Making the most of irrigation water in south west Victoria

A guide to improving irrigation water use efficiency on dairy farms

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A guide to improving irrigation water use efficiency on dairy farms

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1. Introduction

This booklet, "Making the most of irrigation water in south west Victoria", is not intended to be a comprehensive manual dealing with every aspect of irrigation management and practice. Rather, the booklet draws together the results of some eight years' research into improved irrigation practices by the dairy research group of the Department of Primary Industries at Warrnambool. This research has been aimed at how the dairy industry, the largest user of irrigation water in the region, can make more efficient and profitable use of the limited and sometimes unreliable supplies of irrigation water in the region.

The research has been funded by the Government of Victoria through the Department of Primary Industries, WestVic Dairy and Dairy Australia (previously the Dairy Research and Development Corporation).

It is hoped that this booklet will provide useful and practical information for both existing irrigators and to those considering irrigation in the future.

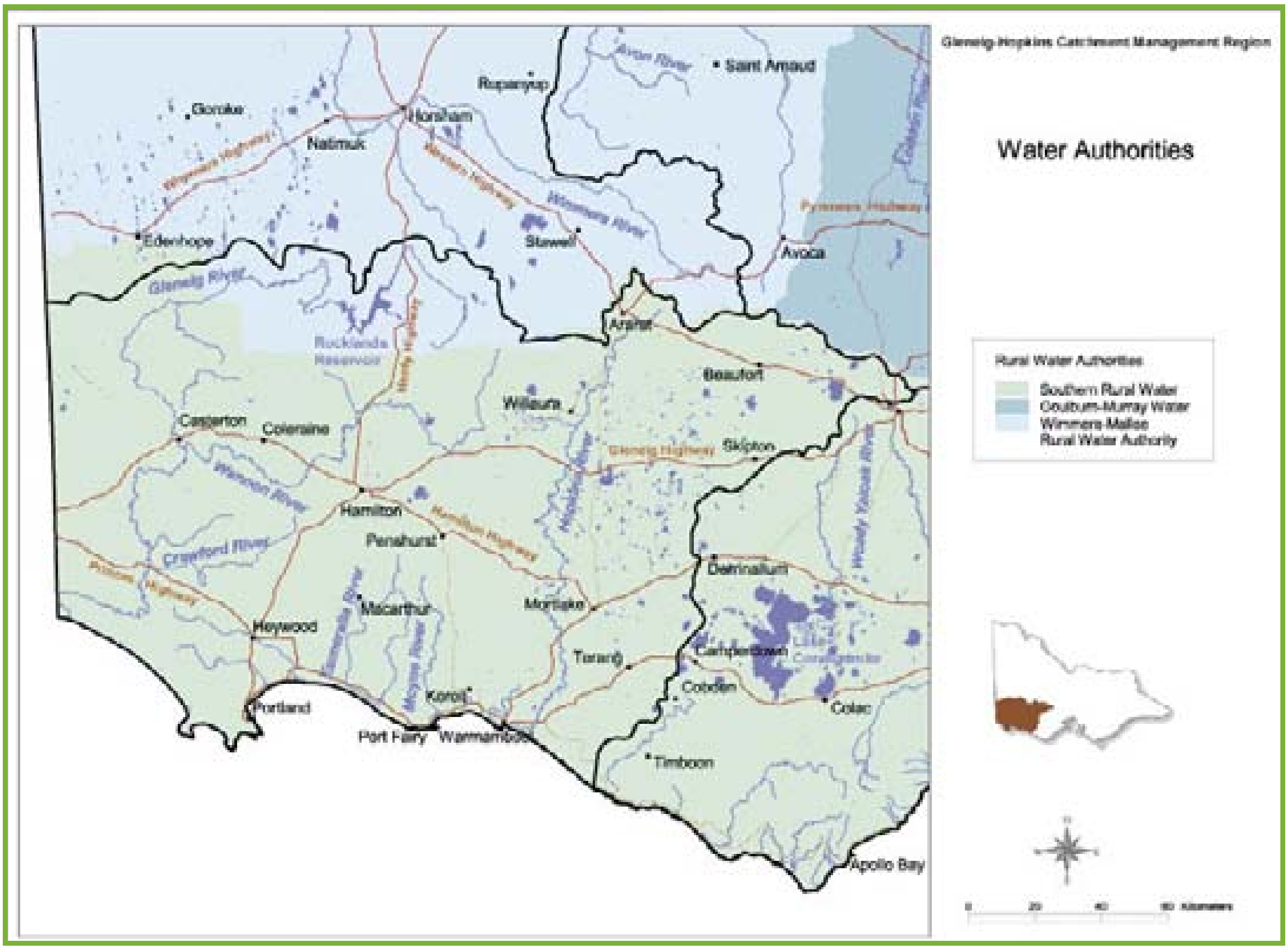


Figure 1. Rural Water Authority boundaries in south west Victoria

2. Irrigation water in south west Victoria

Irrigation water in south west Victoria is sourced from ground water bores, river systems, streams and private dams. There are strict regulations and guidelines governing the supply of irrigation water in Victoria.

Sources of irrigation water

Irrigation water for on-farm use in south west Victoria comes from groundwater (bore), surface diversions from streams and some private dams. With the exception of several regulated systems in the Werribee and Bacchus Marsh irrigation districts, the remaining irrigation in the region is by private schemes. Ground or bore water is the predominant source with an estimated three-quarters of the irrigation water for the private schemes in the region coming from a series of aquifers predominantly in the southern parts of the region. Surface diversions are largely from unregulated streams in the Hopkins-Merri River systems and from streams in the Otway river basin.

Licencing and regulation of irrigation water

The licencing and regulation of both groundwater and surface water diversions for irrigation in the region is under the control of Southern Rural Water (SRW). SRW is responsible for monitoring and regulating rivers, streams, waterways and aquifers across southern Victoria, including the use of water from existing and new farm dams, the construction of new bores and the management of permanent and temporary water transfers.

