, that is the point of entry to the reclaimed water system; the quality recorded in water resource monitoring facilities; and through periodical soil sampling.

The proponent should monitor the following parameters:

- The quantity of wastewater irrigated (minimum of weekly intervals) and record areas irrigated
- The pH, salinity of wastewater at monthly intervals
- Total N and P in wastewater at the commencement of the irrigation season and at 3 monthly intervals until irrigation ceases
- Other contaminants in wastewater should be determined annually. Records of data should be retained on site for scrutiny by regulatory bodies.

For small, rural or remote communities where it is not feasible to apply normal microbiological monitoring, frequencies may be reduced. These would be negotiated on an individual basis on application for approval of a scheme.

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### 5.2 Maintain or restore the character and bed stability of waterways

#### What is riparian land?

Simply put, riparian land is any land that adjoins or directly influences a body of water. It includes:

- The land immediately alongside small creeks and rivers, including the riverbank itself
- Gullies and dips that sometimes run with surface water
- Areas surrounding lakes and wetlands on river floodplains which interact with the river in times of flood.

Good management of riparian lands is not a substitute for good land management practices elsewhere in a catchment. However, it is an essential component of sustainable management of a property or landscape and can yield numerous benefits.

Best practices to protect the character and stability of streams are:

- **Manage remnant native riparian vegetation to maintain or improve its health. Establish native trees, shrubs and rushes along denuded sections of the stream.**

- **Consider rocked or logged riffle zones or chutes to stabilise eroding stream beds, increase habitats for aquatic life and oxygenate the water.**

For information on constructing rocked chutes, refer to Section 2.1.

#### Stream bank erosion – what it is and why it occurs

(LWRRDC, 1999)

It is estimated that at least $50 million is spent each year on preventing or remediying stream bank erosion in Australia. Added to this is the cost of treatment to counter reduced water quality. Given these costs, it is not surprising that there is a rapidly growing interest in techniques to help stabilise streams and their banks.
Stream bank erosion occurs by two processes:
- Scour where sediment is removed from stream banks bit by bit, particle by particle
- Collapse where the bank fails and collapses or topples forward suddenly.

Although collapse is the most obvious and dramatic form of bank erosion, scour is arguably more destructive. If collapsed material is not removed by scour, the bank will probably remain stable. It is scour that primes the bank for the next collapse. Vegetation reduces scour by reducing water velocity (especially close to the bank) and will also ride down with a collapsed bank and protect its toe from scour.

Landholders and managers normally face three general types of stream erosion.

1. **Incised streams**
   The bed is deepening and the banks fail because they are too steep. There is little point in stabilising stream banks until the stream bed has been made stable. Vegetation on the gully floor, while being notoriously difficult to establish, is useful in stabilising the bed, although some initial grade control structures (such as rocked chutes) may be needed. It is important that dense vegetation does not then fill the centre of the gully and divert flow into the banks.

   In some cases the best management is simply to fence the stream off from grazing, stabilise the bed with rock chutes, and allow the bed and banks to be colonised by grass.

2. **Channel widening**
   This may or may not be related to incision. If both banks of a stream are eroding, it may be that:
   - The stream cannot carry the increased flows which have resulted from clearing of the catchment;
   - The channel has deepened;
   - Unusual rainfall has caused a large flood or series of floods; or
   - The banks have been over-cleared.

   In large channels, the key is to establish vegetation as far down the face of the bank as possible, as well as on the bank top. Special attention needs to be given to stabilising the toe of eroding banks, and this may require rocks or other structures to help maintain the toe region while vigorous vegetation becomes established above it.

3. **Erosion of the outer bank**
   This usually occurs on a steep bank on the outside of a meander bend. It is the most common erosion problem on larger streams. The outside bank of a meander is often steep or even vertical, making it difficult to establish vegetation on the bank face. In general, the higher the bank, the less useful vegetation on the top of the bank is in reducing collapse. In channels under three metres high, establishing vegetation on the top of the banks will have some value if the bank suffers rotational failure or topples.

   In this case, vegetated blocks topple to the toe of the bank. If the vegetation is sufficiently vigorous, and there is sufficient moisture, this may stabilise the toe.

**Causes of stream bank erosion**

A stream may erode its bed because a dam built upstream has altered its flow, or because the stream has been deliberately straightened downstream to increase its capacity to handle floods. The subsequent increase in bank height will then lead to collapse.

Clearing for agriculture increases rates of surface flow, and this, combined with over-clearing of vegetation from stream banks, leaves banks especially vulnerable to erosion. The removal of stream-side vegetation and its continued suppression through grazing, or other rural or urban management, is often an important trigger for bank erosion.
How riparian vegetation affects stream banks
(LWWRDC, 1999)

Root systems
The roots of vegetation reinforce the soil in the same way that steel rods reinforce concrete. Fine roots are more important in this process than are thick roots. Root reinforcement by riparian vegetation is usually the most important safeguard against bank collapse.

Buttressing
Riparian vegetation which is present on the face of a stream bank helps support (or buttress) the soil above it so that it does not collapse. When banks do collapse, the soil forms a sloping section at the base. Revegetating this section will help buttress the upper section of the bank.

Reduced velocity
The velocity of water flow in a channel can be decreased by vegetation growing either on the bank or in the water, and by debris or sediment in the stream. The extent to which velocity is reduced is very dependent on the type of vegetation – for example, grass is more effective than widely spaced trees. In some cases, vegetation is highly invasive and actually grows into the river channel. Vegetation growing within the channel will reduce scour by decreasing the average flow velocity.

Water use
Riparian vegetation uses much of the water present in stream banks and also improves the drainage of the bank soils. As most banks collapse when they are saturated with water, riparian vegetation, by using that water and by improving drainage, can help stabilise the bank and reduce the risk of sudden collapse. This effect is usually small.

Riparian vegetation reduces stream bank erosion by complex interaction of the above-mentioned factors. In general, root systems, by strengthening the bank, are the most important way in which vegetation acts to minimise bank collapse. Vegetation growing on the bank face also reduces scour and, thereby, undercutting and collapse. The importance of root systems and buttressing in preventing collapse largely depends on the height and angle of the bank, and the cohesion (soil strength) of the bank material.

Revegetating stream banks
(LWWRDC, 1999)
Maintaining or establishing healthy riparian vegetation are techniques that can provide relatively cheap and long-term stability as well as numerous other benefits. However, in some situations vegetation will have to be combined with other forms of protection to adequately protect the banks.

Understand why erosion has occurred
This may require a simple survey of the river reach or professional advice. Once the cause has been determined, the design revegetation works can be carried out with confidence, matching the type and position of vegetation to the nature of the problem and combining it, if necessary, with structural work.

Work with others
It is important to remember that the effects of over-clearing or loss of vegetation, and of revegetation, may have impacts downstream. There is much to be gained by joint planning and revegetation action by groups of landholders to deal with a whole section or reach of a river rather than individual action by one or two landholders.

Position of vegetation
In revegetating to reduce bank erosion, correct placement is most important. Vegetation in the wrong place can increase local flow velocity and increase erosion.

The best solution is to establish vegetation on the bank face. The decreased flow velocity around the vegetated face will reduce scour and protect the bank toe, which is the most critical erosion point.

Establish vegetation as far down the base of the bank as possible
This may require special work to stabilise the toe of the bank or to batter it to an angle where healthy riparian vegetation can become well established and provide stability. Vegetation on the floodplain and on banks has little impact on in-channel flow where the width of the channel is more than thirty times the depth.

**Choose suitable species**

Dense undergrowth can provide more resistance to bank erosion than can tree trunks, particularly down towards the channel and at the toe of the bank. Species with a dense, fibrous root system and with flexible leaves or stems able to move with the flow are to be preferred. Higher up the bank, which should preferably be sloping, larger shrubs and trees can help to dry out the bank soil while their fine roots add substantially to soil strength.

**Simply re-establishing original species will not necessarily work**

The nature of many streams has changed substantially since European settlement. Revegetation will rarely completely reverse this process and return the stream to its original condition. The type of vegetation needed must be determined once the reasons a area became degraded in the first place are determined and the intended land use is clear.

Introduced or non-local species may be required for especially difficult situations, or to stabilise active erosion sites while native species get a chance to become established. Ensure that any introduced species are not environmental weeds.

**Use a range of plant species**

Copy nature. Natural, stable stream banks support a range of grasses and reeds, shrubs and trees. By replicating this variety, planted vegetation can be self-perpetuating and require little maintenance. Native grasses and reeds, and shrubs with flexible branches often occupy the lowest part of the bank, where they are subject to occasional inundation. Their ability to bind soil and resist flood flows are highly prized characteristics. Further up the bank, shrubs and small trees may predominate, with either an understorey of grassy species or, if there is adequate shade and moisture, a strong mat of fibrous roots present on the outside of the bank. At the top of the bank there may be large trees with a shrub understorey, or a combination of trees and grass.

**Be careful with in-stream vegetation**

If there is evidence that lack of channel capacity during flood flow is a cause of bank erosion, vegetation should not be planted within the channel or allowed to stabilise sediment bars. Although the impact of riparian vegetation decreases with channel size, willows and reeds choking a 15 m-wide channel of about four m depth will roughly halve channel capacity to convey major flows.

**Carefully consider woody debris**

Vegetation and large, woody debris would need to occupy at least 10 per cent of the cross-section of the channel before having much effect on flow velocity and flooding. Snags dragged back against the banks at an angle of 40˚ have little effect in diverting water flow onto the banks. Only in very choked channels has the removal of large, woody debris led to measurable increases in the amount of flow a channel can carry.

### 5.3 Safeguard streams, water bodies and drains

The clearing of catchments for agricultural land, soil disturbance during forestry operations or urban development, and bare areas such as gravel roads and stock paths, have led to substantial increases in the amounts of sediment (gravel, sand, silt and clay) entering our streams and rivers. This sediment can contaminate human and stock water supplies, smother breeding sites for fish and other in-stream animals, and deprive these animals of the deep pools which are a vital refuge in dry seasons and prolonged droughts.
The wetlands and other surface water resources of Western Australia are very low nutrient ecosystems in their natural state. They are particularly susceptible to contamination by materials including sediment (soil particles), nutrients, salts, agricultural chemicals, microbes and litter. Whatever the specific impact of contamination, the end result is likely to be severely decreased water quality.

Vegetation within a riparian zone can slow the overland movement of water, and cause sediment and nutrients to be deposited on land before it reaches the stream channel. Plants can also absorb some of the nutrients being transported. Trees and deep-rooted shrubs and grasses use significant quantities of sub-surface waters. Riparian vegetation can therefore also influence sub-surface water flows and, thus, the quantity of nutrients, salt or other contaminants entering streams by this route.

In addition to applying best soil and nutrient management practices, surface water bodies need to be physically safeguarded by good management of the riparian land around them.

Where riparian vegetation remains, don’t clear it.

A mix of native swamp and riparian species is excellent for nutrient filtration, bank stabilisation and shade. In the natural state the mat of stems, roots and organic matter provided by the native vegetation in broad shallow stream beds prevents erosion. It also provides optimal conditions for in-stream stripping of nutrients.

Leaving vegetation in place confers all of these benefits at much less cost than re-planting. A 10-20 m wide strip along each bank – two to four hectares per km of stream bank – is all that is required. The small cost of fencing and foregoing livestock production from this area is far outweighed by the shelter and wildlife benefits. It is also insurance against future erosion and encroachment of stream banks, which is very expensive to rectify.

**Fencing to protect riparian land**

Experience in the Peel/Harvey and Scott River catchments and elsewhere has shown that fencing and exclusion of stock is a necessary prerequisite for both stream bank rehabilitation and successful establishment of buffer strips.

Three or four wire electric fences have proved to be by far the most cost effective, the capital cost being about half that of conventional fencing.

Funding assistance for fencing and revegetation stream buffers can be obtained through government remnant vegetation fencing programmes.

- Fence to keep livestock off the banks and fringing vegetation (riparian areas) around wetlands, waterways and dams on streams.
- Where watering points are required for livestock, construct rocked access points or pump water out into troughs.

**Separation buffers for sensitive water resources**

Separation buffers to water resources are created mainly to provide barriers to limit the passage of contaminants during normal land use activities or as a result of chemical spills or similar emergencies. Other functions of separation buffers are:

- Maintenance of ecological processes and major food chains.
- Protection from nutrient inputs that could lead to eutrophication.
- Protection from increased salinity by reducing the ingress of saline water.

Separation distances may not always be a strip of set width along a watercourse or wetland. The distance should match the risk and needs of the local environment. The separation distances outlined in Table 1, Section 13.2 of the Code of Practice are recommended by the Water and Rivers Commission for new or expanding vegetable and potato growing operations proposed in the vicinity of water resources.

- In liaison with the Water and Rivers Commission and neighbours, establish adequate buffers to protect environmentally sensitive wetlands and wells or reservoirs used for drinking water supplies.
Vegetated buffer strips to trap nutrients
(LWRRDC, 1999; Heady et al, 1994)

The fencing and revegetating of buffer strips on each side of streams, dams and major drains flowing through farmland, otherwise known as streamlining, is an important technique to reduce nutrient export. For example, over 300 km of streams and drains have been streamlined in the Peel-Harvey catchment during the past 8 years. This streamlining activity, implemented by more than 20 community-based landcare groups, has contributed significantly to reducing nutrient loss rates.

Recent studies in Australia have shown that natural vegetation and grassy filter strips can trap up to 90 per cent of the sediment moving from up-slope. A recent study conducted in the Peel-Harvey catchment shows a specific reduction in nutrient load in a streamlined drain of up to 500% (or 5 times less) when compared to an unprotected section of the same drain. This same study identified a 13 times reduction in sediment load in the same drain due to streamlining.

Although streamlining can be effective in preventing sediment and nutrients from reaching streams, and thereby help to protect and improve water quality, they are not a substitute for good land management. Riparian buffer strips will not be effective if poor management practices leading to excessive soil erosion are permitted on the broader lands of the catchment.

Why and how buffer strips work
(LWWRDC, 1999)

Vegetation buffers can be equally effective in trapping or absorbing nutrients. Vegetation can quickly grow over and through the trapped sediments, thereby protecting them from future storms.

This reduction is due to the combined effects of three factors.

1. Preventing fertiliser from being spread in and adjacent to the stream and preventing fouling by stock

When nutrients are deposited directly into streams or onto stream banks, a very high proportion of these nutrients is exported and can pollute estuaries and wetlands. Although only a small portion of nutrients may be deposited in this way, it can amount to a much higher portion (15-30%) of nutrients exported, because there is little opportunity for them to be trapped or filtered out. Fencing prevents this direct deposition of nutrients from fertiliser and animal wastes.

2. Stripping of nutrients by the filtering effect of fringing and in-stream vegetation.

Run-off, containing fine sediment with adsorbed nutrients is filtered and deposited where it flows through dense, fine-stemmed vegetation. A good cover or vegetation with fibrous roots is necessary to slow the flow sufficiently to prevent re-mobilisation of trapped sediments. Native species such as rushes, sedges, tea trees and native perennial grasses and introduced perennial grasses, such as kikuyu, are ideal. Only native species should be used around streams and wetlands with natural biodiversity value.

A significant amount of the nutrients in the sediments can be absorbed into biomass by the roots of the vegetation. If the vegetation is timber or pasture species, it can be harvested for timber or hay, thus valuable nutrients that would otherwise be wasted can be utilised for production.

3. Reducing stream bank erosion

Stream bank and headward erosion is common on cleared tributaries and drains. Once the surface mat of fibrous roots has been removed, and the banks are pulverised by the hooves of stock, the soils (particularly wet sands) become unstable.

Recorded erosion events on such streams have coincided with higher measured particulate phosphorus loads, indicating that stream bank erosion is a major factor contributing to export of nutrients attached to soil particles.
As part of a streamlining project, vegetation should be established on the banks of the stream. This is one way of reducing stream bank erosion and thus reducing the amount of nutrients entering the stream.

Note that revegetation alone is sometimes not sufficient to achieve stream bed stability. In these cases, drop structures, riffle zones (Section 2.1 under ‘Rocked or concreted chutes’), or logs can be strategically placed to reduce and/or redirect the flow velocity, thus reducing the erosive energy of the stream. If the stream bed is to be reconstructed, the profile should be broad and flat so that flow is shallow and slow.

**Establishing vegetated buffers**
(LWWRC, 1999)

- Establish filtering vegetation along the banks of streams, dams, wetlands and drains and where necessary fence vegetation to exclude livestock.

**Where to place buffers**
To be effective, a buffer strip needs to be established or maintained at points where surface waters enter small river channels. In most catchments, this does not mean a strip of set width along both banks of a channel. Consideration needs to be given to those parts of the landscape where folds and dips collect water, which then flows into the tributary stream.

There may be large parts of the landscape where little or no overland flow enters the channel. The decision may be to maintain healthy riparian vegetation in these areas to improve bank stability or wildlife habitat, but they are not important if the objective is to enhance water quality. Instead, attention should be focused on any landscape depressions and where flow concentrates. In such areas plan a broad well-grassed buffer zone that covers the entire area of flow concentration, because a concentrated flow may break through a narrow grass buffer in times of heavy rain.

**What species to use**
It is possible to combine natural riparian vegetation with a planted, rough grass buffer strip between it and intensively used agricultural land. The grass strip provides an initial slowing of overland flow and trapping of sediment, and this process is continued in the natural vegetation along the stream bank. The natural vegetation should include rushes, sedges and tea trees that grow thickly and form a fibrous root mat that helps to stabilise the bank and provide ecological benefits.

**How wide to make buffers**
The most commonly asked question in relation to the design of buffer zones relates to the width of the zone. If the prime purpose is to trap sediment and nutrients, the appropriate width and management practice for riparian buffers depends on the volumes of water and sediment being transported and the nature of the landscape adjacent to the stream channel. Factors affecting the amount and type of sediment moving in overland flow include soil type, intensity of land use, presence of stock, vehicle tracks or gullies which generate sediment, and the likelihood of the surface flow being concentrated into a narrow pathway.

In general, as the volume of flow or the amount of sediment increases, the wider the riparian strip needs to be. A general recommendation is that a combination of ten metres of grass buffer and ten metres of natural vegetation adjacent to the stream will be effective in most situations. Wider buffer strips may be required wherever factors, such as an intense source of pollutants, steep gradients adjacent to streams, and poor vegetation cover, conspire against trapping efficiency.

Whether the buffer strip required is narrow or wide, it is important that its use and management is incorporated into the farm or local government plan. In many cases, a little thought and planning will enable use of the buffer strip for productive purposes while maintaining its integrity and effectiveness.
How to use buffers

It is not always necessary to take buffer zones out of production, but it is important to maintain them so that there is almost complete ground cover and a good height of vegetation. This will maximise their trapping potential. As these areas are often highly productive, it is important to work out how to maintain productivity while at the same time keeping the grass cover for sediment trapping.

In many cases, it will be possible to build this requirement into the farm plan. For example, a wide grassy area in a depression next to the stream channel could be left for grazing during a cropping sequence, or grazed only lightly for that season of the year when high rainfall is anticipated. Some landholders are experimenting with the establishment of riparian agroforestry plantations, comprising widely spaced trees and a good grass understorey. The grass provides feed for stock, especially during the early years of the plantation.

Such tree crops often have excellent growth rates but care needs to be taken to minimise soil disturbance when the trees are harvested, especially when the ground is wet. Such production systems, whether in the south or the sub-tropics or tropics, offer the potential for farm diversification and significant income, while at the same time making a positive contribution to improved water quality.

Managing stock access

Uncontrolled use of riparian lands by stock contributes significantly to the amount of sediment and nutrients moving into our streams. If not managed carefully, stock will often spend long periods along stream banks, leading to overgrazing and baring of the soil surface. Stock tracks up and down or along banks are major sources of soil erosion into the stream during rain. They break up and pug the soil surface, which then washes away easily. Direct inputs of nutrients by stock through manure and urine add substantially to the loads of nitrogen and phosphorus within the stream, and these nutrients can then support excessive growth of nuisance plants and algae.

Nutrient stripping areas
(adapted from Evangelisti et al, 1998)

Running drainage water through vegetated nutrient stripping areas is an optional practice that can further reduce nutrient concentrations in run-off water.

Small swamps on the property that have little environmental value can in some situations be used as nutrient stripping areas. They would only required fencing and drains leading into them.

Constructing wetlands is an expensive exercise and in many cases would probably not be cost effective. It should only be considered as a last resort option to reduce high concentrations of particulate nutrient concentrations in run-off, where the catchment is small. All other best practices for reducing erosion, run-off and nutrient export should be conducted before considering this option.

Feasibility and cost

The construction cost of a two hectare wetland is likely to exceed $10,000 including design, surveying, fencing, vegetation and a controlled outlet. Cheaper options lacking any of these features are likely to fail and require expensive repairs or modifications.

A wetland is not likely to provide any economic benefit to the farmer except perhaps as a stock water supply, which would need a pumped watering point as stock should be excluded from the wetland. There may be an economic cost of up to $400 per year due to area lost to grazing. However there could be other production from the wetland, such as floral harvesting of rushes or tea tree, or aquaculture.

Wetlands are likely to be most cost effective for small catchments, less than 100 hectares in areas where there is intensive cultivation and/or fertiliser application, such as some horticulture sites. They are unlikely to be effective or economic on third or higher order streams with many tributaries and large catchments. In these situations, alternative management options, such as stock exclusion and riparianBuffer zones, may be more appropriate.
the nutrients are generally more diluted and the high flows necessitate very large basins to obtain the retention time necessary to significantly reduce sediment load.

**Design guidelines**

To be effective constructed nutrient stripping basins must be of adequate size for the catchment area and projected flows. They must also be the right shape and adequately vegetated. It is essential to carefully calculate the catchment area and design the wetland carefully.

**Area in relation to catchment**

Recommendations for wetland areas vary from 0.5% to 5% of the catchment but the 2% to 3% of the catchment area is most commonly used.

**Retention time and volume in relation to flow**

The wetland needs to be designed with a volume and dimensions that will slow the flow sufficiently to allow suspended particles to fall to the bottom and be filtered out by vegetation. As a practical ‘rule of thumb’ criterion for high rainfall coastal plain catchments, a five-day retention time is a practical compromise. This will remove 20-60% of the phosphorus, which is the critical nutrient/pollutant. Nutrient removal does not increase proportionally with area and volume. Increasing the size of the wetland by 100% will only give about 20% more nutrient removal.

Given a retention time of 50 days wetlands could remove 40-90% of phosphorus, 40-65% of nitrogen and 80-90% of suspended solids. Retention times of this magnitude are not practical for high rainfall coastal catchments as the wetland area would have to be more than 5% of the catchment.

**Length to width ratio**

If the wetland is too short and wide, short-circuiting of the flow may occur and if it is too long and narrow stream velocity may increase, causing re-mobilisation of sediments. The recommended range of length to width ratios is from 3:1 to 10:1.

**Depth, profiles and control of flow**

A wetland of average depth 1 metre and area 2% of the catchment could be expected to provide a retention time of around 5 days for up to about 4 mm of run-off per day. Average annual run-off for a typical high rainfall south west coastal plain catchment with 900-1000 mm rainfall is approximately 270 mm. Daily rainfall generally varies from 0-50 mm. Clearly, such a wetland would be ineffective in stripping nutrients during peak flows. However, it would remove significant amounts or nutrients during moderate rainfall intensity events during the wet season – where run-off does – up to 40 mm per day.

Wetlands should be designed with a sequential profile varying from open water (>1.5 m deep) to deep marsh (0.4-0.7 m deep) and shallow marsh (<0.4 m deep), so that the water has to flow through all three phases at least once. Sedimentation will occur in the deeper areas where flow is slower and filtration will occur in the shallower, vegetated areas.

A stable concrete outflow control structure is essential to prevent excessive flow velocity through the filter. To carry peak flows which are beyond the stripping capacity of the wetland, a spillway area should be constructed beside the outflow structure. This should be broad, shallow and vegetated to prevent erosion and re-mobilising of sediments.

**Vegetation**

Any vegetation that is not a declared or environmental weed and has dense thin stemmed growth such as sedges, rushes, tea tree, kikuyu or couch would be appropriate. Only native species should be used if the wetland has a nature conservation value.

**Lining with nutrient fixing soil ameliorants**

Wetlands excavated into clays or lined with red mud such as bauxite mining residues should have greater efficiency. These phosphorus fixing materials should be placed in the deeper parts of the wetland. The shallow areas should be vegetated, as care must be taken not to allow flow velocity to increase sufficiently to remobilise the clay and silt particles.
Harvest or removal of biomass and sediments

To maintain nutrient stripping efficiency, sediments would need to be removed and could be spread on sandy areas in the paddocks. Trapped sediments will build up in the shallow vegetated areas, eventually filling them and decreasing the size of the wetland. If sediment export rates were in the order of 10 cubic metres per hectare, a wetland was 2% of the catchment area and it trapped 50% of the sediment load, it would accumulate about 25 mm of sediments each year. Hence, sediment removal would be necessary after 10-20 years.

How to avoid dam construction failures
(State of Victoria Department of Natural Resources and Environment, 1997)

Disclaimer

Further, but without detracting from the foregoing disclaimer applying to this Manual, this information note may be of assistance to you but the State of Victoria and its officers do not guarantee that it is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this information note.

Dam construction failures can cause significant damage to property and the riparian environment downstream.

This Note gives information on how to minimise the risk of either design failure or operational failure of farm dams located on waterways.

Dams that are to be constructed on waterways should be referred to the Water and Rivers Commission and local government authority to ensure all authorisations have been obtained prior to construction commencing.

How to prevent failures

Usually, the causes of the failure can be easily found. The owner may have been over-confident in undertaking planning, and in doing so, failed to include soil testing in the investigatory program. The other common cause of failure is in the use of inexperienced contractors. Nothing can take the place of a reliable and reputable contractor, and by using experienced machine operators you can reduce the risks of failure dramatically. Their previous jobs can be checked and a good outcome is considered the best recommendation.

Soil assessment and testing

It cannot be stressed too heavily that the soil on the actual site should be examined before detailed planning starts. Many types of soil and subsoil do not "hold" water and it is necessary to confirm the existence of impervious clay to seal the excavation and to form the core of the bank. It is also highly desirable to determine the susceptibility of the soil to tunnel out and cause bank failure.

Many potential failures can be prevented if the contractor is fully aware of any soil limitations on the site. A further requirement is to investigate the materials along the centreline of the bank to ensure that the core trench reaches impervious material.

Equipment

A bulldozer or a scraper is mainly used when constructing a farm dam, preferably in conjunction with a sheepfoot roller on larger jobs. Scrapers generally give better bank compaction, but bulldozers are more manoeuvrable.

Designing bank and excavation

Design the bank and excavation so that the upstream edge of the pit will be covered when the dam is full. This will help to prevent erosion of the edge of the pit.

Completely clear and strip at least 150mm of top soil from the excavation and the bank areas. Stockpile it in a convenient place, for later use.
**Core trench**

As a preliminary to the construction of the bank, a core trench at least 2.4 metres wide and at least 0.6 metres deep should be cut out along the full length of its centre line. It is essential to site the core trench in a foundation of impervious clay. In many cases the core will need to be deeper than 0.6 metres. It is essential that all soft, weak, coarse and organic materials are removed. The whole remaining foundation area of the bank site should be surfaced ripped. The core trench should then be backfilled and compacted with the most impervious material available, to provide a seepage seal.

**Building the bank**

Probably the most important requirement of bank construction is to have effective compaction of soil material. The requirement for compaction cannot be overemphasised. Construction should be undertaken when the soil is moist. Autumn or early winter is usually the best times. Construction is often difficult in mid-winter because sites are too wet. It is not advisable to attempt construction in mid-summer, when the soil is too dry and difficult to compact. Even though the soil moisture content may be ideal in late spring, problems can occur when a newly built bank dries out over summer, and failure can result.

Start to build up the embankment by placing earth in regular and even layers no more than 100mm thick, with a scraper or bulldozer – 150mm layers can be used if compacted with a sheepsfoot roller. If only a limited quantity of good quality clay is available, the best of it should be used to progressively build up the clay core. The least suitable materials should be kept for the downstream section of the bank. Do not incorporate any large rocks, logs or other debris into the bank. To achieve adequate compaction, the soil must be moist, but not so excessively as to be muddy or slushy. In many cases a water cart should be used to moisten soil as it is spread on the bank. The ideal way to compact the embankment is to use a sheepsfoot roller. This will minimise the risk of future failure. However, a bank up to 3 metres (10 feet) high may be satisfactorily compacted with the tracks of a loader scraper provided the soil is: moist; not dispersive; and it is built up in thin layers.

*Figure 5.1 Plan view of dam*
Freeboard and batters

The correct amount of freeboard will vary with the size of the dam, area of catchment and likely wave action. Minimum freeboard should not be less than 1 metre. Even with good compaction some vertical settling of the bank should be expected. Make a 10% allowance for settlement.

For banks up to 3 metres (10 feet) high, the standard recommended slope of batters is 3:1 on the upstream side of the bank and 2:1 on the downstream side. Before building batters steeper than this, it is important to ensure that it is safe to do so.

Spillway

A correctly designed spillway is essential. Many dams fail due to faulty design or construction of the spillway. It must be large enough to handle flood flows without water overtopping the bank. Nor should the flows cause erosion of the spillway or disposal area below the dam. If the spillway has a newly formed earthen surface to take overflows from the dam, a heavy grass cover should be sown and established as quickly as possible. Keep vehicles and stock off the spillway to maintain vegetative cover. A rule of thumb for estimating the width of a spillway: it should equal (in metres) the square root of the catchment area (in hectares). For example, a catchment area of 9 hectares would require a spillway 3 metre wide. If trickle flows of water are likely to be produced from the catchment during winter and spring, installation of a trickle flow pipe should be considered.

Settlement

Settlement of soil banks is common and an allowance must be made for settlement of the dam embankment. The embankment could settle to a level where it is overtopped by water and failure will result. Allow 5% of the height of the embankment (along its length) to cater for settlement. For example, if the intended maximum height of the crest is 5 m, the embankment must be built to a height of 5.25 m (an additional 5%) to allow for settlement to a design crest height of 5 m.

Crest width

The required crest width is a function of the stability requirements of the embankment. At the same time, the minimum crest width must allow the safe operation of construction equipment.
In the absence of engineering design, a good guide to estimating the required crest width of the embankment is to adopt a minimum width of 2.5 m for embankments up to 5 m high. For embankments higher than 5 m, allow an additional 0.2 m for every metre in height greater than 5 m. For example, if the maximum height of the embankment is 7 m, the crest width would be 2.9 m (the sum of 2.5 + 0.2 + 0.2).

**Topsoil**

When construction is completed, the stockpiled topsoil should be spread over the bank. Suitable grass species should then be sown to stabilise the bank and prevent it eroding. Trees should not be used on banks because their larger root system can disturb the compacted mass. Another important feature of placing topsoil back over the bank is that, when grassed, it helps prevent the clay bank from drying out and cracking. If rilling of topsoil occurs, pack pasture sods complete with soil into any rills.

**Stock traffic damage**

Grazing stock will readily remove plant cover by grazing and trafficking. Further, they are likely to cause structural damage as they follow preferred routes.

Fencing-out of the dam (along with a reticulation system) should be considered. If this is not an option, short lengths of fence could be used to deflect stock.

**Outlet pipe**

(Water Authority of Western Australia, 1993)

An outlet pipe should be installed in all gully dams to satisfy the requirement to bypass summer stream flow and allow flushing of saline water and silt from the dam. They can be difficult to install successfully and have been known to leak or fail. Outlet pipes should be installed according to engineers’ specifications, which would include cut-off collars, concrete encasement, inlet strainer, suitable gate valve and rock or concrete pitching at the outlet.

### 5.4 Minimise salinity of water

**Minimising salinity of groundwater**

Saline groundwater inflows can affect bores in some areas especially late in summer.

There is little that growers can do to reduce the salinity of regional groundwater tables. However, they can ensure that their groundwater abstraction bores do not become saline by ingress of saline water.

- To prevent salinisation of irrigation bores, regularly test the salinity of the bore water. Reduce or cease drawing water from the bore when salinity increases.

**Minimising salinity of surface water**

Annual evaporation in the south west is around 1600 mm. Therefore dam levels can be reduced by up to 1.5 metres, or more on windy, exposed sites, by evaporation alone. Although water is lost, the amount of salts remains the same in a lesser volume of water. This process, called evapo-concentration, raises the salt levels in the dam.