If you plan to take and use any groundwater, streamwater or dam water for commercial, irrigation, dairy or industrial purposes you need a licence from SRW. Before planning any irrigation scheme, advice should be sought from SRW on the likely availability of an irrigation licence.

a) Groundwater licences

Before any groundwater bore is constructed, you must apply for a Bore Construction Licence. If you plan to take and use the groundwater for any purpose other than domestic and/or stock use, you must also apply for a Groundwater Licence. In a number of the groundwater irrigation districts of the south west, no new Groundwater Licences for irrigation are being issued as the aquifers are already fully allocated, however, water trading is an option.

Most of the south west groundwater irrigation districts are in either Groundwater Management Areas (GMAs) or Water Supply Protection Areas (WSPA). GMAs usually have a large number of existing bores and need to be closely managed to ensure that existing licenced use is sustainable. If you apply for a new Groundwater Licence within a GMA, the application is assessed against the current licenced volume and the provisions of the Water Act 1989. For some aquifers requiring more intensive management, WSPAs are established and a water management plan is developed. An application for a new Groundwater Licence in a WSPA will be deferred until the Minister for Water has determined the Management Plan. WSPAs in the south west include the Nullawarre, Yangery and Warrion groundwater areas.

When a licence is issued, it is subject to a number of conditions including:

- licenced total annual and daily volume available for use,
- the installation of a meter to measure and monitor water usage,
- the need to comply with restrictions, rosters and bans in extreme circumstances, and
- development clauses - these make the issue of all or part of your licence conditional on the completion of particular increments/stages or finalisation of the whole project.

If an application for a Groundwater Licence is refused due to the resource being fully allocated, irrigation water can sometimes be obtained by a temporary or permanent transfer of water entitlement from an existing licence holder (see Section c).

b) Surface water licences

As with groundwater sources, quantities of irrigation water available from waterways are regulated to ensure sustainable use of the resource. Since the release of the White Paper *Our Water Our Future*, in June 2004, the Victorian Government has placed upper limits on water extractions on all Victorian river basins. For river basins that are fully or over-allocated, no new licences will be issued. In the south west, these include the Hopkins, Glenelg, Barwon and Moorabool river basins. For river basins that are not fully allocated, new winterfill licences can be allocated - in some cases. A winterfill licence allows you to take and use water from the waterway during the winter months (July to October inclusive) to fill appropriate storages or dams for use during the summer months.

Where surface water applications in southern Victoria are refused, in accordance with Ministerial Guidelines, irrigation developments may still occur, provided water can be traded within the river basin. Irrigation water licences may be transferred on a temporary or permanent basis. As there may be restrictions on these transfers depending on the volume of water and the location of both buyer and seller, any applicant should check any proposed transfer with Southern Rural Water early in the planning process.

c) Water trading

Water trading is often the only option for obtaining a new licence or to increase your existing licenced volume in some areas. This can be done on a temporary or permanent basis. Water trading can only take place within the same GMA, WSPA or river basin.

A *temporary transfer* is when you 'lease' all or part of your licenced volume for a season. A season finishes on 30 June each year. Although you are transferring your licenced volume to another landowner for an agreed period of time and price, you continue to hold ownership of the licence.

A *permanent transfer* is when you sell your ownership of all or part of your licenced volume for an agreed price. Depending on the location of the property and/or the volume of the water transferred, Southern Rural Water may request you advertise your intention to permanently transfer water to another landowner in newspapers that are distributed within the area surrounding the buyer's property, notify your neighbours and request submissions from interested parties. If a proposed permanent transfer is within a declared WSPA, it cannot be considered until the Minister for Water has determined the Water Management Plan, developed by a local Committee.

All applications to transfer water must be submitted to Southern Rural Water so that the impact of any proposed change to existing extraction or diversion points on other users and the environment can be assessed. Even though both the buyer and seller have agreed to the transfer, it is possible the transfer application may not be approved.

Southern Rural Water
Further details and advice is available from:

Southern Rural Water
132 Fairy Street
Warrnambool 3280
Phone: 1300 139 510 or 5564 1700
Web site: www.srw.com.au

About one third of the regions irrigation water supplies come from surface diversions such as the Merri River pictured

3. How much irrigation water do I require?

A number of factors need to be considered when estimating the amount of irrigation water required for optimum plant growth.

Growing pasture and crop plants lose water to the atmosphere in a process known as *evapotranspiration* (ET). This is a combination of *evaporation* (E) directly from the soil surface and *transpiration* (T) from the foliage of the plants. Water lost to the atmosphere by evapotranspiration comes from the water stored in the soil and must be replaced by either irrigation or rainfall if plant growth is not to be restricted.

Weather conditions including temperature, wind, relative humidity and solar radiation have major effects on evapotranspiration rates of crops and pastures. Across Victoria, variation in potential ET and rainfall mean that there are large differences in annual irrigation water requirements with the cooler and wetter south west having lower requirements than northern Victoria. In addition, irrigation water requirements at a location will vary from year to year depending on rainfall and other weather conditions.

Estimated irrigation water requirements for perennial pasture

a) Annual requirements

Based on long term weather records, the maximum annual water requirement to fully irrigate perennial pasture in south west Victoria is estimated to be in the order of 6 - 7 ML/ha in the southern parts and 7 - 8 ML/ha in the northern parts of the region. As 1 megalitre (ML) when applied to 1 hectare (ha) of land gives an application of 100 mm , this is the equivalent of 700 and 800 mm, respectively. As lucerne is known to have a higher water requirement than perennial pasture, fully irrigated lucerne is likely to require an additional 1 – 2 ML/ha annually.

In years of higher summer rainfall or lower temperatures leading to reduced evaporation, the requirement will be less. Similarly, above average spring rainfall will often result in later optimum irrigation startup times, reducing water requirements for the season, as will early autumn breaks.

b) Weekly requirements

An understanding of the average and range of weekly irrigation water requirements is important when designing an irrigation system. An irrigation system must be capable of applying the required average quantity of water within normal operating hours, plus have the capacity to apply additional water in weeks of high evaporation.