- Monitor salinity of dam water regularly. Salt in dam water comes from saline run-off from saline land or saline groundwater seepage.

- Reduce the risk of dams becoming saline by applying best practices such as reducing discharge from saline groundwater seeps and reducing run-off from saline land (described in Section 2.4 under ‘Soil salinity’).

Strategically placed trees planted around dams reduce wind velocity and shade the water surface, significantly reducing evapo-concentration of salt in the dam.

- Minimise the salinity of stream and dam water by planting windbreaks of native trees around dams to shelter and shade the water surface, thus reducing evaporation.

The dam water remaining in autumn is always saltier than in early summer. This water should
be allowed to flush through in early winter by opening the gate valve underneath the dam wall. Early winter creek flows are often also saline because salt evapo-concentrated on the soil surface is washed into the stream. Growers should test the salinity of the stream flow with a hand held EC meter, reducing flow from the gate valve and allowing the dam to fill when the stream flow reaches its freshest level.

- Ensure that the water is allowed to flow through gully dams, especially in May and June.

Wetlands, especially those in flat terrain, can be protected to a degree by keeping an adequate buffer of salt tolerant native vegetation around them. Vegetation uses groundwater, helping to keep the water table lower, and provides shade, reducing evapo-concentration of salts at the soil surface.

- Protect wetlands from salinity by creating vegetated separation buffers and planting high water use and salt tolerant vegetation in the buffer areas (Section 5.3).

5.5 Prevent contamination of water by chemicals and fuels

The main sources of chemical pollutants on farms are:

Diffuse sources. Herbicides and insecticides applied to crops or soils that may enter water resources by spray drift, leaching and run-off from rainfall or excessive irrigation.

Best practices for chemical application are the essential first step to minimising chemical export from diffuse sources. Refer to Section 6.4 under ‘The product label’ and ‘Choosing the safest chemical pesticide’ and this section ‘Chemical use near water resources’.

Soil and fertiliser management practices that reduce nutrient export are also crucial to minimise export of chemicals from cropped land. These practices are described elsewhere in this Manual:

- Minimise spray drift from the application of pesticides (Section 10.1)
- Minimise leaching of nutrients (Section 3.3)
- Minimise or virtually eliminate erosion (Section 2.1)
- Correct drainage practice (Section 2.3).

Best practices for preventing pollution by chemicals and fuels from point sources are described below and in Sections 6.2 and 6.3.

Point Sources. Spilt fuels and chemicals. Hazard areas are:

- chemical storage facilities
- fuel tanks
- transport and transfer of chemicals and fuels

Storing and dispensing fuels and chemicals

To protect water resources, growers should always:

- Conduct best practice for storage, transport and dispensing of fuels and chemicals.

Details of these best practices can be found in Section 6.2 and 6.3, ‘Chemical Management’.

Fuel and chemical storage systems in Public Drinking Water Source Areas (PDWSAs) and Underground Water Pollution Control Areas (UWPCAs) require permit approval from the Water and Rivers Commission. Growers operating in these areas should liaise with the Commission to ensure that their existing storage facilities comply with control regulations.

The Water and Rivers Commission policy ‘Pesticide Use in Public Drinking Water Source Areas’ applies special controls in these areas.

- Pesticide formulations or concentrates should not be stored, mixed or diluted within the following areas without the prior approval of the WRC:
  - Reservoir protection zones.
  - Priority 1 areas.
  - Within 50 metres of any water body.
Toxicity of chemicals to aquatic life

The level of toxicity and persistence of pesticides in the environment is generally not stated on the label. However, the label will contain environmental warning statements as required under the relevant labelling code, for example ‘dangerous to fish’. The LD50 and poison schedule of a pesticide (Section 6.4) are not good indications of how long it may persist in the environment or how toxic it may be to organisms other than mammals. To be safe, all pesticides, except biological insecticides (e.g. Bacillus thuringiensis) should be assumed to be toxic to aquatic life and used with caution accordingly.

Certain groups of insecticides are particularly toxic to aquatic life, for example (Australian Bureau of Rural Sciences, 2001):

- All pyrethroids (active ingredient ending in -thrin, for example cypermethrin) and rotenone (a plant derivative) are very toxic to fish and crustacea and may persist in the aquatic environment for several weeks.
- Most organo-phosphates (name of active ingredient generally contains -thion, -oate, -phos or -fos), for example clorpyrifos.
- Organo-chlorines.
- Some carbamates, for example, methiocarb and propoxur.

Most wetting agents used with herbicides are toxic to aquatic fauna, particularly frogs (Thompson, W.T.; 1998). Herbicides that are registered for use near wetlands have ‘frog friendly’ wetting agents.

The triazine group of soil pre-emergent herbicides, which includes atrazine, is an example of chemicals that are at high risk of being transported into streams, wetlands and dams by run-off and erosion. The herbicidal properties of triazines can persist for up to four months.

When selecting pesticides and additives for use near water bodies, be aware of the types that are particularly toxic to aquatic life and avoid using them near sensitive wetlands or aquaculture ponds.

Selection of pesticides to minimise environmental impact

(Australian Bureau of Rural Sciences, Agriculture, Fisheries and Forestry, 2001)

Soil acts as a major sink for many pesticides that are added through soil incorporation or aerial application. Soil properties, pesticide properties and environmental conditions govern the behaviour of pesticides in the soil environment. Some of the factors that should be considered when selecting pesticides to minimise impact on the environment and water quality are:

1. Pesticide properties

The sorption coefficient, Koc, describes the relative affinity or attraction of the pesticide to soil particles and therefore its mobility in soil. Low Koc’s indicate a low capacity to bind to soil organic carbon and therefore high mobility. High Koc’s indicate the compound is more likely to bind to soil organic carbon and hence, low mobility.

The chemical or biological degradation half-life, t1/2, is a measure of persistence of the pesticide in soil.

Aquatic toxicity, LC50, is a measure of the ability of the pesticide to cause 50% mortality in aquatic test species.

2. Soil properties

Hydraulic permeability or conductivity is a measure of the soil’s ability to allow water to percolate through the soil profile.

Organic matter and clay are the important soil properties that provide sites for pesticides to bind, thus reducing their mobility and increasing their opportunity to be degraded by soil micro-organisms.

Slope affects the potential for water to run off the land surface.

3. Management practices

Pesticide application frequencies and rates determine the total amount applied. For example, lower frequencies and rates reduce the potential for contamination.
Method of application (e.g. band spraying) affects the amount of pesticide subject to transport by water. For example, if applied directly to soil, there is a greater probability that more of the applied pesticide will be available for leaching or run-off than if the chemical is applied to the foliage. If the pesticide is incorporated into the soil, leaching may be the most important loss pathway. Pesticide applied to the foliage may be lost to the atmosphere or decomposed by sunlight thereby reducing the amount available for wash-off and transport to water bodies.

4. Irrigation practices

Irrigation practices can also determine the loss pathways of pesticides. Pesticides often move with water, so the less excess water that is applied, the less potential there is for a herbicide to move past the crop root zone or to run-off in surface water. Rainfall can also wash off significant quantities of pesticides from the treated zone.

Estimating risk of pesticide contamination of water resources

(Australian Bureau of Rural Sciences, Agriculture, Fisheries and Forestry, 2001)

The risk of a particular pesticide contaminating our waterways depends on field characteristics, application factors and pesticide properties. Considering the inadequacy of the available information, it is proposed to estimate the relative risk of pesticides to surface or groundwater using soil (organic matter and texture) and pesticide properties (water solubility, soil adsorption, degradation or persistence and toxicity). These factors for a chemical can be easily obtained. Soil adsorption or binding is measured by \( K_{oc} \), which is the tendency of pesticide to be attached to soil particles. Higher \( K_{oc} \) values (> 1000) indicate a chemical that is strongly attached to soil and is less likely to move unless soil erosion occurs. Lower \( K_{oc} \) values (< 300-500) indicate that chemicals tend to move with water and have the potential to leach or move with surface run-off. Solubility is a measure of how easily a chemical may be washed off the treated site, leached into the soil, or move with surface run-off.

Chemicals with solubilities of less than 1 mg/L in water tend to remain on the soil surface. They tend not to be leached, but may move with soil sediment in surface run-off if soil erosion occurs. Chemicals with water solubility greater than 30 mg/L are more likely to move with water either through the soil profile or in surface run-off.

Persistence of a chemical is measured in terms of half-life. In general, the longer the half-life, the greater the potential for chemical transport to non-treated sites.

Table 5.3 is designed to help the grower to assess the risk to water quality of some common pesticides. It shows three factors that indicate risk of chemical export – adsorption or binding to soil particles, water solubility and degradation half-life – and two toxicological parameters – drinking water health guideline value and aquatic toxicology value. Not all the pesticides registered for use in crop production in Australia are listed in the table, but some of those that are commonly used or that have been detected in surface waters or groundwater are included.
Table 5.3  Relative risk estimates for contamination of water resources for some commonly used pesticides in crop production (Australian Bureau of Rural Sciences, Agriculture, Fisheries and Forestry, 2001)

* Higher solubility=high leaching and run-off risks.
** Low K<sub>oc</sub>= low affinity to soil particles= high mobility in soil.
*** Half-life is the time taken for half of the chemical to degrade in the soil.
**** Lower drinking water health guideline values= higher toxicity in drinking water to humans (NHMRC/ARMCANZ, 1996)
***** Lower values of aquatic LC<sub>50</sub>= higher toxicity to fish and crustacea

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Rate of application (L or kg a.i./ha)</th>
<th>Water solubility (mg/L)*</th>
<th>Sorption K&lt;sub&gt;oc&lt;/sub&gt; (mL/g)**</th>
<th>Half-life (days) ***</th>
<th>Relative risk rating for Drinking water health guideline value mg/L ****</th>
<th>Aquatic LC&lt;sub&gt;50&lt;/sub&gt; *****</th>
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</thead>
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<tr>
<td>2,4-D amine (H)</td>
<td>Various</td>
<td>0.25 – 2.3</td>
<td>3000000</td>
<td>20</td>
<td>2 – 16</td>
<td>High</td>
</tr>
<tr>
<td>Atrazine (H)</td>
<td>Various</td>
<td>2 – 4.0</td>
<td>35</td>
<td>39 – 173</td>
<td>40 -100</td>
<td>High</td>
</tr>
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<td>Bromoxynil (H)</td>
<td>Bromicide, Buctril</td>
<td>0.5 – 1.0</td>
<td>130</td>
<td>10000</td>
<td>7 – 14</td>
<td>Low</td>
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<tr>
<td>Carbaryl (I)</td>
<td>Bugmaster</td>
<td>1.0 – 2.0</td>
<td>120</td>
<td>300</td>
<td>7 – 28</td>
<td>Medium</td>
</tr>
<tr>
<td>Chlorpyrifos (I)</td>
<td>Chlorfos, Lorsban</td>
<td>0.5 – 2.5</td>
<td>1.4</td>
<td>6070</td>
<td>30 -120</td>
<td>Low</td>
</tr>
<tr>
<td>Cypermethrin (I)</td>
<td>Cymbush, Cypercare</td>
<td>0.1 – 0.5</td>
<td>0.004</td>
<td>100000</td>
<td>4 – 60</td>
<td>Low</td>
</tr>
<tr>
<td>Dicamba (H)</td>
<td>Banvel</td>
<td>0.25- 2.0</td>
<td>6500</td>
<td>2</td>
<td>7 – 28</td>
<td>High</td>
</tr>
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<td>Dimethoate (I)</td>
<td>Rogor, Danadim</td>
<td>0.2 – 0.5</td>
<td>23800</td>
<td>16 – 52</td>
<td>2 – 16</td>
<td>Medium</td>
</tr>
<tr>
<td>Diquat (H)</td>
<td>Reglone</td>
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<td>700000</td>
<td>1000</td>
<td>1000</td>
<td>Low</td>
</tr>
<tr>
<td>Diuron (H)</td>
<td>Diuron, Diurex</td>
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<td>36</td>
<td>400</td>
<td>90 –180</td>
<td>Medium</td>
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<tr>
<td>Endosulfan (I)</td>
<td>Thiodan, Endosulfan</td>
<td>1.0 – 2.5</td>
<td>0.32</td>
<td>12400</td>
<td>25 – 50</td>
<td>Low</td>
</tr>
<tr>
<td>Fenamiphos (N)</td>
<td>Nemacur</td>
<td>5 – 10.0</td>
<td>400</td>
<td>100</td>
<td>30 – 50</td>
<td>High</td>
</tr>
<tr>
<td>Glyphosate (H)</td>
<td>Roundup</td>
<td>Low</td>
<td>Medium</td>
<td>1.0</td>
<td>86000</td>
<td></td>
</tr>
<tr>
<td>Imidacloprid (I)</td>
<td>Confidor</td>
<td>0.05 – 0.1</td>
<td>610</td>
<td>320 – 480</td>
<td>40 -190</td>
<td>Medium</td>
</tr>
<tr>
<td>Pesticide</td>
<td>Common name</td>
<td>Rate of application (L or kg a.i./ha)</td>
<td>Water solubility (mg/L)*</td>
<td>Sorption Kₐ (mL/g)**</td>
<td>Half-life (days) ***</td>
<td>Relative risk rating for Drinking water health guideline value mg/L ****</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>---------------------------------------</td>
<td>--------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Ally</td>
<td>Metsulfuron</td>
<td>0.04 – 0.05</td>
<td>2790</td>
<td>35</td>
<td>14 – 180</td>
<td>Low-High</td>
</tr>
<tr>
<td>Ally</td>
<td>Methomyl (F)</td>
<td>0.45 – 1.0</td>
<td>57900</td>
<td>72</td>
<td>14 – 30</td>
<td>High</td>
</tr>
<tr>
<td>Ally</td>
<td>Paraquat (H)</td>
<td>0.3 – 0.5</td>
<td>700000</td>
<td>100000</td>
<td>1000</td>
<td>Low</td>
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<tr>
<td>Ally</td>
<td>Pendimethalin (H)</td>
<td>0.6 – 1.0</td>
<td>0.3</td>
<td>5000</td>
<td>90 -120</td>
<td>Low</td>
</tr>
<tr>
<td>Ally</td>
<td>Prometryn (H)</td>
<td>0.5 – 2.5</td>
<td>33</td>
<td>400</td>
<td>30 – 90</td>
<td>Medium</td>
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<tr>
<td>Ally</td>
<td>Simazine (H)</td>
<td>1.5 – 3.0</td>
<td>6.2</td>
<td>103 -277</td>
<td>27 -102</td>
<td>High</td>
</tr>
<tr>
<td>Ally</td>
<td>Trifluralin (H)</td>
<td>0.5 – 1.0</td>
<td>0.22</td>
<td>8000</td>
<td>45 – 240</td>
<td>Low</td>
</tr>
</tbody>
</table>

Examples from Table 5.3

1. Atrazine has low soil sorption (Kₐ), moderate solubility and high leaching risk, and takes a long time to degrade in the soil. This information, together with the fact that atrazine is applied to the soil as a herbicide, indicates that there is a moderate to high risk of it polluting groundwater. The actual risk will depend on factors such as the soil type, rainfall, timing of application, chemical use and irrigation practices.

2. Cypermethrin is extremely toxic to fish and crustacea and moderately persistent in the soil. Although it has a low leaching risk, special care is required to prevent it from entering sensitive water bodies in spray drift or run-off.
Chemical use near water resources

Farm chemicals used in operations have the potential to pollute water resources by run-off and spray drift into surface waters and infiltration to groundwater.

The likelihood of a chemical being present in a water resource at levels high enough to affect public health or the aquatic biota is determined by several factors:

- Level of use of the chemical in the catchment.
- Mobility of the chemical in the catchment environment.
- Toxicity of the chemical and its metabolites.
- The length of time that the chemical or its metabolites remain in a toxic state in the environment.
- The sensitivity of individuals in a population to the chemical or chemicals.
- The extent to which users adhere to the directions for use on the product label, such as the application rate.
- Container and waste disposal.

To minimise the risk of water resource contamination when using chemicals near water bodies:

- Always use pesticides according to their label directions (Section 6.4).
- Avoid mixing or transferring pesticides and additives into spray tanks anywhere near water bodies.
- Minimise run-off; consider the impacts of irrigation weather, irrigation and slope.
- Leave sufficient time for chemicals to be absorbed into plants or soil before irrigating.

This reduces the risk of the chemicals being washed off the site. Do not over-irrigate (Section 4.2), as this increases leaching of chemicals and nutrients. Similarly, do not spray before or during rain.

Sloping sites should be protected by surface water control earthworks (Section 2.1) and cultivated according to best practice, minimising tillage. These practices minimise run-off and erosion, thereby minimising export of chemicals from the site into water bodies.

- Triple rinse used chemical containers and dispose of them at DrumMuster recycling facilities (Section 9.1).
- Remove any unused chemical concentrates from drinking water source areas and dispose of old residual chemicals through the ChemCollect’ scheme (Section 9.1).

Care should be taken to avoid spray drift over dams, streams and wetlands, especially when using chemicals that are highly toxic to aquatic life (Table 5.3).

- Use best practices to avoid spray drift (Section 10.1) when spraying any pesticides near water bodies and wetlands.
- On no occasion should misters or aerial spraying be used over or near water bodies.

Vegetation around water bodies may give some (but not complete) protection against spray drift entering water bodies.

- Maintain buffer areas that are not sprayed around sensitive aquatic environments (Section 5.3, ‘Separation buffers for sensitive water resources’)

(Section 10.1 ‘Spray plans and spray drift awareness zones’).
References


APPENDIX 5.1

Groundwater monitoring bore installation
(Water and Rivers Commission, 2002)

These notes apply to construction of screened or slotted casing groundwater monitoring bores. Bores described in these notes are primarily required to monitor the effects on groundwater resulting from leakage of stored matter or the disposal of wastes. Bores consist of a vertical cased hole, with the lower casing screened or slotted to permit ingress and extraction of representative samples of groundwater for analysis. Bores must also permit standing groundwater levels (SWLs) to be determined.

The location of the slotted/screened interval depends on the type of soil strata penetrated and the nature of contaminant being monitored. Some contaminants float on the water table, others mix with the water body, and others will sink into the base of the aquifer. Sometimes a nest of bores will be needed at a single location to permit effective monitoring for concentrations of contaminants at different depths.

Siting of bores

Bores are normally required both upstream and downstream (in the direction of groundwater flow) to monitor changes in water level and quality across a site. In hard rock areas, bores must be located within geological features, for example faults and weathered zones that are most likely to transmit groundwater.

Where an existing production bore is strategically located, it may be accepted for monitoring purposes in lieu of a new monitor bore, provided the construction technique is unlikely to interfere with the accuracy of contaminants under investigation. The bores should be located as close as practical (at least within 20 metres) to the sites shown on the groundwater monitoring plan.

Bore construction

The recommended drilling methods for unconsolidated soils are hollow-flight auger, dual wall reverse circulation, cable tool rig or similar. For hard rock areas, down-hole hammer or similar percussion techniques should be used. No drilling mud or other additive, which may result in permanent sealing-off of part of a bore, should be used during the bore construction, unless approved by the Water and Rivers Commission.

Contamination of the bore or its surrounds should be avoided during drilling and casing installation. Water contaminants, lubricants, oils, greases, solvents, coatings and corrosion prone materials may affect the suitability of the bore for subsequent groundwater monitoring.

When the bore is to be used to monitor for the presence of contaminants, all drilling and sampling equipment should be thoroughly cleaned before drilling commences.

For bores monitoring trace contaminants, steam cleaning of the rig may be necessary before drilling each bore hole. Care must be taken that casing materials are free from contaminants prior to installation and any water used in construction must be tested to ensure it is free of contaminants.

Depth of bores

Shallow (S) bores should be drilled to terminate at least 5 metres below the standing water level (SWL) in an unconfined aquifer. They are used to monitor water attributes at or near the water table. Where no defined SWL is determined, drilling should continue to a depth where a low permeability (< 10⁻⁹ metres / second) soil horizon limits further water intrusion, or as agreed with the Commission.

Intermediate (I) depth bores are used to monitor the middle / lower levels of an non-confined aquifer.

Deep (D) bores are used to monitor water quality within confined aquifer. Confined aquifers require isolation from an upper aquifer by use of packers and an impervious sealant. Typical bore configurations are shown in Figure A5.1.
Drill core samples and bore logging

An accurate field drilling log should be recorded and a clean representative sample of the soil profile collected at all changes of strata and at a maximum of 3 metre depth intervals for all bores. These samples should be stored in calico sample bags for examination by personnel competent and experienced in hydrogeology. These people should prepare comprehensive bore logs and submit this with relevant bore construction details to the Commission.

Drilling tolerance

All bores should be drilled and cased straight and not deviate from the vertical by more than 200 millimetres, either cumulatively or between consecutive six metre points. For non-standard 50 mm internal diameter bores (if accepted), the recommended method of testing is by lowering a 48 mm outside diameter x 500 mm long steel pipe section to the base of the bore without detecting apparent resistance.

Drilling diameter

Bores should be drilled at least 70 mm in excess of the permanent casing diameter and temporarily cased with drill pipe or rigid casing, except where temporary sealing material is approved. Drilling may be un-cased through material that remains free-standing, e.g. rock.

Permanent casing

Casing material should be selected to suit bore engineering requirements and most importantly the nature of the contaminant subject to investigation. Steel and glass fibre casings are suitable for monitoring most organic substances and generally where bores exceed 50 metres in depth. Polyvinyl chloride (PVC) or glass fibre casings are suited to monitoring most inorganic substances particularly in corrosive waters. Where organic materials are being monitored, bore casing should have mechanical joints (with locking mechanism) to avoid contamination by solvents. Lubricants must not be used on casing joints.

Unless otherwise approved, all bores should be cased with at least an 80 mm internal diameter (ID) pipe placed to the depth described in the table above. Bore casing as small as 50 mm ID may be accepted where a suitably sized submersible sampling pump is available on-site at all times. The bore casing should extend 500 - 700 millimetres above the ground surface.

The bottom of the casing should be sealed with grout or a cap. Any over-drilling below the bottom of the casing should be back-filled with materials equivalent to the original strata.

Screens / slotting of casing

Proprietary brand screens may be used which exhibit the following characteristics:

- Not subject to corrosion either by groundwater or bore maintenance chemicals,
- Screen size suited to the monitored soil type,
- Not be subject to blockage and readily cleanable where bore maintenance is required.

For slotted PVC casing there should be a minimum of 100 slots per metre, each slot to be 50-55 mm long on the inside of the casing, and have between 0.2 and 1 mm opening width. A common width is 0.4 mm. The slots should be horizontal when the casing is installed, 25 mm apart in the vertical direction, arranged in three equal spaced columns around the casing.

External filter socks may be used to exclude very fine soil from the casing.

Granular pack

Where fine soils may cause bore siltation, the annulus between the permanent casing and the hole perimeter should be carefully and evenly filled to a minimum of 2 metres above the screened interval with a graded granular pack. The level of the granular material shall be kept above the bottom of the temporary outer casing as it is withdrawn.

The pack should be uniformly graded between a minimum size material retained on a 1.0 to 1.6 mm sieve and a maximum size passing a 3.2 mm sieve (unless otherwise approved). The granular...
pack should consist of clean coarse silica sand or similar material which will not contaminate the bore.

**Sealing of the annulus above or between monitored intervals**

Cement slurry or bentonite should be used to seal the bore casing annulus to prevent water movement down the casing from the surface or between aquifers. The seal may be achieved using bentonite pellets slowly inserted down the annulus with regular depth checks. Sufficient clean water should then be poured down the annulus to cause the pellets to fully hydrate.

**Centralising of Casing**

The permanent casing should be inserted inside any temporary casing. The temporary casing should be withdrawn vertically as the hole is evenly back-filled to ensure the permanent casing remains centrally located, straight and vertical.

**Bore development**

Bores should be fully developed by pumping, bailing, valve surging or air lifting and cleaned prior to cementing around the top of the bore. Where any nearby soil strata may be contaminated, care must be taken to prevent water re-circulation via the bore annulus resulting in contamination of other strata levels.

At suspected contaminated sites, extracted soil and groundwater should be contained and exported to a secure site for disposal as approved by the Department of Environmental Protection’s Waste Management Division.

**Bore head completion**

Shallow bores should be completed by back-filling their casing annulus up to 1.5 metres below the surface with a suitable stone-free, non-lumpy and free running soil. Intermediate and deep bores should be back-filled with cement grout or Bentonite seal above a packer.

A 1.3 metre minimum length of steel casing protruding a maximum 700 millimetres above the surface should be concreted in to protect the top of the bore(s). Typical bore-head details are shown in Figure A5.1. Where traffic is likely over or near the bore-head, it should finish just below the surface and be fitted with a trafficable cover avoiding a loading on the bore casing and minimising the threat of contaminants entering the bore.

The steel protection casing should be fitted with a lockable steel cap or other vandal resistant device approved by the Commission. All bores should have their registration number permanently affixed at an easily visible site to the outer casing (embossed plaque or welded characters, not painted).

**Taking water samples from bores**

In order of preference, the following sampling methods may be used:

- Dedicated pump i.e each monitor bore has its own installed pump
- Mobile borehole pump i.e pump is moved between successive bores, with careful decontamination of equipment with each move.
- Through flow bailer (sampling tube fitted with flap valve in base which closes as bailer is raised).
- Bucket style tube bailer.

The Commission recommends the following measures as good practice to enhance monitoring accuracy:

- Sample progressively from upstream to downstream groundwater flow monitor points.
- Sample bores expected to be less contaminated before moving to more contaminated bores.
- Use blank or known quality samples to confirm laboratory analytical accuracy.
- Keep sampling equipment in a clean dust free container when not in use.
- Ensure that a well-trained and experienced person is used to take measurements and collect samples.
Fig. A5.1 Standard shallow monitoring bore in unconfined aquifer. (Water and Rivers Commission, 2000)

Note: Develop bore for minimum 2 hours baling or airlift.

Fig. A5.2 Standard shallow monitoring bore in unconfined aquifer. (Water and Rivers Commission, 2000)

Note: Develop bore for minimum 2 hours baling or airlift.
SECTION 6

Chemical Management
Chemical Management

This section outlines best practices for chemical management. It contains extra technical information on:
- Transport of fuels and chemicals
- Loading and unloading of pesticides
- Pesticide spills
- Storage of fuels and chemicals
- Protective clothing

Other best practices that relate to good chemical management can be found in:
- Section 5.5 ‘Toxicity of chemicals to aquatic life’.
- Section 10.1 ‘Minimise spray drift from the application of pesticides’.

6.1 Minimise use of chemicals that are toxic to humans or the environment

The first and most obvious way to reduce the impacts of those chemicals that pose risks to the environment and human health is to use less of them. The main way to achieve this is by implementing an Integrated Pest and Disease Management (IPDM) strategy. There are many management practices that do not involve the use of toxic pesticides and that will reduce the incidence and severity of pest and disease outbreaks. IPDM is an approach to make pest control more effective by coordinating these non-chemical and chemical methods of pest control. Non-chemical and ‘soft’ chemical options are used where possible before resorting to more toxic pesticides. IPDM is outlined in Section 7 ‘Controlling Pests and Diseases’.

☐ Use Integrated Pest and Disease Management Strategy to minimise use of chemicals (Sections 7.1- 7.3).

☐ Where possible, select chemicals that are least hazardous to the surrounding natural and human environment (Section 5.5).

A table of common pesticides and environmental risk factors such as acute toxicity, persistence in the environment and leaching can be found in Section 5.5 ‘Toxicity of chemicals to aquatic life’.

6.2 Transport chemicals and fuels safely

Safe transport of fuels on-farm

☐ Ensure that mobile fuel tankers on-farm are fabricated to approved, ‘Australian Standards Association (ASA) design, with fail-safe spill prevention devices.

Mobile fuel tankers over 250 litres capacity should be parked on a containment pad when filling and dispensing fuel. Figure 6.2 shows specifications for an approved containment pad and dispensing area for mobile fuel tankers.

When transporting and dispensing fuel from drums of 40- 250 litres capacity, ensure that the drums are secured on a vehicle tray with raised edges, so they cannot fall off. Dispense fuel by hand pump from the top of the drum with the drum standing upright.

Safe transport of chemicals

The following best practices should always be adhered to when transporting chemicals (WA Dept of Agriculture, 2001).

☐ Never carry chemicals in the cabin of a vehicle, or on any vehicle containing food, feedstuffs or fertiliser.

☐ Transport chemicals safely and securely in the back of a truck or utility that has a tray with sides and a tailgate, lined with an impervious material.

Non-porous tray beds are preferred to wooden beds because they can be easily decontaminated in the event of accidental spillage. Make sure vehicle is in good operating condition to help reduce the chance of an accident.
Always carry correct documentation, displayed in a prominent position in the cab, describing the dangerous goods that are on board.

If required, comply with other provisions of the Dangerous Goods (Transport, Road and Rail) Regulations 1999, such as the placarding of vehicles, personal protective clothing and public liability insurance.

Always carry a spill kit and set of appropriate protective clothing in the vehicle and be prepared for pesticide spill (see ‘Chemical spills’, Section 6.3).

In the event of a spill in a public place, advise the local shire. In the event of a major spill local government would contact the Department of Environmental Protection and emergency organisations to initiate appropriate actions.

If a chemical spill occurs in a public place, for example on a road or in a town, or is likely to endanger public health and safety, advise the local government authority so that they can manage the clean-up. If the spill is massive, then the LGA will get the Fire and Rescue Service involved, and call out the Health Department, Department of Environmental Protection and Water and Rivers Commission specialists if necessary.

If a spill is likely to cause serious environmental pollution, then the Department of Environmental Protection must be alerted. If residue in agricultural produce is a possible consequence, then the Department of Agriculture Western Australia should be alerted, as the Agricultural Produce (Chemicals Residues) Act 1983 may need to be invoked. If the spill was caused by a licensed Pest Control Operator, then under the terms of their licence, they must notify the Health Department.

Loading and unloading pesticides
(University of Nebraska Cooperative Extension, 2001)

Wear work clothing and chemical resistant gloves even when handling unopened pesticide containers, in case the container should leak. Also, carry protective clothing and equipment in the cabin of the vehicle. It will be needed if a spill or other pesticide-related accident should occur.

Thoroughly inspect all containers at the time of purchase before loading. Accept them only if the labels are legible and firmly attached. Check all caps, plugs or bungs and tighten them if necessary. If leakage has occurred, do not accept the container.

Handle containers carefully when loading; don’t toss or drop them. Avoid sliding containers over rough surfaces that could rip bags or puncture rigid containers. Know safe handling procedures when using fork lifts. Secure all containers to the truck to prevent load shifts and potential container damage. Protect containers made of paper, cardboard or similar materials from rain or moisture.

Unloading pesticides

Never leave pesticides unattended. You are legally responsible if people are accidentally poisoned from pesticides left unattended in your vehicle. Move the pesticides into the storage facility as soon as possible. Inspect the vehicle thoroughly after unloading to determine if any containers were damaged or any pesticide leaked or spilled.

6.3 Store chemicals and fuels safely

The impacts of chemical and fuel pollution on water resources are outlined in Section 5.5.

Safe storage of fuels
(Water and Rivers Commission, 2000)

Leakage and spillage of fuels are the commonest accidents resulting in pollution of water and soil on farms.

Common causes of accidental spillage are jamming of dispensing nozzles, broken hoses, leaking or broken fuel lines in motors and
accidental rupture of mobile fuel tanks. The risks of occurrence of these accidents can be greatly reduced by using appropriate, well-maintained equipment:

- Ensure that all tanks, pumps, hoses and fittings for storage, transport and dispensing of fuels are fabricated and installed to Australian Standards Association (ASA) designs and properly maintained to safeguard against leaks and accidental spillage.

Simplified best practices for the fabrication and installation of fuel storage tanks on farms are as follows:

**Tank and equipment fabrication**

Fuel tanks should be constructed to ASA Standards AS 1692, 1989. ‘Tanks for flammable and combustible liquids’.

ASA approved valves and hoses should be fitted. The transfer nozzle should be of an approved hand held design such as that used at retail fuel outlets, with a valve that is held open by hand pressure and that cannot be left jammed open during transfer.

**Containment pads**

Storage tanks should be located on a containment pad that can effectively capture and contain spills. Figures 6.1 and 6.2 illustrate specifications for containment pads for fixed and mobile fuel tanks. They should include the following:

- Construction of reinforced concrete and clean sand fill with a waterproof membrane underneath.
- Tank footings of concrete, not extending through the waterproof membrane.
- With raised kerb around the edge and/or sloped to drain into a sump, preventing liquid run-off into the environment. The sump should be at least 110% of the capacity of the storage tank.
- The containment pad should include a transfer apron, also sloping inwards towards the sump to contain any spillage during transfer from the tanker vehicle.
- Stormwater from the surrounding area should be diverted by bunds or drains, or having the containment compound on a raised pad.
- The sump should be fitted with a water drainage tap so that water can be drained off from underneath fuel if necessary.

Fuel or chemical spills should be cleaned up on discovery.

The containment compound should be maintained to prevent accumulation of storm water and litter.

For operations in Public Drinking Water Supply Areas, there are more stringent requirements for fuel and chemical storage. The Water Quality Protection Note ‘Above Ground Fuel and Chemical Storage Tanks in Public Drinking Water Source Areas’, prepared by the Water and Rivers Commission outlines the required design.
APPLICATION

This specification applies to chemical storage tanks (including fuel) of 250 litres capacity and greater.

MINIMUM DESIGN CRITERIA:

1. Construction of flammable liquid storage tanks shall be in accordance with AS1940.

2. The below ground liner shall be leakproof, resistant to chemical attack, and capable of retaining any spillage. The sheets must be continuously seam welded at edges, to form an impermeable sheet over the specified area.

3. The membrane liner thickness required is 0.5mm minimum.

4. Footings of the tank and other structures over the liner shall not puncture the sheet. A minimum clearance of 100mm is required.

5. On removal of the tank, all contaminated soil must be disposed of outside any Public Drinking Water Source area, at a waste disposal site approved by the O.E.P. - Waste Management division.

6. The tank dispenser and connections must be located over the liner. The minimum distance between the external edge of the liner and the end of the extended dispenser hose shall be 1.5 metres.

Figure 6.1 Specifications for containment pad, dispensing area and installation of fuel storage tank (Water and Rivers Commission, 2000a).
SECTION 6

Figure 6.2 Specifications for containment pad and dispensing area for a mobile fuel tanker greater than 250 L capacity. (Water and Rivers Commission, 2001b)

**APPLICATION**

This specification applies to chemical storage tanks (including fuel) of 250 litres capacity and greater.

**MINIMUM REQUIREMENT CRITERIA:**

1. The below ground H.D.P.E. liner is to be leakproof and capable of retaining any hydrocarbon spillage. The sheets must be seam welded at edges to form a continuous sheet over the specified area.

2. The fuel tank filler pipe must be located over the H.D.P.E. liner. The Fuel Dispensing valve and nozzle shall not extend beyond the perimeter of the liner.

3. Bund capacity to be a minimum of 110% of total fuel storage.

4. On removal of the fuel tank, all contaminated soil must be disposed of outside any Public Drinking Water Source area, at a waste disposal site approved by the D.E.P. – Waste Management division.
Safe storage of chemicals  
(Water and Rivers Commission, 2000)

Chemical storage site selection
Several points must be considered when selecting the site for a chemical storage facility:

- **Sensitive areas.** Locate the facility well away from sensitive areas, such as houses, work areas, play areas, feedlots, animal shelters or water resources.
- **Wind direction.** The best location is downwind of sensitive areas.
- **Flooding.** The site should be in an area where flooding is unlikely, where stormwater from outside the site run-off can be diverted and drainage from the site cannot contaminate surface or groundwater.
- **Fire.** Locate chemical storage facilities away from bushland. Bushland presents high fire and pollution risks. Toxic fumes may be released in the event of the containers being destroyed in a bushfire.

❑ A properly equipped chemical shed, purpose-built to an approved design is essential.

- Limit access to authorised personnel only.
- Locate the facility well away from water resources.
- The site needs to be clear, to minimise fire risk.

Chemical storage shed design
(Department of Agriculture Western Australia, 2001)

In all cases, store chemicals according to Australian Standard 2507-1998, ‘The storage and handling of agricultural and veterinary chemicals’.

If relatively small quantities of chemicals are to be stored, as on most farms, the ‘minor storage’ conditions of AS 2507 should be followed. In summary, these are:

- An impervious floor with waterproof membrane (as for a house slab).
- Spill containment of at least the capacity of the largest container, plus 25% of the total volume of the stored products.
- Good ventilation.
- Adequate separation distances from other buildings, water courses or drains.
- Secured doors and windows to prevent unauthorised access.
- Appropriate signage at the entrance.
- Segregation of incompatible chemicals.
- Access to running water, first aid and other facilities required by the MSDS.
- An exhaust fan and fire alarm.
- Wooden pallets or metal shelves should be provided, on which to store dry formulations in water permeable containers or sacks, and metal drums, which need to be kept dry. This helps reduce potential deterioration, corrosion and leakage of these containers.

If large quantities of chemicals are to be stored, a ‘storage factor’ may need to be applied in the design of the storage shed. This is calculated from the class of dangerous goods and the quantity in storage. Growers intending to store large amounts of chemicals should contact the Explosives and Dangerous Goods Division on telephone 9222 3333, to determine whether they will require a licence and what storage factors may need to be applied.

Storage of bulk chemicals
(Water and Rivers Commission, 2000)

This section outlines general best practice for correct storage and transfer of toxic and hazardous substances (THS) on farms, in bulk quantities greater than 25 litres. For example large containers or tanks of pesticides such as metham sodium fumigant.

**General requirements**

All facilities should be designed so that under normal operation THS cannot escape to the environment. THS should be stored in secure corrosion-resistant containers. Facilities should
be designed to minimise the risk of escape during abnormal operations or emergencies.

Storage of THS should also comply with the regulatory requirements of other agencies, including

- **Explosive and Dangerous Goods Act** (contact: Department of Minerals and Energy)
- **The Environmental Protection Act** (contact: Department of Environmental Protection (DEP))
- **Occupational Safety and Health Act** (contact: Worksafe)
- Council planning, health and building controls (contact: your local government authority)

**Storage buildings**

THS that are liquid or can be mobilised by water should be stored on an impervious base such as sealed concrete. The base must be resistant to heat damage and reaction with the stored materials. The building should be weatherproof and fire-resistant and maintained in good condition. Separate buildings or separate compartments within a building are required to isolate materials that, if mixed, would cause undesirable reactions to occur such as fires and explosions. The building floor should either have a perimeter bund or slope inwards to a central grated sump to fully contain spills and facilitate clean-up.

**Handling areas**

External areas where THS are handled, temporarily stored, loaded or unloaded should have an impervious paved base as described above for storage buildings. Handling areas need to be kerbed and graded to contain spills, stormwater or fire fighting liquid. They should not have ‘speed bumps’ or irregular surfaces that may cause accidents with containers. External pavement for buildings or compartments used to provide isolation of incompatible materials should be surrounded by bunding, raised edges or a grade break. This is to contain liquids in the local area and to avoid mixing.

**Drainage gully pits**

Gully pits used for collecting THS spills should have a sealed base and be easily accessible for pump-out. Pits should never discharge direct to soak where contaminated waste could easily leach into groundwater or surface water.

**Toxic and hazardous liquid management**

Bulk containers used to decant THS should be fitted with drip trays. Minor spills should be cleaned up immediately using absorbent materials, which should then be placed in storage skips for later removal to an approved waste disposal facility.

The minimum storage capacity required for a lined storage basin used to contain THS spills may be calculated by adding the following volumes together:

- The volume of the largest containment vessels which may lose their contents by spillage.
- Fire-fighting water which may discharge to the basin in one hour.
- The volume of stormwater falling within the containment area, resulting from a 6 hour, 2 year return frequency storm event (calculated in accordance with the *Australian Rainfall and Run-off* published by the Institution of Engineers, Australia).

Unless the storage basin has been designed to allow for complete evaporative liquid disposal, the basin should be emptied after each storm event. Under no circumstances should contaminated water entering the storage basin, or liquid within the storage basin, be allowed to overflow to the ground or an off-site drainage system. Since testing of the stored liquid for contaminants is recommended before release, a reserve capacity must be incorporated to allow for the time for testing, and any necessary treatment prior to disposal.

**Stormwater management**

Stormwater from paved areas that are not used for handling of THS and from roofs should be directed away from buildings or bunded.
compounds that contain THS. Uncontaminated stormwater can be drained to soaks or off-site drainage systems.

Emergency procedures

The site operator should develop a set of operating procedures to cover foreseeable emergency situations. Copies of these procedures should be lodged with the Fire and Rescue Service of WA, Perth, C/- WAHMEMS Coordinator. The procedures should nominate the personnel who will act for the site operator in the event of any emergency (with contact telephone numbers), and the normal goods inventory at the site. All staff at the site should be trained in the hazards associated with the stored chemicals and procedures to follow in the event of an emergency. Signs within the store should reinforce adherence to these procedures.

Chemical spills

❑ Have properly equipped chemical ‘spill kits’ located in the vicinity of the chemical storage and mixing areas.

Equipment required in a spill kit
(ChemCert, 2000)

- Absorbent material to soak up liquids, such as sawdust, vermiculite or sand
- Open topped leakproof drums in which to put waste and contaminated absorbent material
- Shovel
- Broom
- Bleach or washing soda
- Gloves and protective clothing
- Protective clothing and equipment appropriate for the chemicals being handled.

❑ If a spill occurs, soak it up with the spill kit materials, place them in a marked container and hand them in at ChemCollect™ venues (Section 9.1).

Dealing with chemical spills
(University of Nebraska Cooperative Extension EC 01-2507)

If a pesticide is spilled on a person’s body or clothing, the person should leave the contaminated area immediately. All contaminated clothing should be removed as quickly as possible; this is no time for modesty! Wash affected areas of the body thoroughly with detergent or soap and water. In any pesticide contamination accident, follow the instructions given in the label’s first aid treatment guidelines. If necessary contact the Poisons Information Centre.

Spilled chemicals must be contained. If the chemical starts to spread, contain it by bunding with soil or sorbent materials, if this can be done safely without contacting the pesticide or breathing the fumes. Never hose down a contaminated area. This will cause the chemical to spread and infiltrate into the soil, possibly reaching groundwater. If the spill is liquid, use activated charcoal, absorbive clay, vermiculite, ‘kitty litter’ or sawdust to cover the entire spill area. Sufficient absorbing materials should be used to completely soak up the liquid. Sweep or shovel the material into a leak proof drum. Dispose of the material through the ChemCollect™ scheme.

As a precaution, it is wise to read all product labels carefully at the time of purchase and/or delivery to be able to deal quickly and safely with any pesticide emergency.

Chemical records

❑ Keep comprehensive records of chemical purchases and uses
(Department of Agriculture Western Australia, 2001)

The following records must be kept, under the Occupational Safety and Health Act 1984:

- An inventory list or database of all chemicals stored or used
- An up to date copy of the MSDS for every chemical stored and used
- Risk assessments, workplace monitoring or health surveillance results that are required under legislation.

**Cleaning of spraying equipment**

Residual chemicals left in spray tanks or on machinery may increase the risk of operator poisoning and can corrode or block delivery mechanisms. In some cases, the toxicity and effectiveness of chemicals may be altered when they are mixed.

- **Spray all of the contents of the spray tank onto crop or pasture. Wash fresh water through it and hose down the equipment after each operation. Do this in the field, away from water resources to avoid pollution or concentration of chemicals at a single wash point.**

**6.4 When using pesticides, minimise risks to human health**

When used excessively or inappropriately, pesticides can have adverse effects on human health:

- Operators may be poisoned by direct contact with the chemicals.
- The health of the wider community may be indirectly affected through ingestion of pesticide residues in produce and groundwater or inhalation of spray drift.

- **Growers and operators who use pesticides frequently should undergo pesticide residue tests to guard against over-exposure.**

- **If poisoning is suspected:**
  - Follow first aid and safety directions on the label of the pesticide container and Material Safety Data Sheet.
  - Contact the Poisons Information Centre on 131126 (all hours).
  - See a doctor or take the affected person to hospital. Write down the name of the product and or active ingredients and concentration, or take an empty, rinsed container with you.

Antidotes for organophosphate or carbamate poisoning such as atropine should be prescribed and administered only by a doctor (ChemCert Western Australia, 2000).

**The product label**

The essential information for safe use of a chemical is always included on the product label. The Agricultural and Veterinary Chemical Code Act 1994 requires that all farm chemical products must have a label printed in accordance with a national code of practice on labelling. It also requires that all pesticides, herbicides and crop regulators must be registered for specific uses in each State of Australia and that this is shown on the label. Part of the registration process is an assessment of how effective the pesticide is and how hazardous it is to human and environmental health.

- **It is crucial that all operators read and understand the directions on the product label before using any farm chemical.**

- **By law, pesticides must not be stored in unlabelled containers.**

All pesticides are scheduled according to how hazardous they are, and information on this is included in the following warning statements on the label:

- **SCHEDULE 7 PESTICIDES**, label signal words are ‘DANGEROUS POISON’. These are the most dangerous and only licensed pest control operators and other authorised persons are permitted to purchase and use them.

- **SCHEDULE 6 PESTICIDES**, label signal words are ‘POISON’. Moderately toxic, more freely available but retailers may require a permit to sell them.

- **SCHEDULE 5 PESTICIDES**, label signal words are ‘CAUTION’. Low toxicity, with no restrictions on their sale.

- **UNSCHEDULED PESTICIDES** require no label signal words. Very low toxicity.
The ‘Directions for Use’ panel of the product label clearly shows the States of Australia and purposes for which the chemical is registered.

Do not use any chemical other than in the manner and for the purposes shown on the label.

To do so may harm operators, neighbours or the environment and may constitute an offence under the Health (Pesticides) Regulations Western Australia 1956.

The withholding time is the minimum time that must elapse between applying a chemical and harvesting the crop. If a withholding period is required, it will always be stated on the label. It is most important that this is observed, to prevent excessive pesticide residues in produce for human consumption or in crop residues to be fed to livestock.

Be aware of the withholding time stated on the label before applying any chemical to a crop.

The product label will always specify the type of protective clothing and handling precautions required. More details can be found in the Material Safety Data Sheet for the chemical. Chemicals are most hazardous in their concentrated form.

Preventing poisoning
(ChemCert™, 2000)

The most hazardous situations are handling any concentrated chemical, particularly S7 chemicals, for example adding concentrate to the spray tank or applying seed dressings. Following safety directions and wearing protective clothing is particularly crucial when conducting high-risk activities. To avoid poisoning:

Wear the recommended protective clothing as stated on the product label when decanting, mixing and applying chemicals.

Adopt methods to avoid manual handling or pouring of the chemical concentrate; for example, use a suction probe or pump.

Take special care when handling concentrated chemicals.

Keep children away from application equipment, mixing and storage areas.

Have water and soap on hand and if any chemical contacts the skin, wash it off immediately.

Don’t eat or smoke when handling chemicals.

Wash and decontaminate the cabs of spray vehicles and change filters on enclosed cabs regularly.

Do not blow out nozzles by mouth.

Wash or shower after handling chemicals.

Wash spray clothes after each use, separately from family clothes.

Do not store spray clothes or protective equipment in the chemical shed.

Do not use pesticides or wash chemical equipment near water resources.

Mixing pesticides
(University of Nebraska Cooperative Extension, 2001)

To prepare for pesticide applications, remove the pesticide containers from storage and take them to an open area. Always measure and mix pesticides in an open, well-lit, well-ventilated location. Regardless of whether they are partially or completely emptied, never leave pesticide containers open or unattended while the pesticide is being applied. Return all containers to storage prior to application to prevent accidental spills, ingestion or exposure to people, pets, livestock or wildlife.

Use of ‘sucker flusher’ systems to transfer concentrated pesticides to the mixing tank is recommended as this reduces the potential for the concentrate to contact the operator.
Protective clothing and equipment for pesticide spraying operations
(Tremlett, 1997)

Personal protective clothing is an essential part of safe pesticide handling. Protective clothing must worn when:

- mixing the concentrated pesticide with water or oil,
- spraying, or apply dusts or granules,
- entering a sprayed or treated area, such as an orchard, crop or glasshouse before the pesticide has either dried or dissipated or before a statutory re-entry period has expired, and
- handling treated crops within a day or two of treatment, or handling grain that has been treated with seed protectant.

The type of protective clothing required is specified on the product label, according to toxicity and concentration of the pesticide and the conditions in which it is used. For example, a full face respirator is often specified in addition to other protective clothing when using S6 and S7 chemicals.

Protective clothing varies in quality, manufacture and type of materials used. Suppliers are now providing ‘special purpose’ protective clothing specially designed for particular uses such as horticultural applications. Always follow the recommendations listed below when selecting, wearing, and caring for protective clothing.

Gloves

Always wear gloves when handling or applying pesticides. The gloves should be unlined, made of flexible material and long enough to cover as far up the forearm as possible. Check all gloves regularly to ensure there are no tears or holes in them. Never wear leather or canvas gloves, since these absorb chemicals.

Nitrile gloves are recommended because they are impervious to most solvents used in pesticide formulations. They are also tight fitting and give a good feel for delicate work. This type of glove is available as a gauntlet, which gives good forearm protection.

Heavy duty PVC gauntlet gloves have good chemical resistance and forearm protection, but they are considered too cumbersome for use on delicate jobs.

Disposable and surgical gloves are suitable only for delicate jobs, such as cleaning nozzles, provided they are used once only for a short period, and then discarded properly.

Overalls

Wear full-length overalls during all spraying operations. Lighter cotton/polyester fabric overalls can be worn in summer. Bib-and-brace type overalls are not suitable.

Disposable overalls, such as Tyvek® or Kleenguard® are very light, comfortable and effective. These overalls can be washed up to five times, and are shower proof. Their main problem is their tendency to tear under heavy use.

Another lightweight but more durable type of overall is the Breathalon Overall®. This is made from a coated nylon fabric that allows water vapour to escape, but does not allow chemical to penetrate. It has good strength and durability and is useful for a number of spraying operations.

PVC pants and jackets are recommended when there is the risk of becoming wet from spray, mist or spillage of pesticides. They are essential for the more hazardous operations, such as in glasshouses and during some horticultural spraying operations. This type of protective clothing is durable and strong, but it is also extremely uncomfortable to wear, being very hot and sweaty and tending to restrict movement.

When wearing PVC suits or overalls, leave the trouser legs outside the boots and the sleeves outside the gloves. This helps stop pesticides from getting inside the gloves or boots.

The Farm Master® two piece suit is another useful item of protective clothing. It can be used in place of the PVC suit, since it is more comfortable and practical and has a high resistance to chemical penetration.
**Aprons**

It is essential to wear a PVC apron when mixing and pouring concentrates and carrying drums of pesticides. Put a PVC apron on before picking up pesticide drums for pouring. Any spillage can then be quickly washed off without affecting the overalls. Aprons should cover the body from the shoulder to below the tops of the boots.

**Boots**

Never wear leather or canvas boots while spraying, or boots that leak. Unlined rubber boots are acceptable, but PVC boots are best. Steel caps in the toe provide extra safety, but are not essential when spraying.

**Hats**

Hats protect the scalp, which is one of the most absorptive areas of the body. A wide-brimmed washable hat made from a non-absorptive material is best. A hood fitted with respirator filters can also be worn.

**Goggles**

When handling pesticides, especially concentrates, eye protection is essential. While a face shield protects the whole face, it is difficult to wear with the conventional half-mask respirator. Goggles and safety glasses protect the eyes and can be worn with a respirator. Goggles should comply with the Australian Standard 1337-1992 ('Eye protectors for industrial applications'). Non-fogging goggles are best.

**Respirators and filters**

Respirators and respirator filters should comply with the Australian Standard 1716-1991 ('Respiratory protective devices').

A half-face mask respirator satisfies most broad-scale spraying requirements. Good facial fit is a prime factor in obtaining good protection, and some brands come in three sizes to suit various face shapes. To ensure good fit, refer to the section on testing respirator fit. Make sure that the respirator has a low breathing resistance, is easy to adjust and feels comfortable.

Ensure that the respirator seals well. Men with beards, long sideburns, moustaches or any amount of stubble on their face will not be able to obtain a good seal. The leakage of air into a respirator is up to 200 times greater for men with beards. For men, respirators will only provide the best seal on a cleanly shaven face.

Hoods, which incorporate visor and filters, provide eye, face and respiratory protection. Always use them when handling Schedule 7 pesticides or when there is risk of becoming wet from spray or mist. Hoods are available in PVC, Breathalon®, or Tyvek® material.

When choosing a respirator filter for general spraying conditions, be sure it contains both particle and organic vapour filter elements. The particle filter may consist of cotton, paper or plastic foam. Medium efficiency, or class M particulate filters are suitable for most situations. Cotton and paper masks are satisfactory for filtering dusts, such as sawdust or soil, but are not suitable where organic solvents are used. Only organic vapour filters will remove these vapours. The organic vapour filter consists of activated charcoal. When both particle and vapour filter elements are fitted, dust or droplets, and organic vapour are removed.

For hazardous situations, such as mixing highly toxic and volatile pesticides in confined areas, dusting or spraying on a hot calm day, or spraying in a glasshouse, a full face mask with high efficiency vapour and particulate filters is recommended.

There may be rare situations where the concentration of pesticides in the air, even for pesticides of low toxicity, requires a supplied-air device to be worn. For further advice, contact the pesticide manufacturer or protective clothing suppliers.

**Testing respirator fit**

Respirator fit can be tested using a positive or negative pressure test.

**Negative pressure test.** While wearing the respirator, completely seal over the flat exposed surface of the filters with the palms of the hands.
Inhale gently so that the face piece collapses slightly, and hold for 10 seconds. If the face piece remains collapsed and no inward leakage of air is detected, then the fit is suitable. If not, then readjust the face piece, ensuring that it is still comfortable, and repeat the test. If there is still leakage, then try a different size or shaped face piece.

**Positive pressure test.** Seal over the exhale valve(s), put on the respirator and exhale gently. A slight pressure should build up inside the face piece without any outward leakage of air. If not, then readjust the face piece comfortably and repeat the test. If there is still leakage, then try a different size or shaped face piece.

**Care of protective clothing**
Keep all items of protective clothing clean and in working order. Wash hats, boots, gloves, overalls, aprons and visors or goggles at the end of each day or after each spray operation, whichever comes first. Launder overalls in hot water, separately from the household domestic wash. Wash the other items in warm water and soap, rinsing well.

Check gloves carefully for tiny (pin-point)holes. Fill gloves with water and squeeze; discard glove if holes are evident. Also, discard gloves if pesticide can be smelt on the inside of the gloves. Organic solvents in pesticide formulations will remove the elasticisers in gloves, making them brittle and liable to split – especially between the fingers. Therefore, be prepared to renew them regularly.

Keep eye goggles clean, especially the headband. The head-band is often made of material that absorbs pesticides and is in contact with the forehead, one of the most absorptive areas of the body.

**Respirators and filters**
After use, remove filters and set aside. Wash face piece with soap and warm water. If possible, valves should be removed and washed also. Valve seats may need to be scrubbed with a soft brush. Rinse well, dry with a clean cloth, and leave to air in a well-ventilated area away from sunlight and extreme temperatures. Store respirator in a sealed plastic bag or unused lunch box away from direct sunlight and extreme temperatures.

The outside surface of respirator filters can be wiped with a damp cloth, but do not allow water to enter the filter. Activated charcoal filters need to be stored properly to maximise their useful life. They continually absorb organic vapours, even petrol and diesel. After use, also store them in a sealed container, such as an unused lunch box, or a plastic bag.

Periodically check the one-way valves on the respirator to make sure that they are still soft, pliable and functioning. Also, check that the face piece of the respirator has not deteriorated and is soft, comfortable and maintains a good face seal.

Make sure that filters are changed and used in accordance with the manufacturer’s recommendations. Charcoal filters can be tested by determining if a strong perfume can be smelt while wearing the respirator (with the respirator well-fitted with no leakage). If the perfume can be smelt, filters must be replaced. Dust filters must also be replaced when it becomes hard to breathe or draw air through them.

**Choosing the safest chemical pesticide**
When all physical and biological measures have been considered and use of a chemical pesticide is the only practical option, the safest, most selective chemical option should be chosen (Section 7 ‘Controlling Pests and Diseases’).

The toxicity of chemical pesticides is expressed as an LD$_{50}$ number, which is the number of milligrams (thousandths of a gram) per kg of body weight required to kill 50% of a population of animals. LD$_{50}$ is not stated on the product label. However, it is related to the poison schedule, for example S7 poisons have an LD$_{50}$ of less than 50 mg/kg and unscheduled poisons have an LD$_{50}$ of greater than 5,000 mg/kg (ChemCert™, 2000). The poison schedule signal heading on the label is a good indicator of the acute toxicity hazard of the chemical to humans.
If there is a choice of pesticides choose the one with the lowest poison schedule rating to minimise the human health hazard.

Training and licensing
(ChemCert, 2000)

The risks to the human and natural environment are too great for untrained staff to be allowed to use chemicals or conduct spraying operations. The rationale behind this is the same as drivers having to be licensed before they drive on roads, where incompetence will endanger the lives or health of other people. ChemCert is a good example of a one-day course, which covers all aspects of chemical use including pest management, legislation, pesticide residues, pesticide labels, formulations, applications, personal safety and records. A current ChemCert certificate is a prerequisite for anyone undertaking the SQF 2000 cm or SQF 1000 cm quality assurance programs.

Growers and staff aspiring to a career in horticulture are encouraged to become qualified in chemical use. Units of Competence that can be accredited towards Certificates in Horticulture are listed in Appendix 1 of this manual.

Under Occupational Safety and Health legislation, all users of pesticides and other hazardous chemicals must be accredited in a current, approved chemical user-training course.

When using a contract pesticide sprayer, ensure that they are licensed with the Department of Health.

Have knowledge or current reference information (Avcare, 2001), as to:

- Which chemicals are registered for use on various pests in Western Australia.
- The modes of action, environmental impacts and toxicity of the various pesticides.
- How to rotate pesticide groups to minimise build-up of pesticide resistance (Section 7.3)

To check if pesticide uses and products are registered, refer to the National Registration Authority for Agricultural and Veterinary Chemicals website. (http://www.nra.gov.au)

Material Safety Data Sheets
(ChemCert, 2000)

The Material Safety Data Sheet (MSDS) contains additional information about the chemical such as its density (whether it is heavier than water), volatility (whether it forms gases) and whether it is flammable (burns easily). This information is necessary for the operator to assess the hazard presented in the event of spillage, fire or other accidents. The MSDS is not part of, or a substitute for the product label.

Suppliers are required under the Occupational Safety and Health Regulations 1996 to provide an MSDS on the first sale of a hazardous substance and thereafter on request. MSDSs of all chemicals registered for use in Australia are available on the ‘Infopest’ CD produced by Queensland Department of Primary Industries, or the ‘Infinder’ CD produced by Primary Industries and Resources South Australia.

Employers are required to obtain Material Safety Data Sheets (MSDS) and make them available to persons using hazardous substances.

Mixing different chemicals in the spray tank
(Piper, 2001)

At least half the herbicides used in Western Australia are applied as mixtures, primarily because no single product will control all weeds present in a paddock. Herbicides may also be mixed with insecticides that need to be applied at the same time. Combining sprays minimises the fuel used, spray unit wear, and physical damage to the crop. It also makes best use of the best spraying weather.
Constraints on tank-mixing

Not all herbicides and insecticides can be tank-mixed to advantage. Several reasons for two products being incompatible are summarised here.

Formulation incompatibility. This usually happens when emulsifiable and flowable products are mixed. The emulsifiable product can cause the flowable product to settle out. Spraying oils can do the same thing, and emulsifiable products that require oil may be incompatible with some flowables. Mixes of Spray Seed® and a flowable product can also flocculate, especially if the mixing order is wrong. Granular products in general give less problems and should be used if available.

Manufacturers may change the emulsifiers and dispersants in their formulations from time to time in response to supply or price changes. Thus a mix that was stable one year cannot be assumed to be stable later. It should always be jar tested first.

Chemical incompatibility. Some products with ioniically active ingredients will react when mixed.

Biological incompatibility antagonism. Some chemicals reduce the activity of others. This is known as antagonism. Antagonistic herbicides must not be mixed. The chemicals must be applied at least 10 days apart.

It is not possible to determine biological incompatibilities by doing test mixings. The chemicals may be perfectly stable in the tank. It is only after the tank mix is applied that the problem becomes apparent. Weeds may not die if there is antagonism.

A jar test for compatibility

Before making up a full tank of mixture for the first time, check the compatibility of the components. This can be done conveniently on a small scale by making up a medium size screw-top jar of the mixture.

To 500 mL of water in the jar, add 10 mL of each product for every 1 L/ha that will be applied in the field. Use 1/4 teaspoon of granules for each 10 g/ha. This will give the same concentration of products as a tank-mix to be applied at a spray volume of 50 L/ha.

Then cap the jar and shake it well. Look for any obvious incompatibility such as flocculation or precipitation.

Then store the jar for at least two hours, and preferably overnight. Again look for any sign of instability of the mixture. Some settling of flowable or powder products is normal, but note any difficulty in re-suspending sediment; if there is, extra agitation may be needed while spraying.

If the mixture remains stable, it is free from formulation and chemical incompatibilities. However, biological incompatibilities are not revealed by this test.

Take care that the jar is not re-used for foodstuff.

Mixing order

Whether conducting a jar test or making a sprayer full of tank-mix, the correct order of addition is important. At least two thirds of the water should be added, the agitation started, then the products added in the order: granules, powders, flowables, emulsifiables, water-based, and finally any wetters or oils.

Dissolve water soluble solids such as Pacer® separately and then treat them as water-based products. In this way the products most likely to cause difficulty are added when there are less other products present to compound those problems.

Never try to make a tank-mix in a small portion of the final water volume. The mix will be much more concentrated than necessary, and problems will be more likely.
References


Department of Agriculture Western Australia, 2001. Code of Practice for the Use of Agricultural and Veterinary Chemicals in WA.

Further Reading


Government of Western Australia, State Law Publisher. Health (Pesticides) Regulations 1956.

Fuel storage and pesticide mixing areas.

Operator wearing the correct protective equipment for mixing an S6 scheduled poison.

Symbols for protective equipment.
SECTION 7

Controlling Pests and Diseases
Integrated Pest and Disease Management (IPDM) is an approach that aims to minimise the risk to human health and the environment while maintaining pest populations below levels at which crop damage may occur. IPDM makes pest control more effective by coordinating non-chemical and chemical methods of pest control. IPDM can be defined as: ‘Utilising a range of pest management tools to provide economically, environmentally and socially sustainable production’.

This section outlines best IPDM practices for vegetable and potato growing:
- Hygiene and crop cultural practices that minimise the incidence of pest and diseases.
- Monitoring and pest treatment methods that minimise the use of chemicals

A methodical approach to pest control, with stringent adherence to hygiene practices, good record keeping and regular crop monitoring pays dividends in terms of fewer pest outbreaks that require treatment and less expenditure on chemicals. This approach also reduces the risk of the emergence of pesticide resistant pest strains.

Most important are the environmental outcomes: reduced environmental impacts of chemicals in vegetable and potato growing and fewer pest outbreaks.

7.1 Minimise occurrence of pest and disease outbreaks

Hygiene practices
(Floyd, 1990)

Use clean certified planting material

Clean seed is crucial to preventing viral, bacterial and fungal diseases in all horticulture crops. Check the quality of the nursery used to supply seedlings, and how their seed and potting mixes are treated.

Infection of a paddock by soil-borne diseases, such as clubroot in cauliflowers and Sclerotinia rots, is virtually permanent, incurring ongoing costs of control with pesticides. Once introduced, there is a greatly increased probability of infection of neighbouring paddocks through transport of spores by wind, water and transported soil (fungal diseases) or by insect vectors (virus and bacterial diseases).

❑ Use of clean certified planting material is crucial to preventing viral, bacterial and fungal diseases in all horticulture crops.

❑ Check the quality of the nursery used to supply seedlings and how their seed and potting mixes are treated.