The volume of water needed to fully irrigate perennial pasture was estimated at three sites in the south west during the 1997/98 irrigation season. Evaporation from a “Class A” evaporation pan was measured from mid October through until late March. The estimated weekly irrigation water requirement was calculated (Table 1) using a crop factor of 0.8 (see Section 6).

Perennial ryegrass / white clover pasture irrigated using a travelling high pressure gun irrigator

Table 1: Estimated weekly irrigation requirements (mm) for three sites in SW Victoria during the 1997/98-irrigation season

Week Ending		Irrigation Requirement (mm)		
		Allansford	Alvie	Myamyn
October	20	15	14	6
	27	17	25	24
November	3	0	0	8
	10	24	25	24
	17	15	0	0
	24	45	28	31
December	1	33	37	34
	8	23	24	22
	15	35	31	33
	22	27	38	30
	29	43	40	37
January	5	35	45	37
	12	30	41	38
	19	30	30	48
	26	36	28	29
February	2	32	39	32
	9	19	28	25
	16	27	27	29
	23	36	42	42
March	2	37	46	41
	9	26	32	31
	16	32	41	38
	23	29	38	33
Total		646	699	672

Over the peak December to March period, the average weekly irrigation water requirements were:

Allansford:	**31 mm/week**
Alvie:	**36 mm/week**
Myamyn:	**34 mm/week**

In weeks with extreme evaporation conditions, this requirement can increase to around 50 mm/week. A well-designed irrigation system should have the capability of delivering these quantities of water when required.

It must be stressed that the above figures are **MINIMUM REQUIREMENTS** to meet perennial pasture needs. For lucerne, an additional 5 – 10 mm per week over and above the perennial pasture figures is often required to fully meet the plants requirements. It is also necessary to allow for distribution losses (e.g. 10 -30% of water from a travelling irrigator can be lost to evaporation) and poor distribution uniformity. Where highly saline water is used, additional water should be applied to leach accumulating salts down below the root zones (the *leaching factor*).

Requirements for Summer Forage Crops

Forage crops have a lower total water requirement for the irrigation season than fully irrigated perennial pasture. However, forage crops usually have greater evapotranspiration, and therefore uptake of water from the soil, than pasture during their peak growth period.

Reasons for this lower annual water requirement include:

- *Time of sowing*: Forage crops are generally sown after the start of the pasture irrigation season.
- *Shorter growing period*: Forage crops are generally only actively growing for part of the pasture irrigation season.
- *Conserved soil water*: Some spring rainfall is conserved in the soil profile as part of the seedbed preparation process. This is utilised by the growing crop.
- *Evapotranspiration* is less than for pasture for much of the early growth period of the crop when the plants are seedlings and have small leaf areas.
- Our research experience shows that in the southern areas of the south west, a summer forage crop requires 300 to 400 mm (3 - 4 ML/F method, frequency, intensity and waterlogging),
- stage of plant growth (germination, emergence, early seedling growth, flowering),
- climatic conditions (temperature, humidity, light), and
- soil type.

Irrigated Hunter forage Brassica crop

4. Water quality considerations

Poor quality irrigation water can adversely affect soil health and plant growth, particularly water with high salt concentrations.

It is important that any potential source of water be tested for its suitability for irrigation use. Irrigation water from groundwater bores and the summer flows of some unregulated streams can have water quality problems. This is certainly the case in south west Victoria with the majority of the region's irrigation water supplies having higher salinity levels than water supplied in regulated systems in other parts of the state.

Plants differ in their tolerance of salt in irrigation water and/or soil. General differences in salt tolerance between some forage species are listed in Table 2.

Salt tolerance of plants also varies with:

- water management (irrigation method, frequency, intensity and waterlogging),
- stage of plant growth (germination, emergence, early seedling growth, flowering),
- climatic conditions (temperature, humidity, light), and
- soil type.

Table 2. Salt tolerance of a range of forage species to applied irrigation water

Salinity of Irrigation Water	Comments	Forage Species
0 - 750 uS/cm (0 - 500 ppm)	Suitable for use with all crops.	*Sensitive plants*: Subterranean clover, white clover.
750 - 1,500 uS/cm (500 - 1,000 ppm)	Sensitive plants have increasingly reduced growth. Moderately-sensitive plants suffer little or no yield decline.	*Moderately-sensitive plants:* Balansa clover, Persian clover, strawberry clover, lucerne, maize, millet, sorghum, turnip, rape.
1,500 - 3,000 uS/cm (1,000 - 2,000 ppm)	Moderately-sensitive plants will suffer increasing yield loss. Moderately tolerant plants should suffer little yield loss with good management at the lower end of this range. At the upper end, some yield loss will occur.	*Moderately-tolerant plants*: Perennial ryegrass, tall fescue, berseem clover, paspalum, barley, oats, wheat.
3,000 - 5,000 uS/cm (2,000 - 3,300 ppm)	Moderately-tolerant plants will suffer increasing yield decline. Ideally, only tolerant plants should be grown with sustained use of this water.	*Tolerant plants:* Tall wheat grass, barley, couch grass.

General recommendations regarding the salinity of water used for irrigation are:

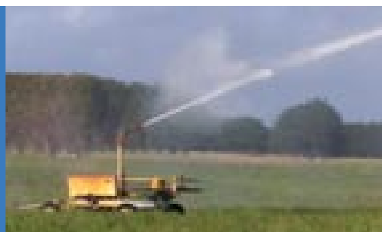
- If salinity is less than 800 uS/cm, the water is suitable for most crops and pastures on moderately to well drained soils.
- If salinity is between 800 - 2,300 uS/cm care is needed. It is unlikely to be suitable for use on salt sensitive species or for continuous use on soils that are not well drained.
- If salinity is greater than 2,300 uS/cm, problems with continuous use are likely to occur.