Nursery accreditation
(Nursery and Garden Industry Australia, 2002)

Nurseries accredited under the Nursery Industry Accreditation Scheme, Australia (NIASA) are recommended as they adhere to prescribed hygiene practices.

The aims of the NIASA are:
- Improve consumer confidence at all levels of the distribution chain.
- Improve the profitability of NIASA accredited businesses through the adoption of best practice.
- Encourage the use of environmentally sound work practices.
- Encourage the continuous improvement of NIASA accredited businesses.
- Focus research to critically analyse and implement best practice.
- Promote the benefits of trading with NIASA-accredited businesses.

NIASA accreditation is available to production nurseries and growing media manufacturers.

The Nursery and Garden Industry Australia (NGIA) has, through its national Accreditation Committee, a coordinating and supervisory role. In particular, it must ensure the Best Practice Guidelines and the administration Guidelines are applied accurately and fairly by each State or Territory Committee and their technical officers.
Lists of NIASA accredited nurseries and details of the Best Practices Guidelines can be found on the NGIA website:

**Seedlings – hygiene**

Strictly control the purchase of seedlings, particularly of small lots to complete a paddock planting. Where plants are needed and cannot be grown on the property, check the quality of the nursery chosen to supply material. Check and be satisfied with their hygiene standards.

Treat bare-rooted seedlings from open beds with considerable caution. Despite fumigation of beds, the risk of reinfection from surrounding soil is high. For maximum safety, seedlings should be grown in trays, preferably in single plant blocks using a steam-sterilised, inert medium such as a sawdust or peat-based compost. The trays should be standing on benches or clean aggregate. At no time should the plants be in contact with the soil or plant residues until planting.

**Certified seed potatoes**

(Department of Agriculture Western Australia Plant Laboratories et al, 1998)

Potato growers in WA should always use seed that is certified under the Western Australian Seed Potato Certification Scheme. This scheme is administered by the Department of Agriculture Western Australia Plant Laboratories and enforces industry-agreed production and marketing guidelines.

Laboratories from which mini-tuber or plantlet seed stocks are sourced must maintain stocks of the required varieties. Stocks must be periodically tested to ensure that they are free of soft rot organisms, bacterial wilt, ring rot, powdery scab, black scurf, gangrene, wilt, dry rot, black dot and potato viruses.

**Vegetable seed treatments**

(Floyd, 1988)

Seed can be treated to kill disease-causing organisms in or on the seed, and to protect the seed when it is planted. Hot water treatment can kill a wide range of bacteria, fungi and viruses in or on seed of many crops. Fungicide dusts can protect seed from soil-borne organisms and are sometimes used to control organisms on or in the seed. For particular problems, insecticide dusts can be used.

Seed treatments are an important means of controlling disease but are most effective when combined with other disease control practices.

**Hot water treatment**

Hot water treatment controls many seed borne diseases by using temperatures hot enough to kill the organism but not quite hot enough to kill the seed. It must be carefully and accurately done. A few degrees cooler or hotter than recommended may not control the disease or may kill the seed.

Hot water treatment can be damaging or not practical for seeds of peas, beans, cucumbers, lettuce, sweet corn, beets and some other crops. Some hybrid varieties of cauliflower may be damaged by the recommended treatment. Seeds that can be treated by hot water are listed in the Table 7.1.

**Method**

Hot water treatment of fresh seed at the temperatures recommended should not reduce germination. However, check seed packets carefully to ensure that the seed has not already been treated by the seed company. Seed should not be treated twice. Also, treating old, out-of-date seed will reduce germination.

Follow these steps for accurate treatment:

Put a few grams of seed in a small porous bag, such as cheesecloth. The amount of seed should be just sufficient to allow thorough and immediate wetting. The bag may need to be weighted down.

Fill an insulated container with water slightly hotter than the temperature required (see table below). Use an accurate thermometer to check the temperature and immerse the thermometer to half way down the container.
When the water reaches the correct temperature, wet the bag and seed with warm water and suspend them in the container of water. Stir the water and the bag of seed regularly during treatment to ensure that all the seed is heated evenly. Check the temperature regularly and add just enough hot water to maintain the temperature needed. Spread the seed out to dry in a thin layer on paper in a shady area. Plant the seed as soon as it is thoroughly dry. Do not store treated seed.

**Fungicide seed treatments**

Fungicides may be dusted on to seed to provide a thin protective layer. These treatments can prevent attack by fungi carried by the seed itself or in the soil around the seed. Diseases that attack germinating seeds and seedlings include damping-off caused by *Pythium*, and wire-stem (*Rhizoctonia solani*). As well as these seedling diseases, dusting can control other problems that can become evident on more mature plants.

Fungicides registered for vegetable seed use in Western Australia are thiram (Thiram 800®), metalaxyl (Apron®) and a mixture of thiram and thiabendazole (P-Pickel T®). Before using any of these materials on seed of a particular crop, the labels must be checked to ensure that they are registered for use on that crop.

**Prevention – quarantine**

(Floyd, 1990)

The list of plant diseases that may be transported in soil and water is long and many of the diseases have considerable economic impact. Bacterial, fungal, viral and nematode disorders may all be moved around in soil and water, both within and between properties and for that matter, countries.

The introduction of club root disease of crucifers in the Manjimup-Pemberton area has highlighted the danger to farm income from soil-borne diseases. A recent and very damaging outbreak of potato cyst nematode in the Perth area has already indicated to potato growers the dangers in indiscriminate soil movement and this new problem serves to alert growers of other horticultural crops to the problem.

Quarantine is the first line of defence against soil-borne disease; that is, prevention is better than cure. Once a soil-borne disease is established, it is a matter of living with the pest.

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### Table 7.1 Recommended water treatment temperatures and times

(Floyd, 1988)

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Temperature</th>
<th>Time, minutes</th>
<th>Diseases controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>52°C</td>
<td>30</td>
<td>black rot, bacterial leaf spot, black leg, damping off, ring spot</td>
</tr>
<tr>
<td>Broccoli</td>
<td>50°C</td>
<td>20</td>
<td>black rot, bacterial leaf spot, black leg, damping off, ring spot</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>50°C</td>
<td>20</td>
<td>black rot, bacterial leaf spot, black leg, damping off, ring spot</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>52°C</td>
<td>25</td>
<td>ring spot</td>
</tr>
<tr>
<td>Tomato</td>
<td>56°C</td>
<td>30</td>
<td>damping off, bacterial canker, speck and spot</td>
</tr>
<tr>
<td>Celery</td>
<td>50°C</td>
<td>30</td>
<td>blights, damping off</td>
</tr>
<tr>
<td>Carrot</td>
<td>50°C</td>
<td>20</td>
<td><em>Alternaria</em>, bacterial blight</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>55°C</td>
<td>15</td>
<td><em>Fusarium</em></td>
</tr>
</tbody>
</table>

Some hybrid varieties may be damaged by this treatment.
through management strategies. An established pathogen is very rarely eradicated.

**Water supplies and irrigation**

Water supplies can be a source of infective material. For example, potato soft rot organisms have been recovered from water supplies. Surface water supplies are more at risk than deep bores.

Control of soil erosion, run-off from paddocks and drainage from wash sites is essential to prevent contamination of surface-stored irrigation water and spread of infection.

**Packing houses**

Although farmers have the primary responsibility to control and examine materials to be brought on to their properties, organisations such as packing houses providing second-hand containers have an obligation to supply those containers in as clean as possible condition. Clean bins and tubs should be provided to at least ensure that the produce supplied for packing and sale is clean and free from soil or other contaminant.

**Cleaning equipment coming onto the farm**

(Floyd, 1990)

Quarantine depends upon hygiene. All used or secondhand equipment brought on to a property must be checked and proved to be clean. This includes bags, boxes, bulk bins, machinery, trucks and contractors’ equipment. It is good practice to restrict visitors’ cars and trucks to a hard standing area near the main area or to roads and raceways. Any vehicles, including one’s own, obviously carrying mud and soil should be left on the entry hard standing or washed before moving on to the farm.

If in doubt, wash down or refuse entry of suspect items. Washing down must be carried out correctly to eliminate risk of disease transmission.

The important potato disease bacterial wilt *Pseudomonas solanacearum* (see below) is a good example of a disease spread by movement of soil or water.

Drainage from infected sites on to new cropping land has been implicated in outbreaks of this disease. The quantities of soil or water needed to move these diseases are often small. As little soil as that adhering to a tuber or the content of a planting plug is sufficient to enable a disease to infect that plant and potentially to spread within the field.

Soil carried on bins or vehicles may also be introduced into a crop and establish an infection. The widespread use of half tonne field bins in horticulture poses a particular threat from their capacity to transfer quantities of soil long distances. Since these bins are taken into the field, any infected soil carried on them is brought into direct contact with the crop. In these circumstances, diseases are readily established and can become well entrenched before being noticed.

The role of water in disease movement can be important. Seepage from infected fields or from washing facilities into creeks and dams can be transferred on to planting fields or seedbeds. Many of the soil-borne pathogens are well adapted to life in water and persist in seepages, creeks and ponds.

- Check and clean all equipment and visitors’ vehicles carrying mud that come onto the property. Remove soil, plant material and seeds.

Check and clean all used or second-hand equipment and visitors’ vehicles carrying mud that come onto the property. Set up a wash station at or near the entrance to the property for this purpose (see below).

**Removal of soil from vehicles, machinery and boots is the most effective hygiene measure for soil-borne diseases. Fungicide dips can be used as an extra measure for disinfecting boots and small items.**

Cleaning of any items contaminated with soil is important:

- First remove the bulk of soil by hosing down.
- Then disinfect the equipment.
- Dip small items such as bags, boxes or plastic crates in a disinfectant solution.
- Spray down larger items such as field bins with a suitable disinfectant if large enough dipping tanks are not available.
- If the disinfectant used is corrosive, complete the treatment with a final water rinse.

Dip treatments are preferred for disinfection, since all parts of the item are treated and the time of treatment can be controlled. Spraying for disinfection can allow some parts to be missed and the time for exposure to the chemical may be inadequate.

Time of exposure to the disinfectant is important. Most commonly used materials suitable for food handling equipment require an exposure of 10 minutes. Formaldehyde solution is no longer recommended because of its toxicity, the long exposure needed (30 minutes) and its corrosiveness to metal surfaces. Suitable materials are listed below, together with comments on suitability and methods of use.

Disinfect equipment before it is brought to the property, so that all contaminated water can be contained. If it is necessary to treat equipment on the property, the area where this treatment is carried out is of great importance.

### Chemicals for disinfecting
(Floyd, 1990)

**Chlorine**
The most suitable materials available commercially for cleaning and surface-sterilising equipment are those containing free chlorine as an oxidising agent. These include sodium hypochlorite, the active ingredient of household bleach, and swimming pool chlorine. The liquid formulations may be safer to handle than powder bleaches, which can pose a fire or explosion risk if stored with fuels.

The level of available chlorine in the wash water will fall with use, in the presence of organic material and soil. If possible, give a preliminary pressure wash with clean water, possibly with a detergent added, to remove gross contamination. After sterilisation, a rinse with fresh clean water will reduce the corrosive effect of the chlorine.

The strength of the disinfectant solution is calculated as available chlorine; a 0.1 % solution is recommended. Make up commercial sodium hypochlorite (12.5%) to this strength by diluting 1:125 with water. Other sources will need dilution calculated from their published concentration of chlorine. Further details on the use of chlorine for disinfection are given in Farmnote No. 9/90 ‘Chlorination in postharvest horticulture’ (Agdex 200/56).

**Quaternary ammonium compounds**
Quaternary ammonium compounds are readily available and suitable disinfectants for food handling equipment. Unlike chlorine bleaches they are not inactivated by organic material and are not very corrosive.

**Iodine**
Iodine compounds, available as dairy sanitisers, are also suitable for disinfection of containers and equipment.

**Phenol compounds**
Some phenol compounds are also available. They have the advantage of longer residual activity on treated surfaces than the other types of disinfectants. One disadvantage of these compounds is that they are poisonous and so must be used with caution.

Note that formaldehyde or formalin is no longer registered for surface sterilisation. It must not be used for cleaning food containers.

### Wash station
(Floyd, 1990)

A wash station should be set up at or near the entrance to the property for cleaning equipment coming onto the farm. Fungicide dips can be used as an extra measure for disinfecting boots and small items.
The essentials for a wash station are as follows:
- Hard standing, with an impervious surface such as concrete or bitumen, properly graded and sloped to contain the wash water and channel it to a sump.
- Drainage from the sump leading away from cropped areas and water storage.
- A source of clean wash water that is not likely to act as a source of infection on its own account.
- If scheme water is unavailable, a pressurised supply able to dislodge caked and ingrained dirt is essential.
- A small, portable, holding tank and firefighting type pump would be adequate in most cases. High-pressure sprayers suitable for washing down vehicles and bins are also available.
- A knapsack sprayer could then be used to apply disinfectant such as chlorine bleach or quaternary ammonium compounds.
- The set-up chosen should be for this purpose only and thus available at short notice if, for example, equipment arrives at night for immediate use.
- As far as possible, a wash station should be near the main entry of the farm so that all entries may be scrutinised and treated as they arrive. Any materials that come in and are stored without immediate treatment are likely to be used untreated.

Contractors’ machinery are the most likely introductions to go directly to the back paddock in the middle of the night, so a portable and dedicated wash plant must be available at short notice for this use. Complaints have been made about introduction of weeds such as doublegee on tyres of contractors’ equipment. Contractors must be aware of the risks involved in moving from property to property. Precautions to be taken should be discussed with and agreed to by them, before the season begins and contracts are finalised.

**Potato disease example – bacterial wilt**

(Floyd and Delroy, 1988)

Bacterial wilt of potatoes (*Pseudomonas solanacearum*) is a destructive disease, not known to occur in WA to date, which is most active during the summer months with high temperatures and abundant moisture.

It is important to the potato industry and any suspect crops must be reported to the Department of Agriculture WA. Several Acts cover the effect of bacterial wilt and these are designed to protect the industry.

The disease can attack potatoes at all stages of growth and will remain infective indefinitely. The disease is easily spread, but difficult to control. The method of handling infected crops will largely determine the likelihood of further spread of the disease.

Field symptoms are usually similar to those of other wilt diseases, including blackleg, and to insect damage. Wilting is usually only seen during high temperatures and may be confused with localised water stress.

Bacterial wilt is most commonly transferred from property to property by the seed. As far as can be determined, all local outbreaks have been caused by use of diseased seed. No guarantee can be given that even with approved seed there will be no risk of contamination. However, the risks are less than when table stock is planted. Check all seed before planting for the presence of any suspicious symptoms.

Cutting the seed increases the spread of bacterial wilt from infected tubers. Frequent sterilisation of cutting knives in 2% sodium hypochlorite solution is a worthwhile precaution during cutting.

When borrowing any potato machinery, thoroughly clean it down and sterilise it with a hypochlorite solution for control of bacterial wilt and other soil-borne diseases.

The recommended material for sterilisation of equipment and machinery is a solution of sodium hypochlorite. The commercial product
contains 12.5 per cent available chlorine and is
diluted by adding 1 L of product to 12 L of water
for a 1 per cent solution (or 8 L in 100 L water).
As the chlorine is lost when in contact with soil,
very dirty machinery may need a second wash
with the solution to remove softened clods.

**Crop rotation strategies**

Most diseases require plants of certain species as
‘hosts’ on which they can breed and produce
more spores. The life cycle of the disease
organism can be broken by ensuring that other
crops or pastures of non-host species are grown
in the period between cropping of the species
susceptible to the disease.

It is crucial that sufficient time is allowed under
non-host crops or pastures. For most diseases
this is at least three years and in many cases
longer. Though it is not a guarantee against
infection, crop rotation will help to reduce the
impact of the disease if it does occur (Lancaster,
2001).

An adequate inter-rotation period is crucial to
control soil-borne fungal diseases and
nematodes. For most diseases this is at least
three years under non-host crops or pastures and
in many cases longer.

Though it is not a guarantee against infection,
crop rotation will help to reduce the impact of
the disease if it does occur. Details of crop
rotation requirements for different diseases can
be found in vegetable growing handbooks.

**Example**

Rotation of cruciferous crops with non-
cruciferous crops is important to reduce the
cubroot spore load in the soil. For example
cauliflowers followed by potatoes, then sweet
corn and finally three years in pasture. Lowering
the number of spores in the soil will lead to
healthier crops. The time between cruciferous
crops should be at least five years.

- Where possible select inter-rotation crops
  or pastures with biofumigation or pest
deterrent properties.

**Biofumigation crops**

Biofumigation is the sowing of plant species that
contain natural chemicals toxic to soil-borne
insect pests. These plants may be grown as
inter-row ‘nurse crops’ or between rotations and
incorporated into the soil. The potential of some
*Brassica* species containing high levels of
biofumigant chemicals called glucosinolates is
currently being researched, but proven
biofumigation strategies are yet to be
established.

**Rotations to control soil insect pests in
dayatoes**

(Learmonth, 2002)

**Whitefringed weevil**

It is known that grasses and cereals are poor
food plants for whitefringed weevil adults to
produce eggs. In paddocks under a legume based
pasture rotation where the weevil is known to be
a problem, it is worth trying a cereal ‘break
crop’ such as oats directly prior to planting
potatoes. It would be important to minimise the
growth of any clover or other broad-leafed plant.
This is likely to decrease the number of weevil
larvae in the soil.

**African black beetle**

Black beetle adults would lay more eggs where
pastures consist of grasses or cereals. Therefore,
by replacing a grass-based pasture with a
rotation crop of a plant such as lupin may help
reduce the abundance of subsequent generations.
Where black beetle is the dominant soil insect
pest, and whitefringed weevil is not a threat, this
strategy is worth trying

However, where both pests are known to be
present, the cereal break crop to deter the more
serious whitefringed weevil pest is
recommended. This is because with current
knowledge black beetle is more reliably
controlled with insecticides.

Monitoring for these pests prior to planting as
described in Section 7.1 ‘Monitoring for soil-
borne pests’ is essential to decide whether
chemical control will be necessary.
Crop cultural strategies

Take care with how, when and where the crop is grown, to minimise the risk of many pests and diseases becoming established in the crop. The following practices are important:

- Ensure breakdown of crop residues and, removal of pest hosts and over-wintering habitats (see below).
- Monitor for pests and diseases regularly before and during cropping.
- Ensure good crop nutrition and watering – healthy crops resist insect pests.
- Minimise and where possible, avoid soil fumigation for soil health reasons (Section 2.2).

Over the years, many of our cropping plants have been selected for their yield, product quality and resistance to specific pests. Unfortunately, a strain bred specifically for resistance to one pest or disease may be more susceptible to another. Today through plant breeding, many disease and pest resistant varieties are available worldwide.

❑ First consider resistance to locally occurring diseases when selecting the variety of potato or vegetable.

❑ Consider conditions for pests and diseases when timing irrigation schedules.

Examples

Irrigating after sunset is a good practice to prevent build-up of diamondback moth numbers immediately after they are first seen in the crop as it disrupts egg laying.

Delay irrigation for as long as possible after applying chemicals to the crop, to maximise the time they can take effect before being washed off or diluted.

Plant spacings affect the humidity, light and temperature conditions in the growing crop and can thereby influence the incidence of diseases.

❑ Consider conditions for pest and disease threats when deciding on optimum plant spacings.

Pest habitats and hosts

Fungal root diseases such as *Rhizoctonia* sp and damping off fungi such as *Sclerotium* sp. thrive on rotting plant material. For this reason, avoid planting straight into a seed bed which has recently had green plant matter ploughed in. From a soil conservation perspective, the best way to ensure adequate breakdown of pasture residues is to spray off the pasture and leave it for several weeks to break down on the surface before cultivation.

❑ Spray off pastures several weeks before cultivation for cropping.

Coarse residues may require chopping up on the surface using a mulching implement to aid breakdown (Section 2.2) and in some cases shallow incorporation. Tillage should be minimal and shallow for soil health reasons except in exceptional cases where deeper tillage may be required to control some diseases.

Most crops can then be planted soon after soil preparation, thus minimising both the risk of soil erosion and at the same time ensuring that there will be minimal rotting plant material present in the seed bed.

If a "break crop" is to be green mulched prior to planting a vegetable crop, incorporate it to minimal depth and leave adequate time for it to break down. To minimise destruction of soil structure and risk of erosion, avoid inverting the soil profile and leave some plant material exposed to protect the soil surface. Surface water control measures may also be needed to protect the cultivated soil from erosion, (Section 2.1) particularly if deep ploughing has been practiced to control *Sclerotinum* diseases.

❑ Ensure that plant residues are broken down well before planting, to decrease the likelihood of disease outbreak.

❑ Chop and lightly incorporate crop residues into the soil.

Make sure that all crop plants are killed as soon as practicable after harvest and that the area is kept free of "volunteer plants", which can act as hosts, allowing many crop pests and diseases to carry over and infect the next crop.
- Destroy pest life-cycle habitats and control pest hosts.

**Disease carrier species**

Some invertebrate pest species are carriers (vectors) of diseases and in many cases controlling the pest vector is an important part of the strategy to control the disease.

- Control disease carrier species

  **Example**

  Although they do not generally cause economic damage to plants directly, the green peach aphid and potato aphid are the main carriers of the potato leaf roll virus. Potato crops grown for certified seed are inspected twice during the growth period and are rejected if aphids are found to be present above threshold tolerance levels. Ensuring that seed potatoes are grown a long way from and preferably up-wind of cropping areas that are infested with the aphid is another important practice in controlling the virus in Western Australian potato crops.

**Lures, traps and deterrents**

Poison baits and lures in traps can be a good option to avoid application of pesticides onto the product and are often used by organic producers. Potent attractants such as sex pheromones can be used to attract insects into traps or to attract natural predators into the crop under attack. Baits containing the pests’ preferred food can be placed around the crop to divert and kill the pests.

- Use lures and traps where possible to monitor for and control invertebrate pests.

  **Examples**

  - Pheromone traps are a recommended early detection monitoring method for diamondback moth.
  - Attractants such as yellow sticky traps reduce the abundance of whitefly in glasshouses.
  - Metaldehyde or methiocarb baits are effective in reducing snail and slug numbers.
  - Bran bait mixed with maldison can be used to control wingless grasshoppers.
  - Baits of cracked wheat, sunflower oil and chlorpyrifos can be used to control some soil insect pests and European earwig.

- Use netting and deterrents for vertebrate pests.

  **Examples**

  - Fencing cropping paddocks with secure mesh fences is common practice to prevent damage by rabbits and kangaroos.
  - Bird scaring gas guns are used to deter wood duck, or maned duck, which can uproot vegetable seedlings soon after planting.

**7.2 Monitor for pests and diseases and base decisions to spray on ‘economic injury’ thresholds**

Monitoring of cropping paddocks should be thorough, ongoing and properly recorded:

- Monitor all cropping sites prior to soil preparation to detect the incidence of pests and diseases.
- Monitor all crops at regular intervals during crop growth to detect when insect pest numbers have reached threshold levels.

Unfortunately, there is little published information on disease thresholds for vegetable crops in Western Australia. It is a specialised subject that is beyond the scope of this Manual, although an example is given under ‘Regular crop monitoring’ below. Research to develop thresholds is an important area for WA industry groups to consider.

Good records of the incidence of pest and diseases on the site should be kept to build up a site history. This enables growers to improve their pest and disease control strategies, by knowing which actions have worked and which have consistently not worked. It is important to record:
- The results of monitoring for soil-borne pests.
- Any outbreaks of pests or diseases.
- The dates that any pests and diseases were observed during daily field inspections.
- The cost – in terms of time, operating costs and chemicals – and results of all pest control measures (Section 7.3 ‘The spray diary’).

Soil-borne pests
Routine fumigation or application of chemicals to the soil is undesirable because of the soil structure damage and operator risks it entails (Section 2.2 ‘Minimising the impacts of soil fumigation’). It is also unnecessary in most situations.

By using simple, reliable soil monitoring procedures prior to site preparation, the grower can determine whether the disease or pest is present at levels likely to cause economic damage. This enables confident decisions as to whether soil treatment will be necessary.

❑ Use prescribed techniques to monitor for soil-borne pests prior to soil preparation.

Monitoring for white fringed weevil
(Learmonth, 2001)
In areas where whitefringed weevil is a problem, potato paddocks should be monitored prior to planting potato crops by using the following simple procedure:
Monitor for the presence of whitefringed weevils in the summer before planting.

Conduct six 30 minute searches of the pasture at 3-4 week intervals during the summer period mid-December to May. Inspect green grassy patches and random points on dry pasture. If no adult weevils are observed over this period, it is a good indication that the paddock is not infected and in this situation fumigation is not required. If several adult whitefringed weevils are found in any one search, there will be a risk of damage to the crop and the soil should be treated to prevent this.

Inspection of the soil for larvae by taking 100 shovelfuls of soil from the paddock in winter before planting, is recommended as a final precaution. If no weevil larvae are found, soil fumigation should not be necessary.

Regular crop monitoring
Effective IPDM can only be achieved by the grower being involved in an active monitoring programme involving the estimation of the numbers of pests and predators, and their rate of increase, at regular intervals. Initially, growers might need to engage consultants or farm advisers specialising in IPDM to monitor the dynamics of the pest and predator populations to determine if it is necessary to take additional action. This should lead to a sound practical knowledge of insect behaviour in the crop and gradually lead to less and less time actually spent in crop monitoring. The crop may be inspected less frequently, concentrating on the critical times in the insect’s growth cycle and during periods of unseasonable weather conditions.

With experience, a grower can undertake the regular monitoring of disease, pest and predator populations in his or her crop and be able to determine when intervention may be necessary. All growers in the area should be monitoring their crops to ensure a coordinated approach to insect control in the area.

❑ Obtain expert assistance in crop monitoring to gain a sound practical knowledge of insect behaviour in the crop.

Knowledge of the basic biology of the pests that affect crops and at what stage of the life cycle they should be treated enables more effective control.

❑ Know the life cycles and basic biology of pest species.

The majority of organisms are not pests, in fact most are beneficial in that they prey on or inhibit pest and disease organisms. Field guides are available for the correct identification of pests, diseases and beneficial insects in vegetable and potato crops. Examples are:
Heisswolf and Brown (1997).
Llewellyn (2000).

- Be able to identify pest and beneficial species.
- Monitor the crop regularly for pests and diseases.

Pests and diseases do not respect property boundaries. Growers need to know what pests are occurring in the area and what measures are being taken to control them.

- Participate in pest monitoring networks, communicating with other growers in the area to ensure a coordinated approach to pest control.

Such a strategy could be used to coordinate spraying of wild radish, which is a serious weed and host plant for many pests of brassica vegetables.

Example - carrot leaf blights
(Department of Agriculture NSW, 1981)

Leaf blight (caused by the fungus Alternaria dauci) and leaf spot (caused by the fungus Cercospora carotae) are two diseases affecting the leaves of carrots, common in damp weather. The symptoms of leaf blight are leaf spotting and scorching. The symptoms of leaf spot are circular tan or grey spots on the leaves with sunken elongated spots on the stalks.

Monitor the crop regularly for early signs of infection. If either or both of these diseases is detected, they can be controlled by prompt chemical treatment with appropriate fungicides registered for that purpose, such as copper oxychloride or zineb.

For control of both diseases, it is essential to practice crop rotation and hygiene to minimise the incidence of disease outbreaks. Grow carrots on the same land only once every three or four years. Destroy diseased trash by burning or turning in promptly.

Spray strategies based on ‘economic injury’ thresholds

Traditionally, some growers have sprayed according to a pre-set program, whether pests were present in damaging numbers or not. This is poor practice because it is over-use of chemicals, is often unnecessary and is costly

- Do not spray to a pre-set program.

Growers need to be aware of the market quality specifications for the product. Some damage is usually acceptable with minimal down-grading.

A fundamental principle of IPDM is for the grower to be content to allow pest populations to exist at levels that will not cause damage, in monetary terms, in excess of the value of the control measures, i.e. the ‘economic injury level’. Growers should estimate the economic injury level, depending on the crop type, growth stage and pest species.

- Consider the use of chemical pesticides as the last option, when the economic injury level of a crop is likely to be exceeded and there are no feasible biological control methods available.

Examples

Monitoring for diamondback moth numbers during the growth of brassica crops is essential to ensure that the crop is protected and that spraying is cost effective. In the Manjimup area several professional crop scouts are paid to monitor diamondback moth numbers. Moth numbers often decrease as summer progresses and it may cost more to spray low-density infestations at this time than can be justified by the small gain in product harvested.

For organic growers, spraying with all but natural and some mineral formulations is not permissible. They must rely on physical and biological controls and hope that reductions in yield and quality incurred by pest invasions will be compensated for by the higher price received for the organically grown product.
7.3 Control weeds and invertebrate pests by timely physical, biological and chemical means

In many cases the old adage ‘a stitch in time saves nine’ holds true with pest populations. The use of physical and biological control measures pre-planting or when a pest is first detected is always preferable to using chemical pesticides after pest populations have reached damaging numbers.

New weed threats

There are many examples of weeds that cause serious damage to horticulture in other countries and the eastern States of Australia. One of the great advantages of Western Australian horticulture is that most of these weeds have not become established here and grower vigilance can prevent this from happening.

- Be vigilant for new noxious weeds and report their occurrence to the Department of Agriculture immediately.

The serious weeds listed below pose particular threats to our industry as they have caused serious economic damage to horticulture overseas and in some areas of Australia.

Examples of serious weeds that occur in Western Australia and would cause serious damage if introduced to vegetable and potato growing areas are.

<table>
<thead>
<tr>
<th>Orobanche</th>
<th>Mimosa bush</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-seeded dodder</td>
<td>Parkinsonia</td>
</tr>
<tr>
<td>Ragwort</td>
<td>Mesquite</td>
</tr>
<tr>
<td>Skeleton weed</td>
<td>Bathurst burr</td>
</tr>
<tr>
<td>Golden dodder</td>
<td></td>
</tr>
</tbody>
</table>

Orobanche or broomrapes
(Agriculture Western Australia, 1999)

The Orobanche, or broomrapes, are parasitic plants that attack the roots of a considerable number of crops including pulses, pasture legumes, oilseeds and a wide range of vegetables. Broomrapes were identified as threats under the Grain Guard and Hort Guard initiatives.

Of the numerous broomrapes worldwide, five are particularly weedy and cause heavy damage in Mediterranean countries, Europe, Asia and America. These are *O. aegyptiaca*, *O. cernua var cernua*, *O. crenata*, *O. cumana* and *O. ramosa*. Major crops will be seriously affected if these weedy *Orobanche* enter the country and become established. One of these (*O. ramosa*) has been recorded in South Australia and is the subject of an eradication campaign. Another strain of *Orobanche* has been found attacking carrots on a property in Tasmania.

Don’t be complacent – report any *Orobanche* on crops to Agriculture Western Australia immediately.

Hosts

Broomrape seeds are triggered to germinate by the presence of suitable host roots. Depending on the species of broomrape, potential hosts include: beans, broadbeans, cabbages, cannabis/fibre hemp, canola, capsicums, carrots, cauliflowers, celery, chickpeas, chrysanthemums, clover, cucumbers, eggplant, lentils, lettuce, lupins, melons, peas, potatoes, sunflowers, tobacco, tomatoes and vetch.

Vigilance is necessary but, to compound the problem, two other *Orobanche* species are naturalised in Australia. *O. cernua var australiana* is a rare native never recorded as attacking crops. Common broomrape (*O. minor*) is common and widespread in Western Australia and doesn’t seem to cause any harm. It attacks several common pasture plants, weeds and garden plants including capeweed, clover, flatweed, nasturtiums and petunias.

Biology and effects

*Orobanche* are true parasites. They have no chlorophyll (green pigment) and can only survive when attached to a host. Broomrapes attach to the host plant via a specially adapted root system and deprive their hosts of nutrients and water. The relationship with the host varies from a benign partner to causing significant yield loss or death. This depends on various factors including species of *Orobanche*, degree
of parasitisation, time of sowing and host susceptibility.

Broomrape seeds are small, like dust, and last for many years in the soil. A single Orobanche plant can produce up to 500,000 seeds, with dormancy of 10 years or more being common. Once they have flowered, broomrapes will produce seeds even after they have been pulled out.

All Orobanche are AQIS prohibited imports but the seeds could enter the country undetected. The seeds can be spread by contaminated soil, produce, machinery, livestock or clothing. If these parasites become established, even in small areas, all Australian export markets could be affected as many of our trading partners prohibit all Orobanche.