Fortunately, relatively few problems with using this high salinity irrigation water have occurred in the region. This is mainly a result of a combination of the majority of irrigated soils having good natural drainage, the plant species grown being relatively salt tolerant and the leaching effects of the high winter rainfall of the region. However, care still needs to be exercised. On the poorer drained, heavier textured soils, there is evidence of salt accumulation in the topsoil resulting from irrigation. In these cases, the pasture yields are lower than expected and there can be a change in the species growing in the pasture such as the more tolerant strawberry clover replacing white clover. The installation of sub-surface drainage has been successfully used in the region to reduce such problems on these soils. Even on well drained soils, it is good practice when using high salinity water to include a 'leaching factor', or an additional amount of water over and above the pasture requirements which will assist in moving the salts down past the root zone. The additional irrigation water that needs to be applied as a 'leaching factor' when saline water is used varies with the salinity level, but is commonly in the order of 10%.

In assessing their suitability for pasture and forage crop irrigation, water supplies should also be tested and assessed for:

- Sodicity or the Sodium Adsorption Ratio (SAR):- i.e. the ratio of sodium to calcium and magnesium in the water. Medium and high sodicity water can cause a breakdown in soil structure, reducing water infiltration rates, aeration and root growth. Further concentration of salt in the root zone is likely to occur. Periodic applications of gypsum may be required if soils turn sodic and lose structure.

- pH:- Water with a pH of 6.0 to 8.5 is generally suitable for irrigation. Alkaline water with a pH greater than 8.5 can result in plant nutrition problems by making some nutrients and trace elements less available. Fouling problems in pumps, pipes and other irrigation equipment can also occur. Routine monitoring of soil pH is recommended if high pH water is used.



5. The irrigation season – when to start and finish irrigation each year

Determining when to commence and cease irrigation is critical to optimise plant production and water use efficiency.

Startup time

Irrigation of pasture in south west Victoria often does not commence until well after the water content of the soil in the rootzone has dropped to a point where plant growth is reduced. Although often not obvious, the plants do become moisture stressed and growth rates decline, resulting in reduced pasture yields. In addition, when irrigation does finally commence, the pasture takes time to recover and can suffer reduced growth rates for a number of weeks.

The reason for these late startups is often because they coincide with the peak spring workload on the farm. In other cases, the irrigator may not be aware of how to determine the optimum startup time. Late irrigation startup does lead to reduced pasture yields that can be avoided.

What is the optimum startup time?

The "optimum irrigation startup time" for pasture is not a specific calendar date. Rather, it is the time at which the moisture content of the soil in the root zone drops to the "refill point", i.e. the critical soil moisture content below which plant growth starts to decline due to moisture stress. As a result this "optimum startup time" will vary from year to year due to seasonal variation. The date can range from September on light textured soils in a dry spring through until December or later on heavier soils in wet years.

Effects of late startup times

In a trial at Allansford during the 1996/97 season (Table 3), delaying the irrigation startup time on a perennial ryegrass - white clover pasture by 10 days past the optimum time resulted in a 674 kg DM/ha (35%) reduction in pasture yield compared to a pasture first irrigated at the optimum startup time. Where the startup time was delayed by 20 days, a 1154 kg DM/ha (60%) reduction in pasture yield was recorded. In addition, the 10 day delay treatment had lower daily pasture growth rates than the optimum treatment for 45 days after the optimum startup time. The 20 day delay treatment had reduced growth rates for 55 days.

Delayed irrigation startup can result in reduced pasture production

Table 3. The effect of a 10 and 20 day delay in irrigation startup time on the yield of pasture during the recovery period and the recovery time of the pasture compared to a treatment irrigated at the optimum time at the Allansford trial site

	Optimum startup time	Treatment 10 day delay	20 day delay
Yield 'Lost' kg DM/ha	0	674	1154
% Yield 'Lost' over recovery period	0%	35%	60%
Recovery Period (days)	0	45	55

When irrigation does commence late, it is important that sufficient water is applied to bring the soil in the root zone up to near field capacity or else further losses in plant growth will occur.

Visual estimation of soil moisture content

Judging when the soil moisture content has dropped to around the "refill point" and hence when irrigation should commence, can be difficult. Our experience is that simple observation of the pasture appearance can be quite inaccurate. By the time visual plant symptoms are apparent in the pasture, the soil refill point has been well passed and the pasture growth rates have already dropped leading to significant pasture losses.

Testing the soil from the root zone of the pasture for moisture content by the "feel" in the hand can in some cases be a useful and practical guide. (Table 4). This "feel" varies with different soil types over different moisture contents and considerable experience is needed in interpreting the results. For pasture it is essential that the soil water content does not drop below 50% of available soil water content if reductions in yields and water use efficiency are to be avoided.

Assessing soil moisture content by feel

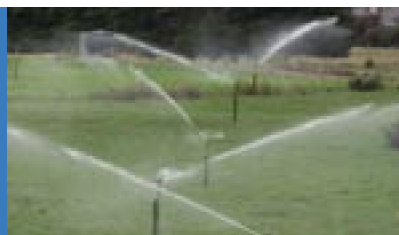


Table 4. Assessing the water content of soils by "feel"

Soil Water Content	Sands & Sandy Loams	Loams, Clay Loams & Clays	General Comments
Above Field Capacity	On squeezing, free water is expressed from the ball of soil.	Soil very sticky and sloppy. When squeezed oozes water.	Soil waterlogged. No air can get to roots. Growth retarded.
Field Capacity (100% available water)	No free water appears on the soil when the ball is squeezed but a wet outline is left on the hand.	Soil sticky. No free water appears on soil when ball is squeezed, but wet outline of ball is left on hand. Possible to roll long thin rods (2.5 mm diameter) between finger and thumb.	Plenty of water and enough air available to the plant.
75% available water	Slightly coherent. Will form a weak ball under pressure but breaks easily.	Soil coherent. Soil has a slick feeling and ribbons easily. Will not roll into long thin rods 2.5 mm diameter.	Adequate air and water. Plant grows well.
50% available water	Appears dryish. Tends to ball under pressure but seldom holds together.	Soil coherent. Forms ball under pressure. Will just ribbon when pressed between finger and thumb	**Close to refill point of the soil. Moisture stress will soon start to reduce growth rates.**
25% available water	Appears dry. Will not ball under pressure.	Somewhat crumbly but will form a ball under pressure. Will not ribbon between finger and thumb	Well past refill point. Very low growth rates.
Wilting Point	Soil is dry, loose and flows through fingers.	Crumbly powdery. Small lumps break into powder. Will not ball under pressure.	Severe moisture stress. Plants begin to die.