Control

The only way to control pest broomrapes is soil fumigation with methyl bromide being the most effective. Some herbicides control pest broomrapes but they develop herbicide resistance. They have also overcome Orobanche resistance bred into crops. For severe infestations the only viable option may be to switch to non-host crops such as orchard crops or vines.

What the grower can do

Look for pest broomrapes in crops. Dig up Orobanche plants to determine which plant is the host. Mark the site in some way so it can be found easily later. Report any crops affected by Orobanche to the nearest office of Department of Agriculture WA. Use the free Grain Guard or Department of Agriculture Plant Laboratories kit to submit samples for identification.

Inter-rotation crops for weed control

Weeds such as wild radish can be a real problem when coming out of a weed infested pasture phase. Many weed species have seed dormancy of more than one year and do not seed or germinate evenly, making their control during the vegetable cropping operation particularly difficult.

- **Planting a break crop is a good practice to reduce risk of weed competition in the vegetable or potato crop.**

  The cultivation will kill a large portion of the weed population and more will be killed by competition from the fast growing cereal crop. The numbers of viable weed seeds left in the ground will be greatly reduced. Break crops have added benefits when lightly mulched in, providing soil stability and increasing soil organic matter. Money saved by reducing weed spraying and the soil health benefits gained are almost certain to outweigh the cost of growing a break crop and any grazing value that may be foregone.

### Treating weeds

*(Sindel, 2000)*

It is far easier to remove a few weed plants when they are first seen on the property than to wait until a large-scale control effort is necessary. This is particularly true of persistent species with long seed dormancy such as doublegees or Patterson’s curse.

- **Where a few weeds are found, pull or spot spray them by hand before they have seeded. Check the area for a few years and spot spray any re-infestation that may occur from dormant seed.**

#### Pre-planting weed control measures

Seed of the species previously occurring on the site will be in the soil and likely to germinate after cultivation. The species of weeds in crops or pasture should be recorded in the spray diary for future reference. Knowing the species present will influence decisions as to whether pre-emergent herbicide application will be needed, how much and what type of herbicide to use.

Pre-planting weed control measures such as cultivation or spraying with pre-emergent herbicides are far preferable and less costly than attempting to treat a weed population in a crop.
Early control of weeds in crops

Control of large weed populations in vegetable and potato crops is very difficult and usually uneconomic once the plants are more than 10 cm in height.

- Control emergent weeds when they are very small, by selective herbicides, mechanical or hand weeding or flaming.

Weeds in access ways and waterways

These should be controlled because they are a source of seed for further spread and also may harbour pest and diseases. In these situations, weeds should not be controlled by cultivation as the risk of erosion is high.

- To control weeds in access ways and waterways, do not cultivate. Use the following alternatives:
  - Mow or slash at or before flowering, leaving the mulch to protect the surface.
  - Use selective herbicides instead of cultivation.

Preventing herbicide resistance

(Avcare, 2001)

Herbicide resistance has developed a strong foothold in Australian agriculture since it was first reported in annual ryegrass in 1982. It has spread and diversified to become a key constraint to crop production in all States with a history of intensive herbicide use.

Today resistance has been confirmed in a growing number of grass and broad leaf weed species. More worrying still, resistance has now developed to seven distinctly different herbicide chemical groups. This significantly reduces herbicide options for the grower. Cases of multiple resistance have also been commonly reported where, for example, annual ryegrass proves resistant to two or more chemical groups.

Avcare with support from the CRC for Weed Management Systems (Weeds CRC) and the Grains Research and Development Corporation (GRDC) introduced a classification system for herbicides enabling farmers and advisors to understand the mode of action grouping. Since 1996 all herbicide product labels have had to carry the designated mode of action group letter in a prominent position. This was a world first for Australia. A recent survey of growers and agronomists (Kondinin, 1998) revealed that 85% of growers are aware of herbicide mode of action groups and consider this important when making buying decisions. This is a good start but anti-resistance strategies require continual implementation to keep the problem at bay.

- To prevent herbicide resistance:
  - Rotate the herbicide groups used.
  - Reduce frequency of herbicide application by considering physical alternatives such as mechanical weeding, cultivation and flaming.

To achieve effective herbicide rotations it is necessary to carefully record when and what chemicals were used and what and where weed outbreaks occurred (see ‘7.3 ‘The spray diary’).

Herbicide modes of action

(Avcare, 2001)

Herbicides act by interfering with specific processes in plants; this is their mode of action.

Herbicide product labels carry a letter code A, B, C, ..., N representing their specific mode of action group.

The main reason resistance has developed is because of the repeated and often uninterrupted use of herbicides with the same mode of action. Selection of resistant strains can occur in as little as 3–4 years if no attention is paid to resistance management. Remember that the resistance risk is the same for products having the same mode of action. Continuing to use products with the same mode of action and not following an anti-resistance strategy creates future problems.

Herbicides are now grouped by mode of action.

Growers and agronomists are now better aided to understand the huge array of herbicide products in the marketplace in terms of mode of action grouping and resistance risk by reference to the
mode of action chart (Appendix 7.1). All herbicide labels now carry the mode of action group clearly displayed such as:

**GROUP B HERBICIDE**

Know the herbicide groups to make use of this!

Not all mode of action groups carry the same risk for resistance development.

- **To effectively manage herbicide resistance, get to know your herbicide groups and follow these simple steps.**
  - Design anti-resistance strategies around integrated weed management guidelines.
  - Check this chart for herbicides in the same group (the resistance risk is the same).
  - Where possible reduce reliance on high risk groups.
  - Rotate between groups across years.
  - Seek advice and further information about anti-resistance strategies.
  - Keep accurate records of herbicide applications on a paddock basis.

**How to rotate mode of action groups**

(Avcare, 2001)

Specific guidelines are below for products represented in Group A (mostly targeted at annual ryegrass and wild oat) and Group B (broadleaf weeds) – HIGH-RISK herbicides – for use of these products in winter cropping systems. Guidelines for the use of Group C products (annual ryegrass, radish) are also provided.

The guidelines should be incorporated into an Integrated Weed Management (IWM) program. In all cases try and ensure surviving weeds from any treatment do not set and shed seed. For all Groups ensure rotation between products from different mode of action groups.

**Group A (fops and dims) herbicides**

1. Apply only one application of a Group A herbicide per season. ‘Fops‘ and ‘dims‘ are both Group A herbicides and carry the same high resistance risk.

2. Where a Group A herbicide has been used on a particular paddock for control of any grass weed, do not use the same Group in the following season, irrespective of the performance it gave.

3. Where resistance to Group A exists, use other control methods to reduce populations to manageable levels and apply populations to other herbicide groups in a future integrated approach.

**Group B (ALS inhibitors)**

1. Apply only one application of a Group B herbicide per season.

2. If a Group B herbicide has been applied as a pre-emergent application, DO NOT apply further Group B herbicides to that crop. Make any further post-emergent applications with herbicides from a different mode of action group.

3. Apply no more than two Group B herbicides in any four year period on the same paddock.

4. If a post-emergent application is made with a Group B herbicide, this should preferably be as a tank-mix with another mode of action that controls or has significant activity against the target weed. If any further applications are required in that season, it should be with a non-ALS mode of action herbicide that controls the target weed.

5. A Group B herbicide may be used alone on flowering wild radish only if a Group B herbicide has not been previously used on that crop.

**Group C (including triazine herbicides)**

1. Do not use Group C herbicides in consecutive years or on winter legume crops.

2. Apply only one application of a Group C herbicide per crop per season.

3. For use of triazines in triazine tolerant canola (TT):
   a) Pre-emergent or post-sowing pre emergent only. (Annual ryegrass plus other specified
grasses and broadleaf weeds, see label for details)
Rate 1 – 2 kg ai / ha

b) Post-emergent application (radish, turnips, mustards, see label for details)
Rate 0.5 – 1 kg ai / ha

c) Consult the triazine ‘Code of Practice’ for use in TT canola.

d) A maximum of no greater than 2 kg ai / ha of either atrazine or simazine or combination of both is to be applied in any one season on TT canola.

4. The resistance status of the ‘at-risk’ weeds should be determined prior to sowing.

Biological control of invertebrate pests

Biological control is the utilisation of predators, parasites, nematodes, fungi, bacteria and viruses to attack many insect pests. In an undisturbed environment, the number of pest insects and their natural enemies remains relatively stable. The abundance of any pest species depends upon the amount of food, the competition from other species and the number of predators.

Nearly all insect pests have natural enemies (termed ‘beneficial species’) and if the environment or their breeding habits can be manipulated to achieve a large population, they can control the pest.

- Use biological control as the first choice for early intervention against insect pests.

Example

A predatory mite can be obtained and introduced against the pest two spotted mite in strawberries.

‘Soft’ pesticides for control of invertebrate pests

- Encourage beneficial species by using soft options.

If a crop must be sprayed to control a pest, soft options – those that are most pest specific and least toxic to humans – should always be considered first.

Use of toxic, broad spectrum pesticides should be avoided because they often kill the beneficial, predator species which help to keep pest numbers down. The result is often that subsequent pest outbreaks are more severe because there are fewer predators to control them.

The major ‘soft options’ are biological pesticides, commonest of which is *Bacillus thuringensis*, a stomach pathogenic bacteria which is non-toxic to humans and specific in its action against leaf eating caterpillars.

Some chemicals are specific in their action against certain insect pests. There are many others that are ‘predator friendly’ – they do not harm beneficial species.

- Wherever possible, use the most pest specific pesticides, that is biological pesticides or those chemicals that are labelled ‘predator friendly’.

Examples of ‘soft options’

*Bacillus thuringensis* (Bt) sprays are an important part of strategies to control leaf eating caterpillars such as diamondback moth (HRDC, Agriculture Western Australia, 2001). Bt sprays are recommended to control diamondback moth during early growth of brassica crops, when the moth larvae (grubs) are small. For control in mid to late crop stages, rotating spraying with different chemical insecticides minimises the risk of the insect developing resistance to a chemical. Use of extremely toxic organophosphate insecticides such as Mevinphos can usually be avoided.

Pirimicarb is the best chemical to use against aphids as it does not affect beneficial insect species (Learmonth, 2001).

Soil treatment for control of African black beetle without soil fumigation (Learmonth, 2001).

If monitoring and past experience indicates that black beetle will be a problem, these can be controlled by applying pesticide to the soil. Spray chlorpyrifos on the soil in front of the
planter or incorporate it using only a single pass with tines and a crumbler. This is not as damaging to the soil as fumigation because the pesticide acts only on insects, not other soil organisms such as fungi that may be beneficial to soil structure.

The method of incorporation is also much less destructive of soil structure than the rotary hoeing. However, for chlorpyrifos to have some effect on controlling whitefringed weevil as well as black beetle, thorough incorporation with a rotary implement is necessary.

**The spray diary**

Keeping a spray diary enables growers to refer to prior spray treatments and results to:

- Identify the most specific, least toxic pesticide and the minimum quantity required for control of the target pests.
- Improve the efficiency and cost effectiveness of their pesticide use.
- Review suitability of chemicals for future applications.
- Prevent build-up of pesticide resistance in the pest species.

- **Maintain a detailed spray diary and record in it:**
  - The dates when the occurrence of the pests were observed in the crop, when their population increased
  - Pesticides used, rate of application, cost
  - Date of spraying
  - Crop sprayed, crop growth stage and crop vigour
  - Effectiveness of the treatment
  - Other factors that can influence the effectiveness of a control measure, such as weather conditions, site history of the pest.

The spray diary records for each crop should be kept, together with crop monitoring records and records of other IPDM control measures.

Comparison of these records will determine the effectiveness of the pest control strategies.

Records of pest control costs and crop returns can be used to estimate economic injury levels for the different crops and pests.

**Insecticide resistance management**

(Insecticide Resistance Action Committee, 2002)

- Implement insecticide resistance management strategies.
- Minimise the use of insecticides by Integrated Pest and Disease Management.
- Use insecticides from different groups in rotation.

Genetics and intensive application of pesticides are responsible for the quick build-up of resistance in most insects and mites. Natural selection by an insecticide allows some insects with resistance genes to survive and pass the resistance trait on to their offspring. The percentage of resistant insects in a population continues to multiply while the insecticide eliminates susceptible insects.

Eventually, resistant insects outnumber susceptible ones and the pesticide is no longer effective. How quickly resistance develops depends on several factors, including how quickly the insects reproduce, the migration and host range of the pest, the crop protection product’s persistence and specificity, and the rate, timing and number of applications made. Resistance increases fastest in situations such as greenhouses, where insects or mites reproduce quickly. There is little or no immigration of susceptible individuals, and the grower may spray frequently.

General insecticide use is no longer the answer to pest control. Insects have developed widespread, insecticide-defeating resistance to many traditional treatments, and the industry may not have enough resources to continually develop and supply the market with new products precisely when needed to replace old ones. Growers with resistance problems do not have enough time to wait for new chemistry. By
working together, insecticide resistance can be managed! It is imperative growers maintain that the effectiveness of available insecticides through adoption of the management principles described below.

*Resistance is costly; management is economical*

It has been estimated that insecticide resistance in the United States adds $40 million to the total insecticide bill in additional treatment costs or alternative controls. Better management of pesticides by farmers and the crop experts assisting them, industry specialists say, could reduce this bill and lead to more effective, more efficient use of products.

*Causes of resistance*

Resistance is defined as a reduction in the sensitivity of a population. This is reflected in repeated failure of a product to achieve the expected level of control, when used according to the label recommendations for that pest species. There are several ways insects can become resistant to crop protection products:

- **Metabolic resistance.** Resistant insects may naturally detoxify or destroy the toxin faster than susceptible insects, or quickly rid their bodies of the toxic molecules.

- **Altered target-site resistance.** The site where the toxin usually binds in the insect has been genetically modified to reduce the product’s effects.

- **Penetration resistance.** Resistant insects may absorb the toxin slower than susceptible insects.

- **Behavioural resistance.** Resistant insects may detect or recognise a danger and avoid the toxin.

Pests often utilise more than one of these mechanisms at the same time.

*Integrating control strategies for resistance*

An integrated approach prevents resistance. The ultimate strategy to avoid insecticide resistance is prevention. More and more crop specialists recommend insecticide resistance management programs as one part of a larger integrated pest and disease management (IPDM) approach.

Insecticide resistance management, involves three basic components of IPDM described in Sections 7.2 and 7.3:

- Monitoring pest complexes for population density and trends.

- Focusing on economic injury levels.

- Integrating control strategies.

Monitoring is just one element of an insecticide resistance management program. To avoid resistance, specialists say growers should take an integrated approach. Incorporate as many different control mechanisms as possible. IPDM-based programs will include beneficial insects (predator/parasites), cultural practices, crop rotation, pest-resistant crop varieties and chemical attractants or deterrents, together with the use of synthetic insecticides and biological insecticides:

- **Cultural practices.** For example, destroying over-wintering areas, can play a role in managing resistance.

- **Preserve susceptible genes.** Some programs try to preserve susceptible individuals within the target population by providing a haven for susceptible insects, such as unsprayed areas within treated fields, adjacent ‘refuge’ fields, or habitat attractions within a treated field that facilitate immigration. These susceptible individuals may outcompete and interbreed with resistant individuals, diluting the impact of resistance.

- **Consider crop residue options.** Destroying crop residue can deprive insects of food and overwintering sites. This cultural practice will kill pesticide-resistant pests (as well as susceptible ones) and prevent them from producing resistant offspring for the next season. However, farmers should review their soil conservation requirements before removing residue.
Planning and conducting spraying according to best practice
(Avcare, 2001)

Avoid broad-spectrum insecticides when a narrow or specific insecticide will suffice. Select insecticides with care and consider the impact on future pest populations.

Protect beneficials. Select insecticides in a manner that causes minimum damage to populations of beneficial arthropods. Applying insecticides in a band over the row rather than broadcasting or using a product in-furrow will help maintain certain natural enemies.

Time applications correctly. Time insecticide and miticide applications against the most vulnerable life stage of the insect pest. Use spray rates and application intervals recommended by the manufacturer.

Mix and apply carefully. As resistance increases, the margin for error in terms of insecticide dose, timing, coverage, etc., assumes even greater importance. The pH of water used to dilute some insecticides in tank-mixes should be adjusted to 6 to 8. In the case of aerial application, the swath widths should be marked, preferably by permanent markers. Sprayer nozzles should be checked for blockage and wear, and be able to handle pressure adequate for good coverage. Spray equipment should be properly calibrated and checked on a regular basis. Use application volumes and techniques recommended by the manufacturers and local advisors.

Rotating insecticide groups
(Avcare, 2001)

Do not repeatedly use, year after year, the same insecticide or related products in the same class. Rotate insecticides across all available classes to slow resistance development. (refer to Appendix 7.2 for insecticides and their groups).

In addition, growers should avoid tank-mixing products from the same product class. Rotate product classes and modes of action, consider the impact of pesticides on beneficial insects, and use products at labelled rates and spray intervals.

Cross-resistance occurs when a population of insects that has developed resistance to one product exhibits resistance to one or more product(s) it has never encountered. Cross-resistance is different from multiple resistance, which occurs when insects develop resistance to several compounds by expressing multiple resistance mechanisms. A classic example of cross-resistance was when many species developed resistance to DDT and subsequently had cross-resistance to pyrethroids.

If resistance is suspected
If growers encounter control failure and suspect they have a case of insecticide resistance, it’s best not to jump to any conclusions until they consult with crop specialists. Several other problems have similar symptoms, so if poor control is experienced, growers should first check for:

Application error. Were the timing of the application and the dosage correct? Were proper product carriers used? Was the correct application method followed? Was the timing for treatment evaluation incorrect, or does the product require more than one application?

Equipment failure. Were the spray nozzles blocked? Were all parts of the applicator functioning properly? Was the equipment calibrated for accurate application using recommended spray volumes and pressures?

Environmental conditions. Did rain or overhead irrigation occur too soon after application? Were temperature, wind or other environmental conditions less than ideal for application?

Be certain it’s resistance
If resistance is suspected, there are several steps growers can take to keep the problem from mushrooming. First and foremost, they should not respray with an insecticide of the same chemical class. Their crop protection sales agent should be contacted to help evaluate the cause of control failure. He or she will call additional experts as needed to accurately confirm insecticide resistance.
To confirm resistance, an evaluation of the surviving insects for the level of detoxifying enzymes or the presence of resistant genes will be made by professionals using a number of methods. In some cases, diagnostic doses of a specific product are applied to surviving insects from the field. Depending on available resources, insects may be taken to a laboratory for immunological or DNA diagnostic techniques. Producers should always work with local crop specialists to determine appropriate monitoring and diagnostic programs for their resistance-related situations.

To manage resistant insect populations, crop specialists may want to counsel growers on the following:
- Short-term spray decisions.
- Resistance management tactics.
- Evaluating the success of a resistance management program.
- Tracking resistance status on a farm or field-by-field basis.
- Determining relative tolerance of pests and bio-control agents.

References


Department of Primary Industries, Qld., 1999. Diamondback Moth in Selected Brassica Vegetable Crops.


Nursery and Garden Industry Australia, 2002. *Introduction to the Nursery Industry Accreditation Scheme.*


**Further Reading**


Agriculture Western Australia, 1994. *Control of Pest Snails and Slugs: Chemical.* Farmnote 113b /94.

Agriculture Western Australia, 1994. *Control of Pest Snails and Slugs: Cultural and Biological.* Farmnote 113a /94.


APPENDIX 7.1
Herbicide Resistance Groups
(Avcare, 2001)

HIGH RISK

GROUP A
Inhibitors of fat(lipid) synthesis–ACC’ase inhibitors.
**Aryloxyphenoxypropionates ("Fops")**: Correct ®, Falcon ®, Fusilade ®, Fusion ®, Hoegrass ®, Puma S ®, Shogun ®, Targa ®, Topik ®, Tristar ®, Verdict ®, Wildcat ®, diclofop

**Cyclohexanediones ("Dims")**: Achieve ®, Fusion ®, Select ®, Sertin ®, Sertin ® Plus

GROUP B
Inhibitors of the enzyme acetylcoenzyme acetolactate synthase–ALS inhibitors.
**Sulfonylureas**: Ally ®, Brush-Off ®, Cut-Out™, Glean ®, Harmony ® M, Logran ®, Londax ®, Monza ®, Oust ®, Renovate ®, Titus ®, metsulfuron, chlorosulfuron

**Imidazolinones**: Arsenal ®, Flame ®, OnDuty ®, Spinnaker ®

**Sulfonamides**: Broadstrike ®, Eclipse ®

MODERATE RISK

GROUP C
Inhibitors of photosynthesis and photosystem II.
**Triazines**: Agtryne ® MA (also contains MCPA – Group I), Bladex ®, Gesagard ®, Gesaprim ®, Igran ®, atrazine, simazine, terbutryn

**Triazinones**: Lexone ®, Sencor ®, Velpar ®, metribuzin

**Ureas**: Afalon ®, Cotoran ®, Graslan ®, Karmex ®, Tribunil ®, Probe ®, Tupersan ®, Ustilan ®, diuron, linuron

**Nitriles**: Buctril ® 200, Buctril ® MA (also contains MCPA –Group I), Jaguar ® (also contains diflufenican – Group F), Totril ®, bromoxynil

**Benzothiadiazoles**: Basagran ®

**Acetamides**: Ronacil ®

**Uracils**: Hyvar ®, Krovar ®, Sinbar ®

**Pyridazinones**: Pyramin ®

**Pheny-pyridazines**: Tough ®

GROUP D
Inhibitors of tubulin formation.
**Dinitroanilines**: Relay ®, Surflan ®, Stomp ®, Treflan ®, Yield ®, trifluralin

**Benzoic acids**: Chlorthal ®

**Pyridines**: Visor ®

GROUP E
Inhibitors of mitosis.
**Thiocarbamates**: Avadex ® BW, Eptam ®, Ordram ®, Saturn ®, Tillam ®, Vernam ®, molinate

**Carbamates**: chlorpropham

**Organophosphorus**: bensulide

GROUP F
Inhibitors of carotenoid biosynthesis.
**Nicotinanalides**: Brodal ®, Jaguar ® (also contains bromoxynil - Group C ), Tigrex ® (also contains MCPCA – Group I)

**Triazoles**: amitrole

**Pyridazinones**: Solicam ®

**Isoxazolidinones**: Command ®, Magister ®

**Pyrazoles**: Taipan ®

GROUP G
Inhibitors of protoporphyrinogen oxidase.
**Diphenyl ethers**: Affinity ®, Blazer ®, Goal ®, Spark TM

**Oxidiazoles**: Ronstar ®

GROUP H
Inhibitors of protein synthesis.
**Thiocarbamates**: Saturn ®

GROUP I
Disruptors of plant cell growth.
**Phenoxy**: 2,4-D, 2,4-DB, MCPA, Barrel ®, (also contains bromoxynil and dicamba – Group C and Group I ), Buctril ® MA (also contains bromoxynil – Group C ), Tigrex ® (also contains diflufenican – Group F), Tillmaster ® (also contains glyphosate -Group M)
Benzoic acids: Banvel ®, Cadence ®, dicamba
Pyridines: Garlon DS ®, Lontrel ®, Tordon ® 242, Tordon ® 75-D, Starane ®, triclopyr

LOW RISK

GROUP J
Inhibitors of fat synthesis.
Alkanoic acids: Propon

GROUP K
Herbicides with multiple sites of action.
Amides: Devrinol ®, Dual Gold ®, Enide ®, Kerb ® WP, Ramrod ®, napropamide, metolachlor
Carbamates: Asulox ®, Betanal ®, Carbetamex ®, asulam
Amino propionates: Mataven L ®
Benzfurans: Tramat ®, ethofumesate
Phthalamates: Alanap ®
Nitriles: dichlobenil

GROUP L
Inhibitors of photosynthesis at photosystem I.
Bipyridils: Gramoxone ®, Reglone ®, SpraySeed ®, paraquat, diquat

GROUP M
Inhibitors of EPSP synthase.
Glycines: Roundup ®, Tillmaster ® (also contains 2,4-D – Group I), Touchdown, glyphosate

GROUP N
Inhibitors of glutamine synthetase.
Glycines: Basta ®

Note: Groups are listed by resistance risk. The listing of trade names does not represent an exhaustive record of registered products. Products listed are primary registered products only and are arranged in alphabetical order. Active ingredient names are additionally included where multiple products are registered.
## APPENDIX 7.2

Mode of Action Classification for Insecticides, by active constituent.
(Avcare, 2001)

<table>
<thead>
<tr>
<th>Active Constituent</th>
<th>Group</th>
<th>Active Constituent</th>
<th>Group</th>
<th>Active Constituent</th>
<th>Group</th>
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<td>3A</td>
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<td>3A</td>
<td>prothiofos</td>
<td>1B</td>
</tr>
<tr>
<td>buprofezin</td>
<td>17A</td>
<td>fluvalate</td>
<td>3A</td>
<td>pymetrozine</td>
<td>9A</td>
</tr>
<tr>
<td>cadusafos</td>
<td>1B</td>
<td>furathio</td>
<td>1A</td>
<td>pyrethrins</td>
<td>3A</td>
</tr>
<tr>
<td>carbaryl</td>
<td>1A</td>
<td>hexafluorid</td>
<td>15A</td>
<td>pyridaben</td>
<td>21A</td>
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<tr>
<td>carbofuran</td>
<td>1A</td>
<td>hexythiazox</td>
<td>10A</td>
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<tr>
<td>carbosulfan</td>
<td>1A</td>
<td>hydramethylnon</td>
<td>20A</td>
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<td>chlorfenapyr</td>
<td>13A</td>
<td>hydroprene</td>
<td>7A</td>
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<tr>
<td>chlorfenvinphos</td>
<td>1B</td>
<td>imidacloprid</td>
<td>4A</td>
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<tr>
<td>chlorpyrifos</td>
<td>1B</td>
<td>indoxacarbin</td>
<td>22A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chlorpyrifos-methyl</td>
<td>1B</td>
<td>isofenphos</td>
<td>1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>clofentezine</td>
<td>10A</td>
<td>lamda-cyhalothrin</td>
<td>3A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cryolite</td>
<td>9B</td>
<td>magnesium phosphate</td>
<td>8B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cyfluthrin</td>
<td>3A</td>
<td>methidathion</td>
<td>1B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A weed-free carrot crop on the Swan Coastal Plain.

Cleaning machinery is an important hygiene measure.
SECTION 8

Maintaining our Native Flora and Fauna
Maintaining our Native Flora & Fauna

In addition to providing refuge for threatened native flora and fauna species, native bush has many other values, such as protecting water resources and producing wildflowers, honey and craft wood. It also contains part of a unique resource, our natural biodiversity, which is the variety of all forms of life, including plants, animals and micro-organisms and the natural ecosystems in which they live. With proper management, native bush can provide all of these benefits and enhance the value of a property.

Even on one farm, a range of ecosystem types may exist, with each requiring a different management strategy. Landcare or Bushcare groups exist in most districts. One of their main roles is to provide advice and funding to take effective action to rehabilitate native vegetation. Farmers seeking help with these issues are encouraged to contact these groups.

This section contains information for growers with native bush on their property, or whose properties adjoin native bush. There are sections on:

- protecting, replanting and direct sowing of native bush species
- controlling environmental weeds
- controlling feral animals

Specific information is provided on controlling foxes and rabbits, and about aquatic weeds and starlings, species not yet established here but which pose a serious threat to our native flora and fauna.

8.1 Manage remnant vegetation on the farm to enhance its quality

Fencing native vegetation

Fencing to exclude stock is the first measure that should be taken to allow remnant native vegetation to regenerate naturally. It is important to maintain access for weed control and fire management.

The type of fence depends on the livestock on the property and growers’ preferences. Electric fences are the most cost effective for broad acre properties where cattle are run. Netting fences are much more expensive but are often used to keep out pest species, or where both sheep and cattle are run.

Part-funding to fence remnant vegetation is available through the Remnant Vegetation Protection Scheme (contact Department of Agriculture WA) and the Bushcare program (contact Department of Conservation and Land Management or local Community Landcare Coordinator). For approved fencing projects to protect native bush, these organisations provide $600 per km or $1200 per km where the farmer agrees to a caveat to protect the bush.

Managing native vegetation

It is much easier to manage existing native vegetation properly and keep it in a healthy condition than to replant or rehabilitate after it has died off or become weed infested.

The following measures, if undertaken appropriately, can keep native vegetation healthy and protect native fauna:

- Minimise disturbance of healthy native bush.

Grazing or in any way disturbing native bush allows weeds to establish, which are difficult and costly to remove.

- Plan the timing and intensity of control burns to maintain or increase the diversity of native plant species.

The appropriate fire management will depend on the type of species association present. Department of CALM or Bushcare officers can provide advice.

- Control introduced weed species in the native vegetation area.
- Control the numbers of feral animals within the native vegetation area.
Plant native under-storey species along stream and water body buffers and wind breaks to encourage native fauna. (see below).

Infestations of *environmental weeds*, weeds that compete with and replace native species, should be sprayed when they are most actively growing (late winter to early summer depending on the species), at or before flowering.

Care should be taken not to spray any native species as these need to grow over and replace the weed species, thus preventing re-infestation.

**Revegetating unproductive areas**

Where possible, revegetate unproductive land to become part of a windbreak and wildlife corridor system on the farm.

**Site preparation for establishing native trees and shrubs**

(Agriculture Western Australia, 1997)

Site preparation is the vital step when establishing native trees and shrubs. The aim of site preparation is to maximise survival and growth of tree seedlings by providing the best environment for plant establishment. For successful establishment of native vegetation, weeds and pests must be controlled. There are also soil problems that can slow early root growth:

- compacted layers
- low organic matter and nutrient levels
- waterlogging
- salinity
- low moisture availability due to non-wetting soil and poor infiltration

Managing these problems enables fast early growth of plants to help them survive their first summer and autumn.

Ideally, site preparation should start in late summer or early autumn for a winter planting. This will allow the most effective ripping and more efficient weed control on mounded areas before planting. Where summer-active perennial species such as couch, kikuyu or sorrel are present it will be necessary to spray to control these species before ripping and mounding. Techniques for site preparation are described below.

**Ripping**

Ripping has been shown to improve tree growth on all farmland soils. It fractures the compaction zone (usually located 200 to 400 mm below the surface), allowing penetration of tree roots, and it improves moisture infiltration. On most soils, aim to rip to at least 500 mm deep, as a single rip line per row of trees. Ripping works best when the soil is dry. Also a winged ripping tine results in better shattering of the subsoil than with a conventional tine. Sites which have hard pans (hard or rocky cemented layers at depth) may require deeper ripping (to 1000 mm) with a bulldozer.

**Ploughing**

Broadscale ploughing is not usually practised because of the cost and danger of erosion. However, ploughing can help make tree planting easier and improve moisture conservation. It is a useful adjunct to using herbicides to control weeds such as couch grass (*Cynodon dactylon*). Also, on heavy soils, ploughing before mounding benefits the formation of the mound.

**Mounding**

Mounding is recommended on all but deep, dry sandy soils. It concentrates topsoil, which is beneficial for survival and early growth.

Mounding is essential on wet sites. A 1993 study showed that tree survival improved from 65 per cent to over 95 per cent by mounding on a site prone to seasonal waterlogging. On wet sites mounds should be aligned to allow excess water to drain off the site without causing erosion. The drainage furrows created on each side of the mound provide important additional drainage. For maximum effect, these should be continuous, and connected into the drainage network. The mound should be constructed at least 200 mm to 300 mm high, about 1000 mm wide and located...
over the rip line. Even larger mounds may be required on very wet sites.

Special mound ploughs are available for mounding and profiling soils. Rollers on mound ploughs consolidate and profile the mound. A roller that forms a shallow ‘M’ shape is best for saline sites as it allows the salt to leach from the mound. Satisfactory mounds can also be created using a small one-way plough or grader in non-saline situations.

**Furrowlining**

Furrowlining can be used to break the water-repellent layer on elevated, non-wetting, deep sands, and allow water to enter through the bottom of the furrow. This is also an effective means of weed control, and can give some shelter to small seedlings. Caution should be used where exposure could lead to wind erosion, or where water erosion could occur down the furrow. In these situations, ripping followed by a press wheel or tyre will provide a suitable entry point for water. Weed control can then be undertaken with herbicides. Furrows are usually 200 to 300 mm deep and about one metre wide. As furrowlining removes topsoil, fertilising of trees may be necessary.

### Table 8.1 Site preparation for different soil types

* NR = Not recommended

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Ripping</th>
<th>Ploughing</th>
<th>Mounding</th>
<th>Furrowlining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-wetting deep elevated sands</td>
<td>500 mm deep</td>
<td>NR</td>
<td>NR</td>
<td>Recommended</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>500 mm deep</td>
<td>For moisture conservation</td>
<td>Beneficial</td>
<td>NR</td>
</tr>
<tr>
<td>Clayey loam</td>
<td>500 mm deep</td>
<td>Beneficial for mounds if soil is cloddy</td>
<td>Beneficial</td>
<td>NR</td>
</tr>
<tr>
<td>Duplex soils – sandy surfaced, heavier below</td>
<td>500 mm deep</td>
<td>NR</td>
<td>Beneficial</td>
<td>NR</td>
</tr>
<tr>
<td>Duplex soils – clay/loam surfaced, heavier below</td>
<td>500 mm deep</td>
<td>Beneficial for mounds if soil is cloddy</td>
<td>Essential</td>
<td>NR</td>
</tr>
<tr>
<td>Wet/waterlogged sites</td>
<td>500 mm deep</td>
<td>NR</td>
<td>Essential – larger mounds required on very wet sites</td>
<td>NR</td>
</tr>
<tr>
<td>Saline sites</td>
<td>500 mm deep</td>
<td>NR</td>
<td>Essential</td>
<td>NR</td>
</tr>
</tbody>
</table>
Tree planting
(Agriculture Western Australia, 1990)

The information in this section is for tree planting in the medium and high rainfall zone of Western Australia.

In Western Australia, most planting of commercial trees is done by hand, using seedlings grown in peat ‘jiffy’ pots, or in specially moulded plastic trays. Purpose-built planting machines are used in some areas, and are particularly suited to planting bare-rooted seedlings.

Ordering seedlings from nurseries

Order in October/November to ensure that the species you want can be obtained. Nurseries sow tree seeds into trays of potting mix from December to February. The seedling trees are then ready for planting after the ‘break of season’ in May.

For larger quantities, most nurseries grow to order, so early ordering helps them meet requirements. Most nurseries factor in a level of discard plants. Check with the nursery how many healthy seedlings can be expected in each tray. Order 5 to 10 per cent more trees than are needed, to replace seedlings that become damaged or that die when transplanted.

If possible, buy seedlings in trays designed for root training. Seedlings that are pot-bound or have tightly coiled roots are likely to develop root problems later. Before taking delivery, remove a few seedlings from their trays or pots and check their root structure.

A good size for seedlings is between 15 and 30 cm. The stem of tree seedlings should be strong, and have a diameter greater than 2.5 mm at the base.

Before planting, ensure the seedlings have been ‘hardened’, that is, ‘weaned off’ shade and nutrients, at the nursery. Deep green, lush and soft foliage indicate unharden seedlings that may suffer from transplant shock, dry conditions and frost. Reputable nurseries sell only ‘hardened’ seedlings.

Collecting, transporting and storing seedlings

If possible, collect your seedlings from the nursery close to the date of planting out. Protect them from sun and wind during transport. Store the seedlings in an open position protected from strong winds. If they must be stored for a long period, place them on raised mesh benches or on coarse blue metal to stop their roots growing into the soil, and to prevent fungal diseases.

Seedlings need a light watering every day during fine weather. Wash ice off the leaves in the morning if the weather is frosty. On the day they are to be planted, give the seedlings a thorough watering to reduce transplant shock and make them easier to remove from their pots or trays.

When to plant

Early June to mid-August is the optimum time for tree planting in southern Western Australia – starting as soon as the soil is thoroughly wet with winter rains and adequate weed control has been achieved. On dry sites, for example deep, elevated sands, it is best to plant trees before the middle of July. Very wet sites can be left until the end of August to minimise stress on the seedlings from waterlogging.

Planting

Remove seedlings from their cells in plastic trays by pushing up from the bottom while at the same time gently pulling on the stem. If the seedlings are pot bound, with tightly coiled roots, make two shallow vertical cuts down the root ball with a knife and gently tease out some of the roots.

If the seedlings are in peat ‘jiffy’ pots, cut off any large roots protruding from the pots, and break off the bottom and one side of the pot to prevent root coiling. Also remove any excess peat from the top rim of the jiffy pot. If not buried properly, the jiffy pot’s exposed rim can act as a wick and dry out the roots.

Plant only healthy, actively growing seedlings – discard others. Prepare only 50 to 100 trees at a time on planting trays, to prevent them drying out, and to reduce transplant shock.
Planting depth

Plant seedlings deeper than they were growing in the nursery, to make sure the roots stay moist while getting established (without being waterlogged). Bare rooted seedlings have a soil mark on the stem, showing how deep they were growing in the nursery. For seedlings grown in trays, make sure the entire root ball is buried.

Choose a depth of planting to suit the soil conditions. On dry sites (especially dry sandy sites), plant the seedlings so the top of the root ball or soil mark is 5 to 7 cm below the soil surface. For heavier soils with adequate moisture, plant the seedlings 2 to 3 cm deep. On very wet sites, plant closer to the surface, or better still, delay planting until the end of winter.

Make sure the roots are planted into mineral soil, not mulch or loose organic matter, and that soil is firm around the roots, that is ‘heeling’ for hand planting or using press wheels for machine planting.

Planting position for seedlings

Plant in the centre of the mound on mounded sites. If hand planting on sites that have been ripped only, place the seedling about 15 cm away from the ripline on the uphill side. For sites that have been furrowlined (usually only the deep non-wetting sands of the Swan Coastal Plain), plant in the centre of the furrow. Only use knockdown (non-residual) herbicides on furrowlined sites.

Planting methods

Trees can be planted by hand, or by mechanical planters. To plant small numbers of trees, a narrow or cut down spade will do the trick. For larger hand planting projects, the easiest and quickest way is to use a planting tube such as the ‘Pottiputki’. Using these devices, more than 2000 seedlings can be planted per day.

To plant using a planting tube:
- Adjust the planting tube to give the desired depth of planting.
- Push planting tube into the ground and press on depth limiter until it reaches the correct depth.
- Take the seedling out of its container, or from the planting tray and drop it into the tube (roots first!).
- Step on jaw-opening pedal.
- Lift planting tube out of the ground with a twisting motion to loosen any soil stuck to the jaws.
- Press the soil firmly around the seedling with boot pressure on either side, to close air pockets, making sure the seedling ends up vertical. Leave a small depression around the plant to collect water (except on wet sites).
- A simple check to see if the trees have been firmly planted is to lightly pull a seedling by the stem. If it pulls out of the ground easily it has not been firmed in well enough.
- Close the jaws of the planting tube using the release lever, and move to the next planting position.

Suppliers of planting tubes

Pottiputki Planting Tube – Prospectors, Unit 4, 195 Prospect Highway, Seven Hills, NSW 2147
Nufab Hand Planter – Lot 28, Moore Road, Dongara, WA (08) 9927 1297
Pottiputki hand planting tube – Namaco, Perth (08) 9354 9200 Fax (08) 9354 9300

Note: These are examples only; please enquire about other suppliers in the area.

Using a spade (for small scale plantings)

Dig a small hole which should be just big enough to hold the teased-out root system of the seedling.

Place the seedling in the hole at the desired depth. Make sure the roots are arranged in a natural position and are not coiled or bending upwards.

Fill the hole making sure the seedling tree is upright. Gently firm the soil around the tree stem with your feet.
Fertilising

Adequate nutrition gives trees a good start, with rapid early root and shoot development. Test the soil before planting to find out if fertiliser is needed. If the site has a good fertiliser history it is usually unnecessary to fertilise in the first year. However, the trees may need a fertiliser application in later years. Tree nutrition will be covered in more detail in a separate TreeNote.

As a general rule of thumb, for sites which need fertiliser in the year of planting, give each seedling about 50 g (equivalent to a small handful) of a general purpose fertiliser containing phosphorous and nitrogen. Suitable fertilisers include DAP, Agras No1, or NPK Blue. Use a spade or planting tube, and bury the fertiliser in a lump, 15 to 20 cm away from the base of the seedling, on the downhill side. This concentrated lump of fertiliser has an extended release period, similar to compressed tree tablets (which cost more, but are easy to use). Burying the fertiliser prevents nitrogen being lost to the atmosphere and reduces potential growth of weeds near the seedling.

Apply fertiliser at the time of planting (to minimise labour costs), or some weeks later when the seedlings have become established (to maximise the effectiveness of the fertiliser). Later fertilising is recommended for wet sites, to minimise the loss of fertiliser by leaching, before the tree roots have grown enough to use it. Fertilising should be completed by the end of September.

Note: Fertilise only if weed control has been successful, otherwise it will accelerate weed growth at the expense of the seedlings.

Direct seeding
(Holt, 1998)

Revegetation with woody perennials will play a major role in reversing land degradation trends in Western Australian agriculture. Direct seeding is seen as a technology with potential for lowering establishment costs. It has distinct advantages in building revegetation areas with biodiversity and nature conservation objectives.

‘Direct seeding’ means applying seed directly to the site where plants are wanted, rather than growing seedlings in a nursery, then planting them on a site.

Direct seeding has several advantages:

- Areas can be revegetated quickly and cheaply. A mixture of trees, shrubs and groundcovers can be sown at the same time. The different rates of germination mimics natural regeneration. This creates better habitats and provides more of the needs of native animals. Direct seeded windbreaks can be more effective because of the mixture of tall, middle and understory plant species.

- Seeds cost less than seedlings. For example: to sow a 5 km windbreak that is 15 metres wide, seed is sown at a rate of 400 grams per hectare. The 7.5 hectares will require 3 kg of seed. This will cost around $900 in seed (depending on species and availability, but assuming the average seed price is 30c per gram). Purchasing 4000 seedlings for the same project (five km long, four rows of seedlings and five metres between seedlings) will cost between $1200 and $1600, depending on seedlings costs (30c to 40c each).

Direct seeding requires less time and labour than seedlings.

Seed is much easier and cheaper to transport and store than the seedlings.

Direct seeding contractors and advisors

Consultants and contractors who conduct direct seeding can be found in the ‘Yellow Pages’ telephone directory.

A network of Bushcare support workers in the agriculture areas provide advice on remnant bush management and revegetation for nature conservation.

Contact your local landcare group or:
Greening WA 10 The Terrace, Fremantle.
Tel: (08) 9355 8933, Fax: (08) 9355 9203.
<table>
<thead>
<tr>
<th>Botanical Name</th>
<th>Common name</th>
<th>Habit</th>
<th>Notes – propagation/uses/soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia saligna</em></td>
<td>Golden–wreath wattle</td>
<td>Large shrub to small tree, 5 metres</td>
<td>Grows on banks of creeks and rivers. Propagate by seed, brushing.</td>
</tr>
<tr>
<td><em>Agonis flexuosa</em></td>
<td>peppermint</td>
<td>Med spreading tree to 10 m</td>
<td>Sands and gravels with shallow fresh water table.</td>
</tr>
<tr>
<td><em>Agonis juniper</em></td>
<td>Warren River cedar</td>
<td>Med tree to 15 m</td>
<td>Fringing plant for creeks, lakes &amp; swamps. Propagate by seed, brushing, cuttings.</td>
</tr>
<tr>
<td><em>Agonis linearifolia</em></td>
<td>Swamp peppermint Rosa/coarse tea-tree.</td>
<td>Shrub to 5 metres</td>
<td>Cut flower trade. Fringes swamps &amp; watercourses – stream stabiliser. Seed, brushing, cuttings.</td>
</tr>
<tr>
<td><em>Agonis parviceps</em></td>
<td>White/fine tea tree</td>
<td>Med shrub</td>
<td>Cut flowers, commercial, stream stabiliser.</td>
</tr>
<tr>
<td><em>Allocasuarina decussata</em></td>
<td>Karri sheoak</td>
<td>Med tree to 15 m</td>
<td>Craft timber.</td>
</tr>
<tr>
<td><em>Allocasuarina fraseriana</em></td>
<td></td>
<td>Med tree to 15 m</td>
<td>Valuable furniture timber. 15 m</td>
</tr>
<tr>
<td><em>Allocasuarina humilis</em></td>
<td>Dwarf sheoak</td>
<td>Small tree</td>
<td>Likes sandy soils.</td>
</tr>
<tr>
<td><em>Astartea fascicularis</em></td>
<td></td>
<td>Open weeping shrub to 2-3 metres</td>
<td>Grows along watercourses &amp; damp soils near winter-wet depressions and swamps. Seed, brushing, cuttings.</td>
</tr>
<tr>
<td><em>Banksia attenuata</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Banksia illicifolia</em></td>
<td>Holley-leaved banksia</td>
<td>Med-large tree</td>
<td>Dry to damp sandy soils.</td>
</tr>
<tr>
<td><em>Banksia littoralis</em></td>
<td>Swamp banksia</td>
<td>Tree to 12 metres</td>
<td>Winter-wet depressions and the edges of swampy areas. Seed, collect autumn to late winter. Good craft timber.</td>
</tr>
<tr>
<td><em>Beaufortia sparsa</em></td>
<td>Swamp bottlebrush</td>
<td>Shrub to 2 metres</td>
<td>Winter-wet depressions and along watercourses. Propagate by seed, brushing, cuttings. Cut flowers, likes winter-wet peaty sands.</td>
</tr>
<tr>
<td><em>Boronia molloyae</em></td>
<td>Tall boronia</td>
<td>Tall shrub to 3 metres</td>
<td>Winter-wet depressions &amp; the edges of swampy areas. Propagation method unknown, try seed with smoke.</td>
</tr>
<tr>
<td>Botanical Name</td>
<td>Common name</td>
<td>Habit</td>
<td>Notes – propagation/uses/soil</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Bossieae aquifolia</strong></td>
<td>Water bush, netic</td>
<td>Shrub, legume</td>
<td>Understorey to karri-marri. Stock like it. Could be good understorey for river foreshores. Grows along Perup River.</td>
</tr>
<tr>
<td><strong>Brachysema sp. (?)</strong></td>
<td>Black pea</td>
<td>Low spreading shrub/ ground cover</td>
<td></td>
</tr>
<tr>
<td><strong>Callistemon glauca/ speciosus</strong></td>
<td>Albany bottlebrush</td>
<td>Med shrub</td>
<td>Cut flowers (red)</td>
</tr>
<tr>
<td><strong>Callistemon phoeniceus</strong></td>
<td>Fiery bottlebrush</td>
<td>shrub</td>
<td>Cut flowers</td>
</tr>
<tr>
<td><strong>E. decipiens</strong></td>
<td>Moit; marlock</td>
<td>Med spreading tree often mallee form.</td>
<td>Fresh damp areas often perched amid saline soils, 500-800 mm rainfall. Red timber; poor form.</td>
</tr>
<tr>
<td><strong>E. ficifolia</strong></td>
<td>Red flowering gum</td>
<td>Med tree to 15 m</td>
<td>Needs well drained soil.</td>
</tr>
<tr>
<td><strong>E. patens</strong></td>
<td>WA blackbutt</td>
<td>Large tree to 50 m</td>
<td>Lower slopes, deep well-drained soils, good timber tree, needs dense planting, heavy culling and form pruning to produce timber.</td>
</tr>
<tr>
<td><strong>E. rudis</strong></td>
<td>Flooded gum</td>
<td>Med-large spreading tree.</td>
<td>Seasonally waterlogged clays on flood plains, salt tolerant up to EM38 of 90; leaf miners attack it; 600-800 mm rainfall; poor form and poor timber.</td>
</tr>
<tr>
<td><strong>Eucalyptus megacarpa</strong></td>
<td>Bullich</td>
<td>Med tree to 15 m white trunk</td>
<td>Clay subsoils.</td>
</tr>
<tr>
<td><strong>Hakea oleifolia</strong></td>
<td>Olive-leafed hakea</td>
<td>Small tree to 5 m</td>
<td>Ornamental, windbreak, screen.</td>
</tr>
<tr>
<td><strong>Hakea varia</strong></td>
<td>Variable-leafed hakea</td>
<td>Medium shrub to small tree.</td>
<td>Grows in seasonally wet areas in winter wet depressions and in watercourses. Propagate by seed.</td>
</tr>
<tr>
<td><strong>Homolospermum firmum</strong></td>
<td>Common tea tree</td>
<td>Shrub to 4 m</td>
<td>Forms thickets in permanently wet areas along watercourses</td>
</tr>
<tr>
<td><strong>Hovea elliptica</strong></td>
<td>Hovea</td>
<td>Small shrub</td>
<td>Purple pea flower.</td>
</tr>
<tr>
<td><strong>Melaleuca alternifolia</strong></td>
<td>Oil ti-tree</td>
<td>Shrub</td>
<td>Commercial oil, not WA native.</td>
</tr>
<tr>
<td><strong>Melaleuca diosmaefolia</strong></td>
<td>Bottlebrush</td>
<td>Shrub</td>
<td></td>
</tr>
<tr>
<td><strong>Melaleuca incana</strong></td>
<td>Grey honey -myrtle</td>
<td>Shrub to 5 metres</td>
<td>Winter-wet depressions and along watercourses. Propagate by seed, brushing, cuttings.</td>
</tr>
<tr>
<td><strong>Melaleuca microphylla</strong></td>
<td>Small shrub to medium tree</td>
<td></td>
<td>Fringing plant for creeks, lakes &amp; swamps. Propagate by seed, brushing.</td>
</tr>
<tr>
<td><strong>Melaleuca nesophila</strong></td>
<td>Honey myrtle</td>
<td>Shrub</td>
<td>Honey, cut flowers.</td>
</tr>
<tr>
<td><strong>Melaleuca priessiana</strong></td>
<td>Paperbark</td>
<td>Small-med spreading tree to 10 m</td>
<td></td>
</tr>
</tbody>
</table>
Where to obtain seedlings

There are many native plant nurseries in most south west districts listed in the telephone book Yellow Pages under ‘Nurseries, wholesale’.

Also the Department of Conservation and Land Management has two plant propagation centres which supply large orders of native trees. The contacts are:

- Manjimup 9772 1377
- Narrogin 9881 1113

8.2 Conserve and enhance the native plant and animal species in local natural ecosystems

Buffer areas

Where properties are located adjacent to sensitive natural ecosystems, leaving fenced vegetated buffers of appropriate width around them is of prime importance.

Conservation and management of existing native vegetation in and adjacent to the horticultural farm should be included in the farm plan where appropriate (Section 1.2).

8.3 Control weeds on farm and adjacent road verges

To control weeds in native vegetation:

- Select herbicides, wetting agents and application rates carefully to minimise impacts on non-target species.
- Treat weeds at the optimum time to minimise the rate of herbicide application required.
- Replace weeds with native vegetation. It is most important that treated areas are revegetated with native species to prevent re-invasion of weeds.
- Growers are encouraged to work with their neighbours, landcare group or local shire to ‘adopt a verge’ or ‘adopt a stream’ in or near their property, which involves helping to control weeds and maintain native vegetation in it.
### Table 8.3 Control of common environmental weeds
*(Manjimup LCDC and Agriculture Western Australia, 2000)*

<table>
<thead>
<tr>
<th>Common name</th>
<th>Description/ toxicity</th>
<th>Methods of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arum lily</td>
<td>Large lily with wide, arrow shaped shiny leaves with a big white funnel shaped flower with an orange rod inside. Toxic to cattle and humans.</td>
<td>Remove all traces of root and burn them. Or Spray green leaves with 1 g Brushoff plus 25 mL wetting agent to 10 L of water before flowering.</td>
</tr>
<tr>
<td>Blackberry</td>
<td>Thorny, fast spreading dense briar bushes up to 4 m high; edible black or red berries and white flowers.</td>
<td>Spray at or before flowering in early late spring/summer with 1 g Brushoff plus 100 mL Roundup plus 25mL wetting agent in 10 L of water.</td>
</tr>
<tr>
<td>Cape tulip</td>
<td>Dark green strap like leaf, salmon pink flowers in spring, poisonous to stock.</td>
<td>Spray actively growing foliage with 1 g Brushoff plus 25 g mL wetting agent in 10 L of water.</td>
</tr>
<tr>
<td>Double gee</td>
<td>Broad leafed plant with seeds bearing 3 sharp spines</td>
<td>Spray with 0.2 g Brushoff or 100 mL Roundup in 10 L water in early winter and spring each year for at least four years. Manually remove and burn seeds.</td>
</tr>
<tr>
<td>Pampas grass</td>
<td>Large, up to 2 m round clump of grass with sharp edged leaves and long, 2-4 m stalks holding 1 m long feathery seed heads.</td>
<td>Cut off and burn flower plumes. Spray with 100 mL Roundup plus 25 mL wetting agent in 10 L water. Burn when dead and re-spray regrowth.</td>
</tr>
<tr>
<td>Watsonia and gladiolus species</td>
<td>Tall, flat leaved lilies with long, 1-2 m stems carrying orange, pale lilac, white, pink or red funnel shaped flowers and a large bulb underground. Reported to be poisonous</td>
<td>Spray with 100mL Roundup, 25 mL wetting agent in 10 L water in August-October before seeds or cormlets form. Or Use 100 g 2,2 DPA (Dalpon) plus 25 mL wetting agent in 10 L of water. (this is less harmful to native broad leaved vegetation).</td>
</tr>
</tbody>
</table>
Aquatic weeds
(Agriculture Western Australia, 1999)

Some declared species of aquatic weeds are banned throughout Western Australia. These include salvinia, water hyacinth, senegal tea, alligator weed and horsetails. There have been several recent finds, mostly around Perth, but some as far afield as Kununurra and Albany.

- Protecting agriculture and the environment is everyone’s business. Report any suspect declared plants to the nearest Department of Agriculture Western Australia office.

- Declared aquatic weeds must not be kept or sold, and must not be imported. If you have any of these plants in a pond or aquarium, they must be destroyed.

The aquatic weeds presented in this section are banned throughout Western Australia. However Agriculture Western Australia has recently found several of them in cultivation. Most finds have been around Perth, but salvinia and water hyacinth have been found as far afield as Kununurra and Albany. These plants must not be kept or sold, and must not be imported. If you have any of these plants in a pond or aquarium, they must be destroyed.

Senegal tea, alligator weed and horsetails have also been found in cultivation in Perth. Alligator weed has been mistakenly cultivated as a leafy vegetable or herb. It can grow in water, on the banks, or in gardens – it has even been found infesting lawns in eastern Australia. These weeds all have the potential to block rivers and waterways and pose a serious threat to irrigation channels. A common feature of all these weeds is their ability to spread rapidly and form a dense mat above or below the water. This mat stops light entering the water and depletes the water body of oxygen. Fish and other creatures will die and all the native plants will be shaded out.

Horsetails are also toxic to livestock. All Equisetum spp. must be destroyed.

- Do not dispose of any plant from an aquarium or pond in or near any waterway or drain.

Apart from horsetail, all of these plants can be killed by being dried out on newspaper. When the plants are dead, bury them or dispose of them with other green waste in accordance with Council by-laws. Salvinia and water hyacinth can also be killed by composting. Horsetails are extremely difficult to kill; seek advice on disposal from Agriculture Western Australia if you have any horsetail (Equisetum spp.) plants.

Aquatic weeds cost!
Apart from environmental damage they cause, aquatic weeds are extremely expensive to eradicate. It cost more than a quarter of a million dollars to eliminate hydrocotyl from Western Australia’s Canning River. In Barren Box swamp near Griffith in NSW over $1 million has been spent to eradicate a two year old infestation of alligator weed.

Prevention is the cheaper option!
Report suspect plants.

Report these plants to the local Agriculture Protection Officer:

<table>
<thead>
<tr>
<th>Fanwort</th>
<th>Lagarosiphon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horsetail</td>
<td>Alligator weed</td>
</tr>
<tr>
<td>Arrowhead</td>
<td>Salvinia</td>
</tr>
<tr>
<td>Water hyacinth</td>
<td>Leafy elodea or Dense waterweed</td>
</tr>
<tr>
<td>Sagittaria</td>
<td>Parrot’s feather</td>
</tr>
</tbody>
</table>

Submit suspect plant samples to the Weed Science Group at:

Agriculture Western Australia,
3 Baron Hay Court,
South Perth.
or by post to:
Locked Bag 4,
Bentley Delivery Centre, WA 6983.

For more information, see Agriculture Western Australia’s Weed Science Website.
8.4 Control feral animals

Humane ways of controlling feral animal pests are outlined in this section. Further advice can be obtained from the local Western Australian of Agriculture District Protection Officer or Department of Conservation and Land Management (CALM) Wildlife Officer.

- It is recommended that the following measures be taken to control feral animals:
  - Bait foxes in liaison with neighbours, Western Australian of Agriculture and Department of Conservation and Land Management.
  - Control rabbits by destroying burrows and poisoning.
  - Control feral dogs, cats and pigs by baiting, trapping or shooting.
  - Watch for new introduced pest species such as sparrows and starlings and report sightings to Agriculture Protection officers immediately.

- If control of native animals such as ring-neck parrots or kangaroos is necessary, use deterrents, netting or fences or cull as a last resort with permits from Department of Conservation and Land Management.

Poison baiting can be very effective in reducing fox numbers. Used with care, it can be safe for humans, non-target animals and the environment.

1080 poison baits
(Agriculture Western Australia, 2000)

1080 is a naturally occurring compound, which is quickly broken down in the environment. Many native animals have developed a high degree of tolerance to 1080 while foxes (and domestic dogs and cats) are very susceptible to the poison.

There is no antidote for 1080 poisoning.

A Farmnote, Guide to the Safe Use of 1080 Poisoning (Agriculture Western Australia, 2000) details important precautions when using 1080, including:

- notification of neighbours
- erection of warning signs
- careful use of 1080 in high risk areas
- responsible security and disposal of baits
- effective personal safety.

To obtain dried meat baits and eggs containing 1080 (sodium fluoroacetate), landholders must follow the following process (Agriculture Western Australia, 2001d):

- Submit a 1080 Baiting Application Form together with a map of the proposed baiting area to the local Department of Agriculture WA. An authorised officer will complete a 1080 Baiting Risk Assessment and Approval Form based on the information submitted by the landholder.

- When the authorised officer approves the application he will provide an Application Voucher to the applicant, and an approved supplier, for example a Licensed Pest Control Officer or S7 poisons retailer may supply the 1080 product on presentation of this voucher.

- The Western Australian Department of Agriculture authorised officer should ensure that the landholder has received appropriate 1080 training.

Fox baiting with 1080 poison
(Agriculture Western Australia, 2001e)

Effective poisoning periods

The most effective fox control is achieved during late winter and spring. At this time food demands are high as foxes are rearing young. Foxes are also less mobile and so reinfestation is delayed.

At other times (especially autumn) foxes are more mobile. Numbers will only be temporarily reduced by baiting as new animals will move in to replace resident animals which have been killed. Consequently repeat baiting may be required.

Community baiting drives

A district-wide campaign involving community groups can reduce the extent and speed of
reinfestation by covering a large area. Such efforts are also more cost-effective. These baiting drives rely on cooperation amongst all landholders to achieve effective fox control.

**How many baits?**

The recommended bait density is five per square km (that is, 5 per 100 hectares). Research has shown that at this rate at least 80 per cent of foxes should be killed but an increased bait density does not appear to increase fox numbers killed. When areas of fox activity can be specifically targeted, less baits will be required.

**Where to lay baits**

Individual baits should be placed at least 200 m apart, otherwise one fox may find and eat more than one bait. Baits should be laid at strategic points including:
- where fox tracks are regularly seen
- along water courses, tracks and at fencelines where foxes enter paddocks
- at prominent points within paddocks (jutting corners, rock piles, posts)
- under or near carcases visited by foxes.

**How to lay baits**

The position of all baits should be marked with marker tape, pegs or something similar so they are easy to recover. Bait recovery is strongly recommended, particularly in High Risk Areas and where pets and other animals may encounter baits.

In High Risk Areas (farms and reserves near closely settled areas), meat baits must always be:
- buried about 10 to 20 mm below the soil surface to reduce the risk of poisoning non-target animals that seldom dig for baits, or
- tethered by a length of cord or fishing line to prevent them being moved (for example, by birds).

In Low Risk Areas (typical rural properties with low numbers of people), meat baits can be buried, tethered or hidden under vegetation, rocks or fallen timber.

In all areas, eggs baits should always be buried 20 to 100 mm below the soil surface to decrease hazards to non-target animals.

**Improving the percentage of baits taken**

- Individual baits should be available to foxes for about 10 days.
- Check baits at least every two days to assess ‘take’.
- If a bait is taken, keep replacing it until no more are removed.
- Move uneaten baits to areas where others have been taken.
- Baits laid on a broken scent trail are more quickly located by foxes.

**Baiting evaluation**

Foxes poisoned with 1080 are seldom located. This can give the false impression that baiting is not effective. If baits are laid correctly, a count of the baits taken will give a good estimate of the number of foxes killed.

**Options for rabbit control**

(Agriculture Western Australia, 2001c)

Each year rabbits cause an estimated $600 million worth of damage to agriculture. They also cause serious erosion problems, prevent native vegetation from regenerating, attack domestic gardens and undermine farm sheds and other buildings. Landholders planning to preserve native vegetation need to control rabbits first. Even landholders not growing crops are still legally obliged to control rabbits to protect their neighbours’ land.

The key to success is persistence. One-off efforts produce only short-term results as rabbits can produce many offspring and recover quickly after control.

Maximum effectiveness is achieved by combining appropriate control methods. Best control is achieved in late summer when rabbit numbers are already low and other feed is limited.
A district-wide campaign can reduce the problem of re-infestation by covering a large area. Sometimes it will not be possible to use poison but other methods are available. Areas intended for planting or conservation efforts, especially near rabbit harbourage, should be thoroughly checked for rabbit populations. This is particularly important in areas where rabbits have previously been a problem.

Rabbit activity is usually indicated by scratchings, dung heaps and active burrows or warrens. More revealing checks can be made late in the day or at night by spotlighting when rabbits are active and more observable.

**1080 baits**

Baiting is the most cost-effective way to reduce rabbit populations, particularly over large areas. Several types of 1080 rabbit bait are available. When approved, landholders may lay 1080 baits themselves.

1080 is quickly broken down in the environment. Many native animals have developed a high degree of tolerance to 1080 but domestic stock and pets are very susceptible to the poison in both the baits and poisoned rabbits.

**Pindone baits**

Pindone is an anticoagulant with an effect similar to products used in some rat poisons. It can sometimes be used near settlements where pets might be at risk from 1080, because an antidote is available for pindone.

Pindone poses a risk to native animals including kangaroos, birds of prey and perhaps bandicoots. The poison must not be used in the presence of these animals.

**Warren fumigation**

Rabbits use warrens as refuges and for breeding. Fumigation is the best method to use when a few rabbits live in widely scattered warrens or inaccessible areas. Fumigant tablets are placed in burrows to release poisonous phosphine gas.

**Warren ripping**

Areas where warrens have been destroyed by cross-ripping the soil are much less likely to be re-colonised. A tractor-mounted ripper is used to penetrate the soil to a depth of at least 60 centimetres.

**Harbourage destruction**

Areas that rabbits use for harbourage/refuge include rock piles, deadfall timber and stumps, old buildings and abandoned farm machinery. Such material should be removed, buried or surrounded with rabbit-proof fences.

**Rabbit-proof fencing**

Rabbit-proof fences can be effective in preventing animals moving into or re-infesting an area. Well-maintained fences can provide a permanent solution to rabbit problems. Fencing can also be used to contain rabbits in an area where they can be more efficiently poisoned.

**Myxomatosis and rabbit calicivirus disease (RCD)**

These viruses have been introduced to reduce rabbit numbers, and can be difficult to manipulate. Their benefits can be enhanced by following up immediately with other control methods.

Shooting, trapping and the use of ferrets can be useful additional tools when very few rabbits are present.

**Further information**

Contact any Department of Agriculture Western Australia office.