Use of tensiometers to determine startup time

A much more objective and accurate method of determining optimum start-up time is by the use of ***tensiometers*** installed in the soil under the pasture or crop. A ***tensiometer*** is a simple instrument that measures how difficult it is for a plant root to extract water from the soil, rather than the actual soil moisture content (see Appendix A for details on the operation and use of tensiometers). Ideally a number (preferably 4 or more) tensiometers should be installed in typical parts of the farm's irrigated pasture in the early spring and the readings monitored regularly.

Findings from our trials across the south west are that irrigation of perennial pasture should commence by the time readings have risen to 35 kPa and 30 kPa for tensiometers installed at 20 cm and 30 cm respectively (Table 5). These critical tensiometer readings have been found to apply across a range of soil types and textures. If irrigation is commenced after these critical values are exceeded, reductions in pasture growth will occur.

Tensiometers installed in the soil under the pasture or crop can provide accurate information to determine optimum irrigation start-up time

Table 5. The "critical" readings (kPa) of tensiometers installed at 20 cm and 30 cm depth in perennial pasture. Irrigation should commence before these critical values are reached to avoid reductions in pasture growth

Depth of Tensiometer in the Soil	"Critical" Tensiometer Reading
20 cm	35 kPa
30 cm	30 kPa

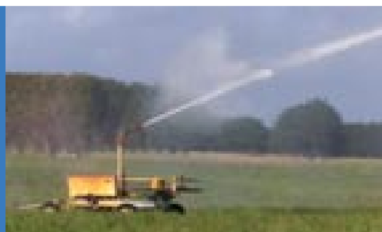
When these "critical" readings are reached, pasture growth rates will be just starting to decline. In practice, we should aim to water all irrigated areas on the farm by the time these "critical" levels are reached. As the tensiometer readings often rise quite quickly with the onset of dry conditions, the tensiometer readings need to be monitored regularly and experience gained on when irrigation should actually commence so that paddocks are irrigated before the "critical" levels are exceeded.

Other soil moisture measuring instruments such as neutron probes can be used to determine optimum irrigation startup times.

When to stop irrigating for the season

One detrimental effect of irrigation can be an increase in the incidence and severity of winter waterlogging. In particular, pastures on heavier textured soils or soils with impeded drainage can suffer significant reductions in winter growth and other problems associated with the earlier onset of waterlogging conditions. Under normal dryland conditions, the pasture extracts large quantities of water from the soil profile during summer creating a buffer for the absorption of the autumn and winter rainfall. In contrast, the soil profile under an irrigated pasture is kept moist and requires much less rain to become saturated.

Unless the soil is free draining, irrigation should cease early enough in the autumn to allow the soil profile to at least partially dry out. Evaporation rates (and hence pasture water use) usually start to drop significantly from mid March onwards. Local experience will be the best guide to when irrigation of particular soil types should stop in autumn. As a general rule, any irrigations after the end of March should be applied with caution.



6. Irrigation scheduling

Improved plant growth and water use efficencies can be gained by more accurately determining when and how much water to apply during the irrigating season.

Irrigation scheduling is the process of deciding ***when to*** apply irrigation water and ***how much*** water to apply. Good irrigation scheduling is critical to maximizing the feed production, water use efficiency and economic viability of an irrigation system. Sufficient water at the right time should be applied to the crop or pasture to match plant requirements and prevent it going into moisture stress and hence suffering reduced growth rates. Similarly, excessive water applications should be avoided, except if leaching salts from the soil (see Section 4).

Many irrigation systems in the south west are still producing well below their potential due to poor irrigation scheduling. In some cases, this is due to the irrigation system being under-engineered - the system is not capable of applying enough water to the area being irrigated within the required time frame. In other cases, the farmer does not know or have suitable aids in place to estimate irrigation water requirements.

Irrigation scheduling methods

There are a number of irrigation scheduling methods available to the farmer. They range from the fairly simple (e.g. time based) through more complex (e.g. evaporation measurement) to detailed assessments (e.g. measurement of soil water content). Generally, the more accurate methods are the more difficult or time consuming.

a) Time based
Irrigations are scheduled on a fixed number of days that can be varied from month to month based on experience. This can be quite inefficient, as it is difficult to take into account variation in evaporation and rainfall.

b) Observational
Physical inspection of the soil (Table 5, Section 5) can give an indication of approximate soil water content. It is not accurate and does not predict how much water is required.
Plant signs are even less reliable - our experience is that reductions in pasture growth rates occur long before wilting is apparent.

c) Weather based scheduling
There are several methods that predict how much water the pasture/crop has lost by evapotranspiration over a period of time, and therefore how much irrigation water should be applied to replace it. In its simplest form, evaporation is measured using an evaporation pan (see Appendix C) and together with rainfall data is used in a simple daily water budget (Appendix B). More detailed weather based scheduling techniques involve the use of data from automatic weather stations to enable the calculation of a more accurate estimation of evapotranspiration from the pasture. This equipment can be expensive and requires good operator skills and knowledge.

d) Soil based scheduling
This involves monitoring the soil water content of the rootzone under the pasture or crop. These readings give the best indication of how much water is available to the plant, especially after rain. Some instruments, such as tensiometers (see Section 5 and Appendix A), will indicate when it is time to irrigate, but not how

much water to apply. Other instruments, such as the neutron probe, measure the actual soil water content and can also be used to calculate the amount of irrigation water to apply. Neutron probes require a licence and specialist knowledge to install and operate. In some districts, private agricultural consultants offer an irrigation scheduling service using neutron probe measurements.