**Control of pest native animals**

It is illegal to kill most native animals. Good fencing and netting to protect crops is the most satisfactory option from an environmental perspective. However, it is occasionally necessary to control excessive numbers of some native animals if they are damaging crops significantly. Permits must be obtained from the Department of Conservation and Land Management for culling to be conducted.
If control of native animals such as ring-neck parrots or kangaroos is necessary, use deterrents, netting or fences or cull as a last resort with permits from the Dept of CALM.

The starling- an introduced pest threat
(Agriculture Western Australia, 1999)

Watch for new introduced pest species such as sparrows and starlings; report sightings to Agriculture Protection officers.

In Australia the starling is a pest which eats soft fruits and cereals and destroys feed by defecating on it. It is also a pest of urban areas, nesting in houses and tree holes, and has been implicated in the deaths of roost trees and the decline of native species. Evidence from established wine growing areas indicates that ten to fifteen per cent of crops can be lost due to damage caused by starlings.

If starlings ever became established in WA they would cause severe damage and be extremely difficult to eradicate or manage. It is for these reasons that starlings cannot be introduced or kept and are eradicated when found in WA.

The starling (Sturnus vulgaris) is also known as the common of European starling. Starlings have been introduced and become established in North America, Jamaica, South Africa, New Zealand and south-eastern Australia. Starlings were released near Melbourne in the late 1850s and are now distributed throughout all of Victoria, New South Wales and Tasmania. They are also found in many parts of Queensland and South Australia, but are not established in WA.

Since 1971 small flocks have crossed into south-east WA via the Nullabor Plain but so far all of these have been removed by Department of Agriculture Western Australia officers. Starlings have also been found in other parts of WA, most recently a starling was found at the Cadjebut mine in the Kimberley region.

Identification

Starlings are stocky birds with fine, pointed beaks and short tails. They are about 21 cm in length – slightly bigger than a welcome swallow. They have glossy black feathers with a green, purple, blue or bronze sheen. In autumn, the feathers are tipped with buff or white, which gives starlings a spotted appearance. By spring the birds have lost their spotted look and appear glossy black. The beak is a blackish colour for most of the year, but it is yellow while the birds are breeding. Young birds are a dull mouse-brown colour but they may appear patchy as they moult to adult plumage.

Starlings prefer open grassland for feeding but they can be found in a wide variety of habitats from urban to rural. They are most frequently seen on the ground where they waddle along; they do not hop. Flocks are often seen on the wing wheeling and turning quickly in tight groups.

The sparrow
(Agriculture Protection Board, 1991)

The house sparrow is a grey and brown bird about 15 cm long, similar in size to the welcome swallow. The male has a grey crown and white cheeks with black over the bill and on the throat and upper chest, with a black bill. The female has a brown bill, the upper body is dusky brown and there is almost no almost black on the throat.

The tree sparrow is similar but slightly smaller. Sparrows feed in flocks of several hundred, damaging crops and fruit and pulling up germinating seed. They compete with and displace native bird species and carry diseases.

If you see birds that might be starlings or sparrows, contact the nearest Department of Agriculture Western Australia office.
References

Agriculture Western Australia, 1997. Preparing sites for tree planting in the greater than 600 mm rainfall zone of Western Australia. TreeNote No. 2


Agriculture Western Australia, 2000, Guide to the Safe Use of 1080 Poisoning. Farmnote


Agriculture Western Australia, 2001e. Fox Baiting. Farmnote 59/2001


Agriculture Western Australia, 1999. Wetlands not Weedlands. Weednote 1/99


Rose, B., Dewing, J and Cranfield, R., 2001. Table of Local Native Species for Planting Around Streams and Dams in >800 mm Rainfall Southwest. (Unpublished).
Riparian and remnant native vegetation provides a refuge for native fauna species.

Wetland surrounded by a vegetated buffer – a valuable flora and fauna area.
SECTION 9

Waste Management
Waste Management

This section outlines practices for waste minimisation by recycling and re-use.

Waste materials generated during modern horticultural operations fall into three categories:

1. Residual farm chemicals, for example residues left in empty containers and on spraying equipment.
2. Solid non-biodegradable wastes, for example empty chemical containers, plastic wrapping, plastic mulch and plastic irrigation pipe, scrap metal.
3. Biodegradable wastes, for example crop residues, manures, and domestic putrescible wastes.

All of these wastes can be managed so that they will not pollute the environment, by using the recommended practices described below.

9.1 Reduce, re-use and recycle wastes where possible

Used chemical containers

All farm chemicals are now packaged in containers that are either:

- Re-useable
- Recyclable, or
- Water-soluble packs that dissolve in the spray tank.

All of these containers can be disposed of without harm to the environment for re-use or recycling.

- Never leave used, unwashed chemical containers lying around, where they may poison people or stock, contaminate of food products or pollute water bodies.

- Do not burn any chemical containers. This practice produces toxic emissions and is illegal.

- Do not bury empty chemical containers on the farm. Plastic materials will not break down in the soil and chemical residues may contaminate groundwater.

Some suppliers of large containers of farm chemicals now offer a return packaging policy for their re-useable containers. Using and returning re-useable containers is the best practice and should be adopted where possible.

All chemical containers that are not returnable are recyclable. If rinsed and recycled, chemical containers do not pose a threat to the environment.

How to properly rinse

(Avcare, 1999)

There are three acceptable methods of rinsing chemical containers.

Manually rinsing by triple rinsing

- Triple rinse all used chemical containers. Return the rinse water to the mixing tank.
  - When preparing sprays, empty the container into the sprayer mixing tank and drain for at least 30 seconds until empty.
  - Recommended practice is to fill emptied containers about 1/5th full with water and shake or roll the container for at least 30 seconds, with cap on. Add the rinse water to the chemical tank in the place of an equivalent quantity of make-up water.
  - Repeat at least three times.
  - Check the container thread, cap and outside of container and rinse with a hose into the spray tank.
  - Let the container dry completely and replace the cap.

Pressure rinsing

Pressure rinsing is generally faster and easier than manual triple rinsing and can be used with plastic (non-refillable) and non-pressurised metal containers.

A special nozzle designed to pierce the container is attached to the end of a hose.
- Remove the cap from the container and empty contents into the spray tank, allowing to drain for at least 30 seconds after the flow reduces to drops.
- Insert the pressure nozzle by puncturing through the lower side of the container. Turn the water on and rinse until the rinsate coming from the container is clear (at least 30 seconds). Gyrate the nozzle to rinse all inside surfaces.
- Rinse the outside of the container, thread and cap and allow to dry as for triple rinsing (above).

Probes and 'sucker-flusher' transfer systems

Some farmers use chemical concentrate transfer systems that incorporate a flushing operation. These systems typically involve connection of a probe to the container opening to extract the chemical concentrate.

These types of systems have the added advantage of reducing significantly the potential for exposure of the operator to the concentrate while transferring it to the spray tank.

When the contents are removed, a rinse cycle is activated. In all cases the manufacturer’s recommendations should be followed. Generally speaking the rinse cycle should last at least 30 seconds. Check and rinse the outside of the container, thread and cap as for triple rinsing above.

DrumMuster™ scheme for recycling of used chemical containers

(Avcare, 1999)

There are adequate facilities available for growers to recycle their used chemical containers. The DrumMuster program has collection points in most south west areas and the shires provide details of the local collection venues.

- Recycle all rinsed chemical containers by either returning them to the manufacturer or depositing them at a DrumMuster collection point.

Enquire at the local shire council for details of the local DrumMuster program.

For some shires, such as Manjimup, the DrumMuster collection is at the local refuse and recycling centre. Farmers can ring the site manager to arrange a time to deposit drums.

DrumMuster is the national program for the collection and recycling of empty, cleaned, non-returnable crop protection and animal health chemical containers over one litre or kilogram in content.

It has been set up to provide finance and planning to councils across Australia for chemical drum recycling. DrumMuster is a solution to the disposal problem of containers for farmers and a cleaner environment for the community. It is cost-neutral and provides a service to ratepayers in that less containers end up as landfill in municipal tips.

DrumMuster involves farmers, councils, chemical manufacturers and resellers.

Manufacturer

- Identifies non-returnable containers by applying DrumMuster sticker
- Pays 4 cent/ L or kg levy to DrumMuster and invoices distributor/ reseller

Containers that are designed for multiple use or to minimise waste (such as water soluble packaging that dissolves in the spray tank) are not subject to the DrumMuster levy.

Reseller

- Explains DrumMuster levy to farmer.
- Invoices 4 cent/ L levy to farmers/farm chemical users.

Farmer

- Flushes, pressure rinses or triple rinses used containers.
- Brings containers with DrumMuster sticker into DrumMuster collection centre on designated days.
Section 9

Table 9.1 WA shires participating in the DrumMuster scheme

| Augusta-Margaret River Shire Council | Harvey Shire Council |
| Beverley Shire Council | Jerramungup Shire Council |
| Boyup Brook Shire Council | Katanning Shire Council |
| Bridgetown-Greenbushes Shire Council | Kent Shire Council |
| Bunbury City Council | Kondinin Shire Council |
| Busselton Shire Council | Manjimup Shire Council |
| Capel Shire Council | Merringin Shire Council |
| Chittering Shire Council | Nannup Shire Council |
| Collie Shire Council | Narembeen Shire Council |
| Coorow Shire Council | Nungarin Shire Council |
| Cuballing Shire Council | Pingelly Shire Council |
| Cunderdin Shire Council | Quairading Shire Council |
| Dalwallinu Shire Council | Wagin Shire Council |
| Dardanup Shire Council | West Arthur Shire Council |
| Donnybrook-Balingup Shire Council | Wickepin Shire Council |
| Dumbleyung Shire Council | Williams Shire Council |
| Esperance Shire Council | |
| Gnowangerup Shire Council | |

The Council
- Establishes collection centre and informs farmers of dates it will be open.
- Inspects containers and accepts cleaned containers.
- Employs materials recovery contractor to process empty containers.
- Costs eligible to be reimbursed by DrumMuster.

The Processor
- Processes empty containers, sending material back into recycling stream
- Costs eligible to be reimbursed by DrumMuster.

DrumMuster is a joint initiative developed under the Industry Waste Reduction Scheme, by the National Farmers Federation (NFF), Avicare, the Veterinary Manufacturers and Distributors Association (VMDA) and the Australian Local Government Association (ALGA).
Disposing of residual chemicals, oils and dip solutions

Many growers have containers of residual chemicals that can no longer be used because they are out of date, no longer registered for use or unidentified. These pose a threat to human health and the environment, particularly if they are in unlabelled or corroding containers.

- To avoid having left-over chemicals:
  - Only purchase enough of the chemical for the job on hand.
  - Avoid mixing more spray than is required. Systems that automatically inject the pesticide into the spray line are recommended.

Residual pesticides and other farm chemicals that can no longer be used should not be kept on the farm and particular care needs to be taken in their disposal. The only safe way to dispose of them is through the ChemCollect™ scheme.

- Place containers of residual chemicals in larger leak proof containers for safe storage and transport. Keep them in a locked chemical shed until they can be taken to the nearest ChemCollect™ venue for disposal.

ChemCollect™ is a scheme for the safe collection of residual chemicals. Enquiries may be directed to local government authorities or the Department of Environmental Protection (DEP) for details of collection points and times.

The Code of Practice ‘Disposal of Pesticide Residues from Pesticide Spray Applications’ by the Health Department of Western Australia offers practical advice to pesticide users.

Burning of oils is not acceptable as toxic air pollutants are produced. Neither should used oils be emptied onto the ground as they pollute soil and water for long periods of time. Used engine oils may also contain contaminants such as metal particles, heavy metals, fuel, rust and carbon.

- Approved practices for disposal of dip solutions are:
  - Pre-treating the solution and spreading it onto pasture or cereal crop, where it will be biodegraded naturally. Avoid grazing the pasture for 28 days. Or
  - Store in a safe chemical storage tank for collection and off-site disposal by an approved hazardous waste contractor.

Disposal of plastic and other solid wastes

Most plastics, such as the polyethylene used for agricultural plastic sheeting and irrigation tube, do not degrade. They take up large volumes in landfill sites, and are classified as hazardous wastes in some States.

Burying of polyethylene plastic waste on-farm is not a good option, as it will remain undegraded indefinitely and may be unearthed, creating problems in the future.

Low temperature (open air) burning of plastics is illegal because toxic gases and particulates are produced.
Currently the best option for disposal of plastic waste is recycling. In the United Kingdom the plastics industry has started a plastics recycling scheme, funded by a levy on agricultural plastics but such a scheme is not yet operating in WA.

However, plastic sheeting can be recycled, although plastic film is bulky and difficult to handle. To make handling easier it can be baled using standard hay balers, or purpose-built waste balers.

Biodegradable plastic mulches, which can be ploughed in and break down in the soil, are being developed. They should be used in preference to polyethylene mulches where possible and when commercially available.

- Separate plastic wastes into their plastic groups. Press and bale the waste using a commercial baling unit. In some cases, hay balers can be used. Deposit the bales at one of the many recycling depots provided by local government.

- Use biodegradable plastic mulch products when they become commercially available.

Scrap metal waste has a lasting negative aesthetic impact when dumped in the environment. This is unnecessary as many scrap metals have an economic value.

- Separate scrap metals into metal groups and re-use on farm, deposit at recycling depots or have them collected by scrap metal companies.

The lead contained in batteries is a toxic heavy metal that can contaminate land and water resources, resulting in poisoning of stock and native fauna. Lead can be absorbed through the human skin. Batteries should not be buried or mixed with other wastes. Lead can easily be recycled.

- Use the facilities provided by local government or scrap metal companies to deposit batteries for recycling.

### Disposal of plant, putrescible and domestic wastes

*Do not dump putrescible wastes in heaps to rot.*

Discarded vegetables or other putrescible wastes are a potential source for fly breeding and vermin.

*Do not dump garden or any other solid waste in bushland.* Some domestic plant species can shoot and have the potential to become environmental weeds within areas of native vegetation.

*Do not bury green wastes in landfill.* This practice causes the waste to break down anaerobically, producing methane, which is a powerful greenhouse gas (Section 10.3).

#### Green wastes

The best practice options for disposal of green wastes on farm are:

- Vegetable wastes and crop residues can be chopped up, spread in the paddock and incorporated into the soil. Used in this way they increase soil organic matter and improve soil health (Section 2.2 ‘Increasing soil organic matter’).

- Green wastes are readily composted under controlled conditions and the compost may ultimately be returned to the soil.

Composting can be conducted on-farm. If conducted correctly, with acceptable mixes of feed-stocks and regular aeration, the high temperatures generated prevent the breeding of flies and vermin (Section 2.2 ‘Compost for sustainable horticulture production systems’). Compost heaps can be aerated by turning with a front-end loader or custom-built machine. Composting should be conducted away from residential areas and water resources.

#### Domestic wastes

Domestic wastes are often a mixture of paper, plastic, metal and putrescible waste that is difficult to sort but requires regular disposal.
Where possible, use local government refuse and recycling facilities to dispose of domestic waste.

In situations where this is impracticable, the alternative is to bury it on the farm at a suitable site. The water table should be more than 3 metres from the surface, the site should be well away from waterways and wetlands and preferably within clay subsoils.

This alternative should only be used where household wastes are not contaminated by farm chemicals and in circumstances where it is impractical to use shire refuse and recycling facilities.

Compact the landfill and cover it with at least 300 mm of soil, to prevent breeding of flies and vermin.

Disposal of wastewater

Wastewater includes contaminated water and drainage from processing or storage sites. It may contain contaminants such as pathogens, pesticides and high levels of nutrients and chemicals.

Drain wastewater into impermeable storage/ treatment ponds and dispose by controlled on-site irrigation.

Irrigating vegetated land with nutrient-rich wastewater

(Water and Rivers Commission, 2002)

Scope

These notes apply to the irrigation of treated effluent from intensive animal industries, recycled run-off from agricultural land, and treated municipal wastewater, which is applied to land to promote the growth of healthy vegetation.

These notes do not apply in sensitive areas where detailed risk assessment is necessary, i.e. in Public Drinking Water Source Areas (PDWSAs), within 200 metres of conservation value wetlands, managed estuaries, or where the depth to groundwater is less than 2 metres.

PDWSAs include Underground Water Pollution Control Areas, Water Reserves and Public Water Supply Catchment Areas declared in accordance with the Metropolitan Water Supply, Sewerage and Drainage Act 1909, or the Country Areas Water Supply Act 1947.

Preamble

The following requirements reflect the Water and Rivers Commission’s current position. They are recommendations only and may be varied at the discretion of the Commission.

Irrigation of wastewater with inadequate planning has the potential to cause the following impacts:

- Soil erosion and turbidity in water resources
- Leaching of nutrients into water resources which can produce eutrophication and toxic effects
- Salinisation and waterlogging to land

Table 9.2: Vulnerability categories for soils and environments receiving wastewater

<table>
<thead>
<tr>
<th>Vulnerability</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Coarse sandy soil/gravel draining to surface water with <strong>moderate/high</strong> eutrophication risk.</td>
</tr>
<tr>
<td>Category B</td>
<td>Coarse sandy soil/gravel draining to water with a <strong>low</strong> risk of eutrophication.</td>
</tr>
<tr>
<td>Category C</td>
<td>Loam/clay soil (PRI &gt;10) draining to water with <strong>moderate/high</strong> eutrophication risk.</td>
</tr>
<tr>
<td>Category D</td>
<td>Loam/clay soil (PRI &gt; 10) draining to water with a <strong>low</strong> risk of eutrophication.</td>
</tr>
</tbody>
</table>

Note: PRI means Phosphorus Retention Index, a scientifically determined measure of the phosphorus retention capacity of surface and near surface soils.
Site selection

Proponents intending to irrigate wastewater to land should design systems suited to the infiltration capacity and the nutrient retention ability of the soil.

Soil characteristics will influence the rate and frequency of irrigation, and should be taken into account to minimise waterlogging and the leaching of excess nutrients into waterways and sub-surface aquifers.

Irrigation rates

Irrigation schemes should be managed to avoid build-up of salts in the soil. Ideally, wet season rainfall should flush accumulated salt away from the site prior to the commencement of the seasonal irrigation scheme.

Irrigation rates should take into consideration seasonal evapo-transpiration (ET) rates and the water requirements of the selected vegetation. Watering requirements can be calculated at 60-80% of pan evaporation depending on application method. Rates will also vary according to the intended cropping and species uptake rates. Factors including soil type, soil moisture content, irrigation method, land slopes and depth to water table will also influence application rates.

For clay soils, irrigation rates up to 5 mm/hour are reasonable, while sandy sites may accept 15 mm/hour without run-off. Irrigated areas should ideally have a slope of 0.5 – 10% to avoid ponding or erosion. Irrigated water should always be applied evenly and the irrigated area allowed to dry out for 24 hours between applications during hot, dry weather, and 3 to 7 days during cool, wet weather.

Soil nutrient status

Wastewater should not be applied to sites where there has been extended application of nutrients such as annual applications of superphosphate or urea or long term grazing of animals, unless the soil nutrient status has been determined and considered in the site irrigation management plan.

Application criteria

Wastewater containing volatile (degradable) organic matter should not be applied at rates exceeding 30 kilograms/hectare/day expressed as Biochemical Oxygen Demand (BOD), to avoid offensive odours. For wastewater with BOD concentrations exceeding 150 mg/L, further biological stabilisation methods should be used prior to irrigation. Heavy metals in wastewater should not exceed the irrigation water quality criteria in ANZECC’s Australian Water Quality Guidelines for Fresh and Marine Waters (1992).

Irrigated areas should normally be at least two metres above the highest seasonal groundwater table and have no ponded irrigation water present on the site.

Table 9.3 Recommended maximum nutrient (nitrogen as N and phosphorus as P) application criteria for irrigation water

<table>
<thead>
<tr>
<th>Vulnerability Category</th>
<th>Nitrogen (N)</th>
<th>Phosphorus (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Application rate kg/hectare/year</td>
<td>concentration mg/L</td>
</tr>
<tr>
<td>A</td>
<td>140</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>180</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>300</td>
<td>19</td>
</tr>
<tr>
<td>D</td>
<td>480</td>
<td>30</td>
</tr>
</tbody>
</table>
Nutrient concentrations in Table 9.3 are based on an average of 50 mm (500 kL/ha) of water applied/week over 32 weeks/annum and no other nutrient sources. Facilities for the storage of wastewater should be available over the wet season, or when precipitation meets the water needs of the vegetation.

The application criteria are based on these quantities of nitrogen and phosphorus being available to promote viable vegetation growth and needed by the selected plant species. Nutrients should be applied to coincide with the seasonal needs of the selected vegetation species. If nutrients are applied at times when plants cannot uptake them, leaching of nutrients to water resources is likely to result.

**Biological contaminants**

Advice should be sought from the Health Department concerning irrigation constraints to minimise the incidence of disease-causing organisms, i.e., bacteria, intestinal worms, protozoa and viruses.

**Salts, metals, foaming substances, petroleum derivatives, pesticides and radioactive substances**

All these materials at various concentrations may be harmful to vegetation or other aspects of the receiving environment. Irrigation scheme planners and operators should determine concentrations of contaminants which may be present in waters to be irrigated.

The Commission uses the *Australian Water Quality Guidelines for Fresh and Marine Waters* published by ANZECC (1992) as a guide to the quality requirements in water resources, which may receive run-off or leachates from irrigated land. This document contains tables which state criteria for various uses of water resources. Assistance should be sought from qualified and experienced people who are able to assess the likely fate of these contaminants when they move in the environment after application to land.

The Commission employs environmental modelling techniques and risk assessment procedures to judge whether such contaminants are in sufficient concentrations to cause harm.

**Monitoring and reporting**

The Health Department and Water and Rivers Commission normally require chemical and microbiological monitoring of reclaimed water quality depending upon the extent of application and access afforded to the public.

Monitoring must be able to assess water quality at three stages: the point of supply, that is the point of entry to the reclaimed water system; the quality recorded in water resource monitoring facilities; and through periodical soil sampling.

The proponent should monitor the following parameters:

- The quantity of wastewater irrigated (minimum of weekly intervals), and record areas irrigated
- The pH, salinity of wastewater at monthly intervals
- Total nitrogen and phosphorus in the wastewater at the commencement of irrigation season and at 3 monthly intervals until irrigation ceases
- Other contaminants in wastewater should be determined annually. Records of data should be retained on site for scrutiny by regulatory bodies.

For small, rural or remote communities where it is not feasible to apply normal microbiological monitoring, frequencies may be reduced. These would be negotiated on an individual basis on application for approval of a scheme.
References

Avcare Website http://www.avcare.org.au

Avcare, 1999. Proper Management of Empty farm chemical containers. Brochure


Treated liquid effluent can be irrigated onto paddocks.
SECTION 10

Minimising Air Pollution
Minimising Air Pollution

The main issues in air pollution for horticulture are at a farm, neighbourhood and global scale. They are, for the farm and neighbourhood:

- Chemical spray drift
- Odours and flies

At the global scale, the issue of greenhouse and ozone depleting gases emission relates to vegetable and potato growing as for other industries, to the extent that these gases are produced by the operation.

Chemical spray drift is discussed in detail because it has the highest potential impact on the surrounding neighbourhood. All growers should adopt the practice of spray planning, with spray drift awareness zones.

10.1 Minimise spray drift from the application of pesticides

Spray drift of pesticides
(Schulze et al, 2001)

Spray drift of pesticides away from the target is an important and costly problem facing both commercial and private applicators. Drift causes many problems including:

- Environmental contamination, such as water pollution and illegal pesticide residues.
- Damage to susceptible off-target sites.
- A lower application rate than intended which can reduce the effectiveness of the pesticide, wasting pesticide and money.

Drift occurs by two methods: vapour drift and particle drift. This section mainly focuses on conditions that cause particle drift and methods to reduce the drift potential from spraying pesticides.

Drift dynamics

Particle drift is the actual movement of spray droplets away from the target area. Many factors affect this type of drift, but the most important is the initial size of the droplet.

A solution sprayed through a nozzle divides into droplets that are spheric or nearly spherical in shape. Droplets smaller than 100 microns are considered highly driftable and are so small that they cannot be readily seen unless in high concentrations such as fog.

Small droplets fall through the air slowly, and are carried farther by air movement. With a greater proportion of the total spray volume in smaller droplets, the potential drift onto off target sites increases.

Small droplets also evaporate quickly, leaving minute quantities of the pesticide in the air.

Larger droplets are more likely to be deposited on the intended target.

Selecting equipment and nozzle types
(Schulze et al, 2001)

All nozzles produce a range of droplet sizes. Some spraying equipment produces large amounts of very fine droplets below 100-150 microns, which are the main cause of spray drift. A droplet size in the range 300-500 microns will ensure good coverage and minimise spray drift.

The small, drift-prone particles cannot be eliminated but they can be reduced and kept within reasonable limits.

Altering droplet size

Nozzle type, orifice size and operating pressure are the three factors that affect droplet size.

Nozzles produce a wide range of droplet sizes. A nozzle that can produce only one size of droplet is not available at the current time. Therefore, the goal in the proper application of pesticides is to achieve a uniform spray distribution while retaining the spray droplets within the intended target area.

Examples of different nozzle types and the way they produce droplets are:

- Fan nozzles force the liquid under pressure through an elliptical orifice and the liquid spreads out into a thin sheet that breaks up into different-sized droplets.
- Flood nozzles deflect a liquid stream off a plate that causes droplets to form.
- Whirl chamber nozzles swirl the liquid out an orifice with a circular motion that aids the droplet formation with a spinning force.
- Full cone nozzles produce the largest droplets which results in lower drift potential.

For many herbicide applications, a large droplet will give good results but for good plant coverage (i.e. post emergence application), large droplets may not give good pest control.

☐ Select suitable equipment and operate it properly to minimise spray drift.

Spray nozzles

☐ Use larger orifice sizes where possible. Avoid using nozzles that produce large amounts of very fine droplets under 150 microns.

☐ Use drift reduction nozzles where possible, for example nozzles that produce bubbles that burst and produce fine droplets only when they contact the crop.

☐ Nozzle spacing- as a general guideline, do not exceed a 75 cm nozzle spacing or else the spray pattern uniformity begins to degrade. To allow low boom heights and attain uniform coverage, use a combination of nozzle spacing, height and direction which gives 100% overlap.

☐ Wide angle nozzles are preferred, as these can be used with low boom heights and still give uniform coverage.

Boom height and travel speed

Operating the boom as close to the sprayed surface as possible (within manufacturer’s recommendation) is a good way to reduce drift. A wider spray angle allows the boom to be placed closer to the target. Booms that bounce will cause uneven coverage and drift. Wheel-carried booms stabilise boom height, which will reduce the drift hazard, provide more uniform coverage, and permit lower boom height. Shielded booms also reduce the drift from excessive air movement from travel speed and wind.

☐ When using conventional boom sprays, operate the boom at a low height and keep it stable. Using wide-angle nozzles enables lower boom height.

☐ Keep travelling speed below 8 km/hour.

☐ Use shielded booms and shroud covers when band spraying, especially for operations near residential areas.

Setting up spray equipment

Spray equipment can be set up to reduce the amount of over-spray and spray drift that may lead to off-site contamination. All sprayers need to be calibrated, with trial runs (using water) to ensure the rate of application is even and correct before application of chemicals commences.

Spray Pressure

☐ Avoid using high operating pressure as it creates finer droplets and more spray drift. The recommended maximum for conventional broadcast spraying is 40 PSI (276 kPa) and sprayers can usually be operated at 25-35 PSI (172-240 kPa).

Spray pressure influences the formation of the droplets. The spray solution emerges from the nozzle in a thin sheet, and droplets form at the edge of the sheet. Higher pressures cause the sheet to be thinner and the sheet breaks up into smaller droplets.

*If the application rate needs to be increased select a higher volume nozzle tip with a larger orifice size, rather than increasing the pressure.*

For example, if an operator tried to double the flow rate through the same nozzle, a four-fold increase in pressure would be required. This action would produce many more small droplets, and greatly increase the potential for spray drift.

Calibration of boom sprays

Calibration of a sprayer is the process of ensuring that the sprayer is operating the way the operator wants. That is, if the operator wants to apply 40 L/ha, then the sprayer is applying 40
L/ha evenly distributed across the boom. Calibrate the sprayer at least at the start of every season and preferably more often.

If the sprayer is not properly calibrated, money will be wasted by either the application of more chemical than necessary or a poor pest kill. Directions for calibration are given in the publications listed under ‘Further reading’.

**Following directions for use of chemicals**

- **Read and follow the pesticide label.**
  
  Instructions on the pesticide label are given to ensure that pesticides are used safely and effectively with minimal risk to the environment. Each pesticide is registered for use on specific sites or locations.

  Surveys indicate that approximately 65% of the drift complaints involved application procedures in violation of the label. Apply a pesticide only if economic thresholds warrant an application.

- **It is important to use pesticides and spray additives within label guidelines.**

  Spray additives include surfactants, which influence droplet size and pesticide effectiveness, and wetting agents, which have been shown to reduce spray drift. Some spray additives act as spray thickeners when added to a spray tank. These materials increase the number of larger droplets and decrease the number of fine droplets. They tend to give water-based sprays a ‘stringy’ quality and reduce drift potential.

  Non-volatile chemicals are much less likely to cause spray drift. Information on volatility can be found on the Material Safety Data Sheets.

- **Use low or non-volatile pesticides in preference to volatile types.**

  Droplets formed from an oil carrier tend to drift further than those formed from a water carrier because oil droplets are usually smaller, lighter and remain airborne for longer periods but don’t evaporate quickly.

**Weather conditions**

(Schultz et al, 2001; Department of Agriculture Western Australia, 2001)

**Wind Speed and direction**

The amount of pesticide lost from the target area and the distance it moves both increase with wind velocity. As a rule of thumb, spray drift is manageable when wind velocity is under 15 km/h if appropriate equipment is used. Using shielded booms and lower boom height will minimise the effect of wind on spray drift.

- **Monitor and record wind direction, wind speed, temperature and humidity prior to (and if necessary during) every spraying operation and check that they are within acceptable limits.**

- **Avoid spraying when wind speed is greater than 15 km/h or blowing towards sensitive crops, gardens, dwellings, livestock, water sources or wetlands.**

  Wind speed should be between about 3 and 15 km/hr for most operations. If necessary, use an anemometer to accurately measure wind speed.

  Be aware that spraying when the wind is light and variable, or is dead still, can lead to unpredictable spray drift.

  Do not spray when the wind is blowing towards sensitive crops or areas, unless an appropriate vegetation buffer or buffer distance is imposed. Where possible, spray with a cross-wind working towards the unsprayed area. Be alert to changes in wind direction and be prepared to modify or cancel a spray operation as necessary.

**Air Stability**

- **Avoid spraying in conditions where temperature inversions exist.**

  Vertical air movement is often overlooked when choosing suitable conditions for spraying. **Temperature inversion** is a condition where cool air near the soil surface is trapped under a layer of warmer air. This can keep spray drift close to the ground where it is most likely to affect people in the surrounding area.
A strong inversion potential occurs when ground air is 1-3˚C cooler than the air above. Temperature inversions sometimes occur on still mornings when cold air forms a layer near the ground, preventing the normal upward dispersion of air pollutants.

Observing smoke is a way to identify inversions. Smoke plumes moving horizontally close to the ground would indicate a temperature inversion. This can be detected by the use of a smoke generator.

Spray drift can be severe under inversion conditions. Small spray droplets can be suspended and move several miles with a gentle breeze to susceptible areas. Spraying should not take place when conditions indicate the risk of an inversion.

Relative Humidity and Temperature
Low relative humidity and/or high temperature conditions cause faster evaporation of spray droplets and thus, a higher potential for drift. During evaporation, the droplets become smaller, so evaporation increases the drift potential.

Avoid spraying in conditions of high temperature and low humidity.
Spray during lower temperature and higher humidity conditions. As a rule of thumb, if the relative humidity is above 70%, the conditions are ideal for spraying. However, a relative humidity below 50% is critical enough to warrant special attention.

Aerial spraying
(Department of Agriculture Western Australia, 2001)
Of all spray application methods, aerial spraying presents the greatest risk of spray drift. Aerial spraying in inappropriate weather conditions or using poor practice can cause airborne contamination up to kilometres from the site of application.

Do not conduct aerial spraying unless weather conditions are optimal.

Be aware of those pesticides for which regulations prohibit aerial application.
- Spray only when the aircraft is straight and level above the crop.
- Fit smoker devices to aircraft to monitor changes in wind direction and turbulence.
- Fit micronair spray nozzles with transducers to monitor rotational speed.
- Consider spraying only the upwind section of the area in order to provide a practicable buffer distance, having regard for the chemical, its formulation, the sensitivity of the adjoining area and the wind speed and direction.

The spray operator’s duty of care to minimise air pollution
(Extracted from: Department of Agriculture Western Australia, 2001)
Operators should conduct operations according to the best practices outlined in this section. Operators should also be aware of their duty of care to:

- Be responsible for the safety of workmates, the general public and the environment, before, during, and after use of agricultural chemicals. This responsibility is at two levels:
  - A statutory responsibility under current Commonwealth and State legislation.
  - A common law ‘duty of care’ to ensure that no harm is done to oneself, to any other person, or to their property.

- Not carry out a task known to be illegal or unsafe. If aware of any risks to safety for which they have not been adequately trained, or which they consider are not being managed effectively, cease the task until corrective action has been taken.

- Ensure that they have received proper training in the safe handling and application of farm chemicals. Table A1 in Appendix 1 includes suitable training courses.
• If applying chemicals as a contractor, obtain a current Health Department licence. For details, contact the Pesticides Safety Section by telephoning 08 9383 4244.

• Ensure that they apply chemicals strictly in accordance with any spray drift agreement(s) that exist between the Owner/Manager and any neighbours.

• Ensure that they have been given a spray plan that shows the location of sensitive areas or crops.

• Notify neighbours and erect signs if appropriate, to prevent inadvertent entry into sprayed areas within a safe period.

Spray plans and spray drift awareness zones
(Department of Agriculture Western Australia, 2001)

Some areas are particularly sensitive to contamination by some chemicals. These areas should be identified in spray plans.

Have a spray plan for all routine spraying operations. Once spray plans are prepared for each paddock, these can be used for future spraying operations and updated as the areas or conditions change. The plan should consist of a map showing:

The area to be sprayed

The spray drift awareness zone (SDAZ, see below).

All sensitive areas in the SDAZ, such as residential or public areas, aquaculture dams, sensitive vegetation, crops and buildings in the vicinity of the property.

Other notes for the operator, such as prevailing wind strength and direction, sensitive areas, drift reduction buffer zones and safety measures.

❑ Ensure that the operator has an up to date copy of the spray plan before each spraying operation.

Regularly notify all immediate neighbours and others in the locality as appropriate, having regard for:

- the spray plan
- the chemicals to be used
- the sensitivity of their crops or enterprises
- the length of notice they would need to minimise their risk of damage.

If your neighbours’ enterprises are particularly sensitive to the chemicals you use, you could consider offering to enter into an agreement with them to specify the conditions under which you may and may not apply chemicals.

Spray drift awareness zones

❑ Adopt the concept of spray drift awareness zones (SDAZ), as part of the spray plans.

A spray drift awareness zone (SDAZ) is a means of identifying all potentially sensitive areas around each paddock to be treated with chemicals.

Bear in mind that each part of the property to be treated will have a slightly different SDAZ as the focus of the zone shifts from paddock to paddock across the property.

The SDAZ is a zone for consideration of impacts of spraying operations. Under most circumstances, the awareness zone for ground spraying could extend up to 1 km from the paddock to be treated. For aerial application, it is likely to extend well beyond that distance.

The following are some factors that should be considered within SDAZs:

Method of application. Aerial spraying may have impacts kilometres away. Ground application where hooded booms and drift reduction nozzles are used may not have impacts more than 50 metres from the operation.

The nature of the sensitive environment, for example, an A-class wetland bird breeding reserve or a residential area would require maximum precautions.
Toxicity of the chemicals to the particular sensitive environment. For example, pyrethroids should not be used where spray drift may contaminate aquaculture ponds. Hormone herbicides must not be used anywhere near vineyards (see ‘Hormone herbicides, this section).

Example

The Department of Environmental Protection has set a guideline minimum separation distance of 500 metres between vegetable and potato growing operations and residential development in areas zoned residential.

The SDAZs should take into account all buildings, crops or areas outside the paddock that may be sensitive to spray drift, e.g. schools, dwellings, wetlands, aquaculture ponds, organic farms etc.

However, remember that the SDAZ is an awareness zone. It does not necessarily mean that spray drift damage will always occur within that zone, depending on the sensitivity of the crop or area, the weather and application conditions at the time of spraying, and the size of the zone. Also, the presence of any physical or vegetative buffers downwind of the spraying operation will reduce the risk of damage.

Figure 10.1 Example of spray drift awareness zone shown on a spray plan, identifying sensitive areas
**Hormone herbicides**  
(Fisher and Hawley, 1999)

Hormone herbicides have the potential to damage surrounding sensitive crops by spray or vapour drift. The Agriculture and Related Resources Protection (Spraying Restrictions) Regulations 1979 restrict the use of hormone herbicides. There is a ‘duty of care’ for landholders and spray contractors not to cause off-target spray damage. Please read this document before using hormone herbicides, especially if the intention is to spray within a 10km radius of a sensitive crop.

**Symptoms of damage by hormone herbicides**

Hormone herbicides are so called because they function in a similar way to plant growth regulators. They may also be called ‘phenoxy’ herbicides, as the most common are derivatives of phenoxy-acetic and phenoxy-butyric acids. Low dose rates can sometimes stimulate growth or assist fruit set. High dose rates can cause reduced and abnormal growth.

Hormone herbicides are translocated through plants after uptake through leaves and sometimes roots, and concentrate in the growing points (meristematic tissue).

They interfere with cell division, which results in the development of malformed leaves and stems. Adventitious roots are also often formed.

The leaf twisting caused by hormone herbicides means that off-target damage is very obvious, and can be noticed almost immediately (refer to photos).

Herbicides which fall into the category of a hormone are those which contain the active ingredients of the following: MCPA, MCPB, 2, 4-D, 2,4-DB, Dicamba, Picloram, Triclopyr, Clopyralid, or combinations of these and other herbicides.

Note that neither triclopyr nor clopyralid are covered by the regulations discussed in ‘Restrictions on use of hormone herbicides’ below, as they came into use after the regulations were gazetted, and no amendments have been made. Users of the chemicals are still bound by a ‘duty of care’ and are liable if they cause damage.

**Drift hazards of hormone herbicides**

Off-target spray damage can occur by:

- droplet drift
  
  and

- vapour drift.

Droplet drift is the movement in the wind of small droplets that fail to settle onto the target plants. This type of drift could result from misting by spray equipment and spraying in strong winds. All chemicals are subject to droplet drift.

Vapour drift is caused by the herbicide evaporating (due to its volatility) and moving as a vapour with the wind. Evaporation occurs mainly from the soil and plants after the spray has landed but it can be from a droplet.

Evaporation can occur several hours after the spraying activity and the evaporation rate will depend upon the volatility of the chemical. The formulations therefore pose the added hazard of vapour drift (see tables on page 243 for examples).

**Formulations of the hormone herbicides**

Hormone herbicides are amines, sodium and potassium salts and ester formulations. The degree of volatility of the ester formulations depends on the particular alcohol used to make the ester.

Table 10.1 below shows the vapour pressures of some hormone herbicides and other commonly used herbicides, simazine and trifluralin.

Amines and the sodium and potassium salts are non-volatile.
Table 10.1 Volatility (vapour pressure) of some common herbicides
Note that higher vapour pressure = higher volatility

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Vapour pressure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simazine</td>
<td>0.000000083 Pa</td>
<td>Known to be non-volatile</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>0.0073 Pa</td>
<td>Known for its volatility</td>
</tr>
<tr>
<td>MCPA iso-octyl ester</td>
<td>0.0038 Pa</td>
<td>Volatile</td>
</tr>
<tr>
<td>2,4-D iso-octyl ester</td>
<td>0.0023 Pa</td>
<td>Volatile</td>
</tr>
<tr>
<td>2,4-D butyl ester</td>
<td>0.054 Pa</td>
<td>Highly volatile</td>
</tr>
<tr>
<td>2,4-D ethyl ester</td>
<td>0.15 Pa</td>
<td>Highly volatile</td>
</tr>
</tbody>
</table>

As can be seen from Table 10.1 above, the butyl and ethyl esters have the highest vapour pressures and hence are the most volatile and therefore the most hazardous in terms of potential off-site damage.

Table 10.2 Some common commercial hormone herbicides

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>Commercial products ®</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCPA</td>
<td>Davison MCPA 500 Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>Farmco MCPA – 500 Selective Weedkiller</td>
</tr>
<tr>
<td></td>
<td>Nufarm MCPA 500 Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>Tigrex Selective Herbicide (also contains difluafenac).</td>
</tr>
<tr>
<td>MCPB</td>
<td>Tropotox Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>Farmco MCPB – 400 Selective Herbicide</td>
</tr>
<tr>
<td>2,4 – D</td>
<td>Farmco D – 500 Selective Weedkiller</td>
</tr>
<tr>
<td></td>
<td>Amicide 500 Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>Davison 2,4 – D Amine 500</td>
</tr>
<tr>
<td></td>
<td>Nufarm Amacide GC – 500 Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>*National 2,4 – DLV Ester 600 Herbicide</td>
</tr>
<tr>
<td></td>
<td>**Farmco D – 800 Selective Weedkiller</td>
</tr>
<tr>
<td></td>
<td>** Estercide 800 Herbicide</td>
</tr>
<tr>
<td></td>
<td>** Davison 2,4 – D Ester 800</td>
</tr>
<tr>
<td></td>
<td>** Rhone Poulenc 2,4 – D Ester 800 Herbicide</td>
</tr>
<tr>
<td>2,4 – DB</td>
<td>Buticide 2,4 – DB Herbicide</td>
</tr>
<tr>
<td></td>
<td>Davison 2,4 – DB Selective Herbicide</td>
</tr>
<tr>
<td></td>
<td>Legumex Herbicide</td>
</tr>
<tr>
<td>Dicamba</td>
<td>Banvel 200 Herbicide</td>
</tr>
<tr>
<td></td>
<td>Nufarm Dicamba 200 Herbicide</td>
</tr>
<tr>
<td>Picloram</td>
<td>DowElanco Tordon 50 – D Herbicide (Also contains 2,4-D)</td>
</tr>
<tr>
<td></td>
<td>DowElanco Tordon 242 Herbicide (also contains MCPA)</td>
</tr>
<tr>
<td></td>
<td>*DowElanco Grazon DS Herbicide (also contains triclopyr)</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>*DowElanco Garlon 600 Herbicide</td>
</tr>
<tr>
<td></td>
<td>*DowElanco Grazon DS Herbicide (also contains picloram)</td>
</tr>
<tr>
<td>Clopyralid</td>
<td>DowElanco Lontrel L Herbicide</td>
</tr>
</tbody>
</table>

*Low volatile ester formulation **Volatile ester formulation
Restrictions on use of hormone herbicides

Under the ‘Agriculture and Related Resources Protection (Spraying Restrictions) Regulations 1979’ the use of the restricted hormone herbicides is controlled within a 10 km radius of commercial vineyards and tomato gardens (see below). Their use near other sensitive crops is not controlled by the Regulations, but landholders and spray contractors should exercise a ‘duty of care’ when spraying. Under the Regulations:

- Within a 5km radius of commercial vineyards or tomato gardens only amine and sodium and potassium salt formulations are approved for spraying under permit.

- Between 5 and 10 km radius of these crops both amine, sodium and potassium salts and low volatile ester formulations can be used without permit.

- Outside of a 10km radius all formulations, that is amine, sodium and potassium salts and low volatile and volatile ester formulations can be used without permit.

Note: Landholders and spray contractors in the Geraldton, Swan Valley and Ord Irrigation Districts need to consult the Regulations for more precise information on restricted spraying areas. They vary in these districts from the above.

Permits

Permits are issued, with conditions, by officers authorised on behalf of the Chief Executive Officer of Agriculture Western Australia, for the purpose of regulations 4 and 5 of the Regulations. The permits take into account:

- Name of property owner, address and telephone number.

- Location numbers and area (ha) to be sprayed.

- Weed species.

- Herbicide, formulation and rate of application.

- Method of application.

- Approximate distance and direction to the nearest commercial vineyard or tomato garden.

- Wind velocity and direction.

- Period in which spraying is to be conducted.

- Special conditions required for safe application such as water volume, operating pressure, operating speed and temperature. These are varied according to the time of the year, depending on the weather and stage of development of the sensitive crop. The most critical time when spray damage may occur is early growth to fruit development.

Future restrictions on use of hormone herbicides

The ‘Agriculture and Related Resources Protection (Spraying Restrictions) Regulations 1979’ are currently under review. It is expected that the regulations 4 and 5 of the Regulation will be repealed which means that there will be no requirement for permits. However, it is expected that the new legislation will focus on a ‘duty of care’ for all users of all chemicals in all situations.

In addition to this, in the Agriculture Chemical Spraying Review of 1997, the Review Committee recommended that, ‘The legislation provides for the mandatory notification of new and diversified crops by growers to a Register, created and maintained preferably by Local Government Authorities’. If this eventuates, landholders and spray contractors could refer to this register to exercise ‘duty of care’. It would be in the best interest of growers of all new and diversified crops to have them registered.
10.2 Minimise impacts of dust, odours and flies

Dust and odours and flies from poorly managed horticulture often evoke complaints from near neighbours. This is not surprising, as these nuisances are likely to result in health problems, especially in aged or sensitive individuals.

**Dust**

Most dust problems are from on-site machinery operations and vehicle traffic on unsealed farm tracks. For the health and welfare of humans and other sensitive environments, dust should be kept at a minimum.

- Avoiding cultivating at high speeds when the soil is dry.
- Driving at moderate speeds especially on unsealed roads.
- Establishing vegetated screening buffers.
- Irrigating bare cultivated soils during windy conditions.
- Protecting bare cultivated soil by leaving stubble or crop residues on the surface.

Wind strengths and directions should be observed, to determine the likely directions in which dust will be blown. Vegetation screens are an important part of dust control and their location will be determined by the orientation of buildings, prevailing wind direction and proximity to neighbours.

**Odours and flies**

Burning of plastics and other solid wastes produces smoke, which is a nuisance to neighbours and often contains toxic air pollutants. It is known that certain toxins produced from burning plastics can remain in the human body for long periods of time and that some of these, such as dioxins, are carcinogenic. These wastes should never be burned and there are disposal alternatives (Section 9.1).

Managing fly breeding when using manure (Paulin, 1997)

Manures are useful organic fertilisers as they are good sources of nutrients and provide organic matter for the soil. However, pig and poultry manures are common sources of odours and breeding places for flies, when used in their raw form.

Stable fly, a stinging insect that affects livestock and humans, is a particularly problematic pest that breeds in raw, damp manures.

- Treat manures to eliminate odours and flies by either:
  - Composting with other organic wastes to give the required carbon:nitrogen ratio for use as soil amendments.
  - Transporting them to factories where they are dried and granulated to produce organic fertiliser products such as Dynamic Lifter™.

**Storage of manure**

If manure is to be stored on-farm it must be dried and kept dry at all times. Manure heaps must be located outside the range of sprinklers and completely covered. Covers need to be durable, waterproof, a single sheet and secured so that flies and water cannot make contact with the manure. Such covers will prevent flies that may be present in the manure on delivery from hatching, providing they are left in place for at least 10 days.

**Use of manure**

Use manure that is free of clumps and incorporate it immediately. Manure and rotting organic matter should be covered with at least 50 mm of soil to prevent flies from laying eggs.

Avoid side dressings of manure, particularly during the warmer months October to April.

On established land, for vegetable crops, the recommended maximum application rate is 30 cubic metres per hectare per crop, up to a maximum of 75 cubic metres per hectare per year.
Litter management

Care should also be taken to prevent wastes such as empty bags, paper and plastic wrapping from being blown into surrounding areas and creating a litter problem.

- Cover garbage bins and loads of potentially polluting materials such as manure, empty bags, plastic and other rubbish.

10.3 Minimise emissions of greenhouse gases and ozone depleting gases on farm

What is the greenhouse effect?

The greenhouse effect is caused by increasing levels of greenhouse gases in the atmosphere. These gases trap radiated energy from the sun within the atmosphere, gradually increasing average global temperatures. The results are detrimental effects on the Earth’s climate, rising sea temperatures and rising sea levels. The greenhouse effect is becoming a major environmental issue of the 21st Century.

Climate modelling by CSIRO scientists predicts that the south west of Western Australia will be one of the worst affected areas. By 2070, average temperatures are predicted to be 1-5 degrees higher (depending on strategies adopted). Rainfall is predicted to be up to 20% lower, more erratic and with more rainfall and wind events. Even a one-degree increase in temperature will increase evaporation by 80 mm and more than double the number of severely hot days, which will have significant impacts on the horticultural industry (CSIRO Atmospheric Research, 2002).

The greenhouse gases are mainly carbon dioxide, methane and nitrous oxides. The main sources of greenhouse gases and their contribution to the total in Australia are (Australian Greenhouse Office, 2002):

- Burning fossil fuels for power generation (56%)
- Agriculture, from ruminant animals, nitrogen fertilisers and cultivation (21%)
- Burning fossil fuels for transport (17%)
- Industrial, waste and ‘fugitive’ emissions from coal oil and gas extraction (6%)

Land clearing makes an additional contribution equivalent to about 15% of emissions by converting carbon that was permanently stored in forests into carbon dioxide.

Table 10.1 Relative effect of greenhouse gases
(Australian Greenhouse Office, 2002)

<table>
<thead>
<tr>
<th>Greenhouse gas</th>
<th>Formula</th>
<th>Source</th>
<th>Global warming potential relative to 1 tonne of CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>Burning organic matter in air</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>Anaerobic decomposition of organic matter</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous oxides</td>
<td>NOₓ</td>
<td>Burning fossil fuels</td>
<td>310</td>
</tr>
</tbody>
</table>

Of the 49.3 million tonnes of CO₂ (equivalent) produced annually in Western Australia, 27% is emitted from the agricultural sector (Australian Greenhouse Office, 1998).
Table 10.2 Source of greenhouse gas emissions from agriculture in Australia (Australian Greenhouse Office, 2002)

<table>
<thead>
<tr>
<th>Source of greenhouse gas emissions</th>
<th>% of total net emissions Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock</td>
<td>13.7</td>
</tr>
<tr>
<td>Agricultural soils and burning vegetation (soils about 2/3 of this)</td>
<td>6.6</td>
</tr>
<tr>
<td>Fossil fuel use</td>
<td>Not available for agriculture</td>
</tr>
<tr>
<td>Rotting of manures and mulches</td>
<td>&lt;0.1%</td>
</tr>
</tbody>
</table>

Reducing greenhouse gas emissions on the farm

Horticultural operations are relatively large producers of greenhouse gases.

The main sources of greenhouse emissions from vegetable and potato growing operations are:
- Nitrous oxides from nitrogen fertilisers.
- Methane and carbon dioxide from cultivation of soil and crop mulching practices.
- Consumption of fossil fuels by motorised vehicles and machinery such as irrigation pumps and tractors, which emits carbon dioxide and nitrous oxides.
- Rotting of mulches and manures in piles that are not aerated, producing methane.
- Land clearing (if this is conducted).

Every effort should be made to minimise generation of greenhouse gases on-farm.

The practices used in several aspects of management of vegetable and potato growing operations greatly influence the quantity of greenhouse gases produced.

Nitrogen fertilisers produce nitrous oxides, which are 310 times more powerful greenhouse gases than carbon dioxide. The most important practices to minimise greenhouse gas emissions from vegetable and potato growing relate to management of nitrogen fertilisers:

- **Minimise quantity of nitrogenous fertilisers used and use best practice for efficient application** (see Section 3).
- **Do not apply nitrogen to waterlogged ground.**

Good soil management reduces greenhouse gas emissions by increasing the soil organic carbon sink. A carbon sink is something that removes or stores carbon dioxide from the atmosphere. Soil organic carbon, forests and permanent native vegetation are large carbon sinks. Increasing the soil organic carbon content by 1% over one hectare would prevent over 10 tonnes of CO₂ emissions. Mulching of crop residues near the soil surface increases soil organic carbon, while improving soil health and minimising methane production.

- **Ensure that organic wastes are composted or mulched on or near the soil surface.**

Excessive tillage is to be avoided because it accelerates the rate of oxidation of soil organic matter thus producing carbon dioxide and methane.

- **Minimise tillage to maintain high soil organic carbon levels.**

Although most vegetable and potato growers are not usually involved in clearing land, revegetation is to be encouraged because it has the opposite effect to land clearing. Woody vegetation removes carbon dioxide from the atmosphere and converts it to wood, a carbon sink.

- **Avoid clearing woody vegetation and where possible revegetate with woody species.**

Fossil fuel usage is a major source of greenhouse gases on horticultural farms, chiefly from the operation of irrigation pump motors and tractors. A large operation with annual fuel usage of 60,000 litres is equivalent to running about 30 cars. This would emit 180 tonnes of CO₂.
 Reduce fossil fuel use by making irrigation, cultivation and transport as fuel-efficient as possible.

Natural gas is more ‘greenhouse friendly’ than other fossil fuels. Petrol, diesel and coal produce increasing amounts of greenhouse gases per kilogram used. Conversion of engines to gas is to be encouraged particularly where properties have access to piped natural gas.

Where there are economic alternative energy sources consider the one with least greenhouse impact.

Solar hot water systems are an economic option for domestic and industrial purposes and the only greenhouse gases produced are in the manufacture of the hot water system. Solar water heating can reduce fossil fuel consumption in a typical household by over 30%.

Use solar hot water and other renewable energy systems to supplement household and industrial requirements where possible.

Bio-fuels are a ‘renewable energy’ source and are ‘greenhouse friendly’ fuels. There is the potential to set up commercial bio-fuel production from crop wastes and other renewable energy generation such as wind power and solar power on large farms and at packing or food production operations. Power generated at private premises can now be sold through the State power grid.

Current and future efforts towards on-farm production of renewable energy are greatly encouraged.

Ozone depleting gases

These gases are mainly man-made chlorofluorocarbon chemicals produced in relatively small quantities for specific purposes, such as refrigerants. However, they have devastating effects on the atmosphere by destroying ozone and causing ‘ozone holes’ in higher latitudes, resulting in increased ultraviolet radiation reaching the earth’s surface.

Take old refrigeration equipment and fire extinguishers (the yellow ones) to licensed refrigeration technicians for degassing.

They will store the ozone depleting chemicals for treatment.

Methyl bromide, which was used as a soil fumigant, is an ozone depleting substance and its use for soil fumigation is now prohibited.

References


Website: http://www.dar.csiro.au/information/greenhouse.html

Department of Agriculture, Western Australia, 2001. Code of Practice for the Use of Agricultural and Veterinary Chemicals in Western Australia.


http://www.ianr.unl.edu/pubs/pesticides

Further Reading


Department of Natural Resources and Environment, Victoria, 1999. Code of Practice for Farm Chemical Spray Application.

Training – Units of Competency

The Units of Competency listed in Table A11.1 are recommended for growers and operators wishing to obtain formal qualifications in aspects of environmentally sustainable vegetable and potato growing. In general the 2-300s units are at operator level and 4-500s units are at supervisory and managerial level.

These units can all be accredited towards Certificates or Diplomas in Horticulture and are from the Rural Training Council of Australia Horticulture Training Package (www.rtca.com.au/hortpdf/HORTICUL.pdf)

Table A11.1 Units of Competency relevant to environmentally sustainable vegetable and potato growing

<table>
<thead>
<tr>
<th>BEMP Section</th>
<th>Unit number</th>
<th>Unit Title</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Core 2A</td>
<td>Meet workplace health and safety requirements</td>
<td>Prerequisite for all other units</td>
</tr>
<tr>
<td>9 and others</td>
<td>521A</td>
<td>Implement sustainable horticulture practices</td>
<td>Includes conducting an environmental audit</td>
</tr>
<tr>
<td>2</td>
<td>319A</td>
<td>Prepare field soils for planting</td>
<td>Soil testing, preparation, disinestation</td>
</tr>
<tr>
<td>2</td>
<td>358A</td>
<td>Survey soil characteristics</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>312A</td>
<td>Install a drainage system</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>359A</td>
<td>Implement a plant nutrition program</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>438A</td>
<td>Develop a plant nutrition program</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>226A</td>
<td>Undertake irrigation system maintenance activities</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>315A</td>
<td>Operate irrigation systems</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>313A</td>
<td>Install irrigation systems</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>532A</td>
<td>Maintain, monitor and evaluate irrigation systems</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>424A</td>
<td>Manage irrigation drainage and treatment systems</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>515A</td>
<td>Design irrigation, drainage and water treatment systems</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>530</td>
<td>Manage wetlands</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Core 3A</td>
<td>Use hazardous substances safely</td>
<td>A prerequisite. Storage, transport, handling, use, emergency.</td>
</tr>
<tr>
<td>6</td>
<td>212A</td>
<td>Apply chemicals and biological agents</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>216A</td>
<td>Maintain supplies of chemical and biological agents</td>
<td>Includes chemical records</td>
</tr>
<tr>
<td>6</td>
<td>353A</td>
<td>Select chemicals and biological agents</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>432A</td>
<td>Manage and notify a chemical spillage and/or leakage</td>
<td></td>
</tr>
</tbody>
</table>
Table A11.1 (continued)

<table>
<thead>
<tr>
<th>BEMP Section</th>
<th>Unit number</th>
<th>Unit Title</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6, 7</td>
<td>201A</td>
<td>Treat weeds</td>
<td></td>
</tr>
<tr>
<td>6, 7</td>
<td>202A</td>
<td>Treat pests and diseases</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>316A</td>
<td>Control weeds</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>317A</td>
<td>Control pests and diseases</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>219A</td>
<td>Maintain a crop</td>
<td>Watering, monitoring.</td>
</tr>
<tr>
<td>7</td>
<td>352A</td>
<td>Implement an Integrated Pest Management (IPM) program</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>530A</td>
<td>Manage weed, pest and disease infestations</td>
<td>Managerial level</td>
</tr>
<tr>
<td>7</td>
<td>413A</td>
<td>Develop and IPM program</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>237A</td>
<td>Support vegetation works</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>306A</td>
<td>Establish planted areas</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>531A</td>
<td>Conduct vegetation surveys</td>
<td></td>
</tr>
</tbody>
</table>
For the purposes of this Code, the terms used are assumed to have the following meanings:

<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>aquifer</td>
<td>Discrete underground water resource.</td>
</tr>
<tr>
<td>best environmental management practice</td>
<td>The best practical methods of meeting expected environmental outcomes.</td>
</tr>
<tr>
<td>biodiversity</td>
<td>The variety of all forms of life, including the different plants, animals and micro-organisms, the genetic material they contain and the ecosystems they live in.</td>
</tr>
<tr>
<td>brassica</td>
<td>Family of vegetables including cauliflowers and broccoli.</td>
</tr>
<tr>
<td>conservation</td>
<td>Protecting and preserving natural life forms or resources.</td>
</tr>
<tr>
<td>environmental</td>
<td>About the surrounding conditions that sustain all forms of life.</td>
</tr>
<tr>
<td>Environmental Management System</td>
<td>A voluntary, audited system, which growers can develop for their operation to improve environmental sustainability.</td>
</tr>
<tr>
<td>evapo-concentration</td>
<td>Process by which salts become more concentrated and may crystallise when evaporation occurs on the surface of saline water or soils.</td>
</tr>
<tr>
<td>eutrophication</td>
<td>Nutrient enrichment of waterways leading to algal growth and deterioration in water quality.</td>
</tr>
<tr>
<td>export of nutrients and chemicals</td>
<td>Process by which nutrients and chemicals can move through and over soils dissolved in water or attached to soil particles.</td>
</tr>
<tr>
<td>expected environmental outcome</td>
<td>Expected general condition or state of any aspect of the environment resulting from the practices of growers.</td>
</tr>
<tr>
<td>farm chemicals</td>
<td>Commercially produced substances with specific uses in agriculture or horticulture. Includes pesticides, spray additives, solvents, cleaning agents and veterinary chemicals.</td>
</tr>
<tr>
<td>fertigation</td>
<td>Application of soluble fertiliser through an irrigation system.</td>
</tr>
<tr>
<td>fertiliser</td>
<td>Chemical or organic products that contain nutrients to promote plant growth.</td>
</tr>
<tr>
<td>flow line</td>
<td>Area on a hill slope where run-off will tend to collect and flow. Smooth open depression, which is not a creek bed, on a hill slope.</td>
</tr>
<tr>
<td>fossil fuel</td>
<td>Fuel originating from fossil plant or animal remains, such as coal, oil and natural gas.</td>
</tr>
<tr>
<td>genetically modified organism</td>
<td>Any living thing, which has genes that have been altered by mankind.</td>
</tr>
<tr>
<td>greenhouse gas</td>
<td>Gas that contributes to the global warming phenomenon known as the greenhouse effect.</td>
</tr>
<tr>
<td>integrated pest and disease management (IPDM)</td>
<td>Utilising a range of pest management tools to provide economically, environmentally and socially sustainable production. The aim of IPDM is to minimise the risks to human health and the environment while maintaining pest populations below levels at which crop damage may occur.</td>
</tr>
<tr>
<td>invertebrate pests</td>
<td>Adult and larval forms of pests that are ‘animals without backbones’, such as insects, mites and nematodes.</td>
</tr>
<tr>
<td><strong>irrigation scheduling</strong></td>
<td>Monitoring soil moisture and evaporation to decide when and how much a crop needs to be irrigated.</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>legislative</strong></td>
<td>Relating to laws.</td>
</tr>
<tr>
<td><strong>natural ecosystem</strong></td>
<td>System of interacting native plants and animals in a particular area or habitat.</td>
</tr>
<tr>
<td><strong>nutrient</strong></td>
<td>Chemical elements of fertilisers or manures, which are essential for plant growth, for example phosphorus, nitrogen, potassium, calcium, sulphur and trace elements.</td>
</tr>
<tr>
<td><strong>pan evaporation rate</strong></td>
<td>Standard measure of evaporation, equal to millimetres of water evaporated off a still water surface.</td>
</tr>
<tr>
<td><strong>pesticides</strong></td>
<td>Chemicals (or in exceptional cases biological or fungal agents), usually man-made, used to kill pests or diseases. Includes herbicides, insecticides and fungicides.</td>
</tr>
<tr>
<td><strong>phosphorus retention index (PRI)</strong></td>
<td>Numerical index expressing the ability of a soil to hold on to phosphorus. Low numbers denote a low capacity to hold phosphorus.</td>
</tr>
<tr>
<td><strong>principles (of environmental management)</strong></td>
<td>Fundamental element of the code of practice, stated in general terms that guides best management practices in relation to a particular aspect of management.</td>
</tr>
<tr>
<td><strong>renewable energy source</strong></td>
<td>Energy source that can be replaced, such as wind or solar energy and bio-fuels. Fossil fuels are not renewable.</td>
</tr>
<tr>
<td><strong>riparian (land and vegetation)</strong></td>
<td>Adjoins or directly influences a body of water, including • immediately alongside small creeks and rivers, including the riverbank itself and flood plain • gullies and dips which sometimes run with surface water • surrounding lakes and wetlands</td>
</tr>
<tr>
<td><strong>sodic soil</strong></td>
<td>A soil containing sufficient sodium to interfere with the growth of most crops plants.</td>
</tr>
<tr>
<td><strong>soil structure decline</strong></td>
<td>When excessive cultivation of or traffic on the soil breaks down the aggregates that make up soil types with clay and loam content. The result is a compacted, poorly aerated soil that forms clods when cultivated.</td>
</tr>
<tr>
<td><strong>sustainable</strong></td>
<td>Describes land uses or development that has the capacity to be continued in perpetuity without due impact on environmental, social or economic values.</td>
</tr>
<tr>
<td><strong>sustainable production</strong></td>
<td>A system of agricultural production that aims to reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term and maintain stable rural communities and quality of life.</td>
</tr>
<tr>
<td><strong>tensiometer</strong></td>
<td>Simple instrument that measures soil water content. Public Drinking Water Source Areas for underground water, which are proclaimed and protected by the Water and Rivers Commission under government Acts. The WRC can regulate potentially polluting activities and land use, inspect premises and to take steps to prevent or clean up pollution.</td>
</tr>
<tr>
<td><strong>Underground Water Pollution Control Areas</strong></td>
<td></td>
</tr>
</tbody>
</table>
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