Neutron probes measure soil water content and enable the calculation of the optimum amount of irrigation water to apply

Penalties of not applying the required quantities of water

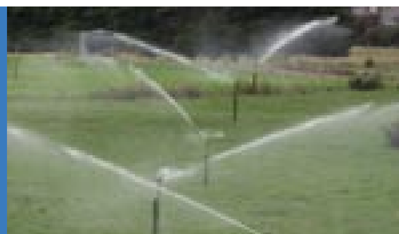
Applying either too little or too much water to an irrigation pasture results in losses and inefficiencies. An example of these is provided by experimental results from Myamyn in February 1998 (Table 6). Pasture water requirements were estimated using evaporation rates from a "Class A" pan and a crop factor of 0.8 (see weather based scheduling below).

Table 6. The yield (t DM/ha) and water use efficiency (t DM/ML) of pasture deliberately underwatered and overwatered compared to one watered with the optimum requirements at Myamyn in February 1998

	Irrigated with full water requirements	Deliberately underwatered by 30%	Deliberately overwatered by 30%
Yield of Pasture: t DM/ha (21 days regrowth)	1.5	0.9	1.5
Water Use Efficiency: t DM/ML	1.7	1.5	1.3
Irrigation water applied: mm over 21 days	90	60	120

Clearly, under summer conditions applying less water than the irrigation requirement leads to:
a) a major reduction in the yield of pasture per hectare
a) less pasture grown for every megalitre applied.

Applying more than the predicted irrigation requirement leads to:
a) no more pasture grown per hectare
b) less pasture grown for every megalitre applied.



Optimum Irrigation Intervals

The optimum irrigation interval is the number of days a pasture can go between irrigations without suffering reductions in yield. From trial work in the region, the optimum irrigation interval for pasture in the south west is between three and six days for most of the irrigation season. With intervals longer than this, marked reductions in pasture yield and water use efficiency can occur, even though the same total quantity of water is applied. This is illustrated by the results of a frequency of irrigation experiment at Allansford (Table 7) which showed a 35% reduction in both yield and water use efficiency for a 12 day irrigation interval compared to a 3 day interval.

Evaporation pans can be used to estimate pasture and crop irrigation water requirements

Table 7. The pasture yield (t DM/ha) and water use efficiency (t DM/ML) for irrigation intervals of 3, 6, 9 and 12 days at Allansford for the January – March 1998 period

	Irrigation Interval			
	3 day	6 day	9 day	12 day
Pasture Yield t DM/ha (January – March)	4.1	3.8	3.1	2.7
Water Use Efficiency t DM/ML	1.6	1.5	1.2	1.1

In practice, this "optimum" interval will vary from week to week depending upon the amount of evaporation and hence the crop water use.

Our experience from measurements of daily pasture growth rates on a range of soil types in the south west following a full irrigation are that the maximum pasture growth rates will be maintained up until, and then start to decline when:

Evaporation (E) (less effective rainfall*) = **25 – 30 mm**
Evapotranspiration (ET) (less effective rainfall*) = **20 – 25 mm**

*evaporation measured using a "Class A" evaporation pan (see Appendix C), and effective rainfall being the total rainfall for a rain event less 3mm (see Appendix B).

Therefore on extreme days with evaporation (E) rates of over 12 mm per day, the "optimum" interval can be as short as every two days. Correspondingly, in periods of cool weather with effective falls of rain this "optimum" interval can increase to more than a week.

Optimum Irrigation Schedules and System Capabilities

Guidelines for the "optimum" irrigation schedule

The "optimum" irrigation schedule that will maximize the yield of pasture and give the best water use efficiency will vary from week to week depending on the pasture water use.
Our findings, outlined below, indicate what a spray irrigation system on pasture should be designed and operated to deliver, as part of its normal operation.

Water application per week

The system should be designed to be capable of delivering 40 mm of water to the pasture per week in its standard hours of operation. On average during the December through to March period, around 35 mm per week is required. Additional capacity to apply a further 20% is required to meet peak demands and to cover leaching/uniformity requirements.

Irrigation interval

If possible, the system should be designed to enable an irrigation interval (i.e. days between irrigations) of between three and six days. Ideally the system should have the capability of covering the area in three to four days. Intervals of greater than six days lead to excessive reductions in pasture growth rates.

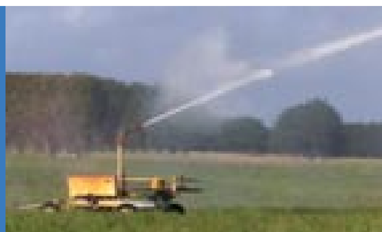
Water application per pass

Water applications per 'pass' or 'shift' ideally should be in the range of 15 to 25 mm. Applications of greater than 25 mm per shift on pasture are likely to be inefficient as:
a) Pasture growth rates are likely to have slowed already if these quantities are required and,
b) With heavy applications, some of the water will be lost beyond the root zone. Applications of less than 15 mm are likely not to infiltrate far into the soil, leading to the development of a shallow root system. Such shallow root systems make the pasture more vulnerable to drought stress.

Water application per hour

The optimum rate will vary depending upon soil type. As a guide it should not be more than 10 – 15 mm per hour. At higher application rates, the soil infiltration rate can be exceeded and water will be wasted by runoff.

Other factors that also need to be considered in the design of an irrigation system include the **running costs**, **evenness of watering** and the **labour requirements** of operating the system. The less even the water application, the more water will need to be applied to ensure that the minimum amount of water is applied over most of the area. Systems with reduced or minimum labour requirements will usually be preferred, but the generally higher capital costs of these types of systems needs to be considered.



7. Management of irrigated pasture

Appropriate grazing and fertiliser management of irrigated pasture will significantly improve its productivity and sustainability.

a) Grazing Management

The yield, persistence, water use efficiency and, ultimately, the profitability of irrigated pasture in the south west are commonly reduced by poor grazing management. As a result, the irrigated pastures do not perform to their potential and irrigation water is not used as efficiently as it could be. A common fault is that the period between grazings, or the grazing interval is too short. This has the effect of weakening plants and reducing growth rates. Other poor practices include grazing pastures too low and for too long.

Grazing irrigated perennial pastures over the summer period should be based on the same principles that apply to actively growing dryland pastures at other times of the year. These principles have been well established for perennial ryegrass and should be applied to obtain the best from an irrigated pasture. The three most important aspects of grazing management are grazing interval, grazing intensity and grazing duration.

i) Grazing interval or rotation length

A grazing rotation length coinciding with the regrowth of 2 to 3 leaves per tiller is optimal for ryegrass persistence, productivity, utilisation and quality. Repeated grazings at less than 2 leaves will not allow the plant to restock its energy reserves. As a result, growth rates and yields decline, the plants become weaker and are likely to have persistence problems particularly during stress periods. Grazing at more than the 3 leaf stage may result in a higher growth rate, but will waste feed with an increase in dead leaves, herbage will be of lower quality and the pasture may thin out.

Regular grazing at less than the optimal 2 - 3 leaf stage also has the effect of reducing the plant rooting depth. Shallower roots reduce the amount of water that the pasture can extract from the soil profile. An overgrazed pasture with an effective rooting depth of 15 cm would only be able to access around one half of the soil water of a pasture with a 30 cm effective rooting depth. This will require a shorter irrigation interval and result in less efficient use of water.

In south west research, the leaf appearance rate - or the rate at which new ryegrass leaves emerge has been found to be as low as 5 to 7 days in the peak of spring. However, under full irrigation during January and February, ryegrass leaf appearance times were at least 10 days. As a result, grazing rotation lengths less than 20 days are likely to be detrimental to irrigated pasture yield and persistence. Under these conditions, a rotation length of between 20 and 30 days would be more suitable.

ii) Grazing intensity or how hard to graze

Grazing irrigated perennial ryegrass pasture too hard and too low is a real risk and temptation when green feed is limited on the farm. The ideal grazing residue for ryegrass when the cows come off the paddock should be 4 to 6 cm of stubble. Regularly grazing to less than 4 cm stubble height will run down ryegrass plant energy reserves and weaken the plant leading to lower growth rates, a retardation of the root system, an increase in tiller death, decreased ryegrass plant survival and invasion of less desirable species into the pasture.

Leaving a residue of greater than 6 cm might lead to faster regrowth in the short term but can also lead to a reduction in herbage quality and increased wastage of feed. In addition, there is increased shading of the pasture leading to reduced ryegrass tillering and white clover growth resulting in a more open pasture.

iii) Grazing duration or how long to graze
Cows should not be allowed to graze an area of growing ryegrass pasture for more than 2 days at a time. If the paddock is being strip or block grazed for more than 2 days, a backfence should be used to prevent the cows from regrazing the previously grazed area. Grazing the new leaves and shoots that are regrowing from the stored energy reserves of the plant will further weaken the ryegrass plant reducing future regrowth and threatening the survival of tillers.

Good grazing management is essential to maximize irrigated pasture growth

b) Nitrogen Fertiliser Use

Recent research conducted in the south west has found that the growth of irrigated perennial ryegrass - white clover pasture is restricted by a lack of nitrogen. Regular applications of nitrogen fertiliser to the pasture over the irrigation season have been found to be an effective and cost efficient method of increasing pasture yields and in improving water use efficiency of irrigation systems.

How much nitrogen fertiliser should I apply?
Results from trials conducted at Nullawarre and Mepunga indicate that on balance the optimum rate of nitrogen to apply to perennial pasture during the irrigation season is 50 kg N/ha after each grazing. This is provided that optimum irrigation management and grazing management (including at least a 21 day rotation) is practiced.

Responses to and economics of nitrogen fertiliser
In these trials, nitrogen as urea was applied after each grazing at 0, 25, 50, 75 and 100 kg N/ha during the irrigation season, which extended from mid October to the end of April.

As illustrated in Table 8:
- Low rates of nitrogen, 25 kg N/ha per application, gave the most efficient nitrogen response with 1 kg of nitrogen growing on average 10 kg DM (10 kg N/kg N) of additional pasture consumed by the cows (note this is pasture consumed which will be less than what was actually grown)
- This low rate of 25 kg N/ha per application also gave the cheapest cost of extra pasture grown at $90 /t DM of additional pasture consumed (based on a cost of $400/t of urea).
- As the rate of applied N increased, the relative rate of response to N declined. The high (75 & 100 kg N/ha) rates gave the highest extra pasture consumed, but the efficiency of nitrogen response declined. At these high rates, the cost of the additional pasture grown ($/t DM) increased substantially and may not be economic.
- The 50 kg N/ha per application gave a good nitrogen response efficiency of 8 kg DM/kg N of additional pasture consumed at an attractive cost of $120/t DM. Given this and the practical considerations of spreading different rates of N fertiliser, it is suggested that the 50 kg N/ha per application is appropriate.

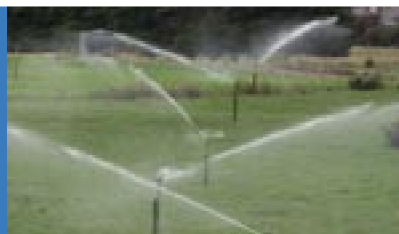


Table 8. Effect of a range of rates of nitrogen applied after each grazing on additional pasture grown, the efficiency of the nitrogen response and the cost of the extra pasture grown at Nullawarre (mid October 2003 - end April 2004)

N applied after each grazing (kg N/ha)	Total N applied (kg N/ha)	Total pasture consumed (t DM/ha)	Extra pasture grown (t DM/ha)	N response efficiency (kg DM/kg N)	Cost of extra pasture consumed ($/t DM)
0	0	5.9	0	-	-
25	225	8.2	2.3	10	90
50	450	9.6	3.1	8	120
75	675	10.4	4.5	7	170
100	900	10.3	4.4	5	220

Other considerations

Best responses to N fertiliser are obtained on pastures with a high proportion of sown, improved grasses such as perennial ryegrass. Suitable pastures should also be well supplied with other nutrients including phosphorus (P), potassium (K) and sulphur (S). N applications to pastures with a low improved grass content, or on soils of low fertility are less likely to be economic. Although N fertiliser will usually increase pasture growth rates, it does not speed up the rate of leaf appearance of the grasses. Therefore, the length of the grazing rotation should not be reduced when N fertiliser is used and should still be based on the 2-3 leaf stage of perennial ryegrass.

If irrigation management is poor, nitrates can be carried below the root zone of the pasture or crop. This will lead to inefficient use of the fertiliser and can cause pollution of ground water.

8. Irrigation of summer forage crops

Irrigated summer forage crops such as turnips, rape, maize and millet can be a high yielding alternative to irrigated perennial pastures.

The irrigation of summer forage crops, instead of perennial pasture can be a more efficient and productive use of irrigation water in some situations. This is particularly so when water supplies are limited, or when the availability is unreliable. It should also be noted that yields of irrigated maize will be affected at least as severely as perennial pasture if water supply is unreliable. Our district trial work shows that responses to and the benefits of irrigating a crop will vary from year to year depending on seasonal conditions. In addition, irrigators need to consider the additional costs and time involved in establishing and managing crops, the effect on timing of feed availability and the quality of the feed produced.

Over the last seven years, DPI Warrnambool has conducted a number of district trials on the irrigation of summer forage crops. These crops have included turnip cultivars, regrowth brassica species such as Hunter and the C4 tropical grass, millet. Some of the relevant observations and conclusions from these trials are presented in the following pages.

A. Benefits of irrigating summer forage crops

i) Yields of irrigated summer forage crops
The response of a summer forage crop to irrigation varies from year to year. In an average to drier summer, irrigation can double the yield of a summer forage crop compared to a non irrigated crop (Table 9). In other years, smaller but still quite useful responses to irrigation occur. However, in a wet summer, such as at Ecklin in 2001- 02, turnip responses to irrigation were small and were unlikely to be the most efficient use of the irrigation water.

The high yields of the millet crops are a characteristic of the C4 tropical grass crops - which are typically more efficient converters of water into dry matter growth than the C3 or temperate plants. However, the lower feed quality of the herbage produced must be considered (see section *B iii*) and the susceptibility of these crops to lower yields in the sometimes cool south west summers.

Irrigation can double the yield of a summer forage crop compared to a non-irrigated crop

Table 9. The yield (t DM/ha) of turnip, Hunter brassica and millet forage crops under full irrigation (100% of estimated requirement) compared to a dryland crop at Ecklin and Wollaston trial sites

			Yield (t DM/ha)	
Crop	**Trial Site**	**Year**	**Dryland**	**Fully Irrigated**
Turnips	Ecklin	2000-01	5.0	10.1
Turnips	Ecklin	2001-02	9.1	10.3
Hunter Brassica	Wollaston	2002-03	7.8	12.6
Hunter Brassica	Wollaston	2003-04	8.4	14.3
Millet	Wollaston	2002-03	12.0	14.9
Millet	Wollaston	2003-04	8.0	13.8

ii) Water Use Efficiency (WUE) of irrigated summer forage crops

The water use efficiency (WUE) of a crop or pasture is defined as the amount of herbage produced for every megalitre of irrigation water applied. This is often expressed as the tonnes of herbage dry matter produced per megalitre of water applied (t DM/ML). Where irrigation water supplies are limited, high WUE systems can be important.

Summer forage crops can have higher WUEs than perennial pasture, and therefore are often more efficient converters of irrigation water into feed. Typically, a commercial irrigated perennial ryegrass-white clover pasture will have a WUE in the range of 0.5 - 1.5 t DM/ML. New, well-managed pasture with high nitrogen fertiliser appplications will have higher WUE's than poorly managed old pasture.

Results from the Wollaston irrigation trial over the summer of 2003-04 indicate the type of WUE results from irrigated summer forages in an average to drier south west Victorian summer (Table 10). In this trial, two regrowth brassica forage crops (Hunter and Graza) and millet were irrigated at 100%, 50% and 25% of the estimated perennial pasture irrigation water requirement. In cooler and wetter summers, the crop responses to irrigation are likely to be lower with correspondingly lower WUEs.

Table 10. The water use efficiency (t DM/ML) of two brassica regrowth crops (Hunter and Graza) and a millet forage crop irrigated at 100%, 50% and 25% of estimated perennial pasture water requirements at the Wollaston trial site during the summer of 2003-04

	Water Applied		
Crop	**100%**	**50%**	**25%**
Hunter	1.6	1.8	1.8
Graza	1.4	1.3	1.4
Millet	1.5	2.9	3.3

iii) Responses to restricted irrigation regimes

There is good evidence that summer forage crops (with the exception of maize) are more tolerant than perennial pasture of "underwatering" or the deliberate application of quantities of irrigation water less than full plant requirements. Perennial pasture is quite sensitive to "underwatering". Growth rates and WUE falls off quite quickly as the pasture plants go into partial moisture stress when only part of their full water requirement is applied. However, fodder crops in some cases (Table 10) show an improvement in WUE when only part of the estimated full irrigation water requirement is applied, e.g. 50% of estimated full requirement. Part of the better water use efficiency may also be a result of the deeper root system of forage crops allowing more of the water stored in the soil profile to be used. Total yields from the crops will be lower than if they are fully irrigated, but more additional herbage is grown per megalitre of water applied.

iv) Lower total water requirements for the season

Irrigated summer forage crops require less total water for the irrigation season than an equivalent perennial pasture (see section 3). Our experience is that a fully irrigated summer forage crop in the southern part of south west Victoria requires between 3 and 4 ML/ha of irrigation water for the season. Fully irrigated perennial pasture requires approximately 7 ML/ha.

Reasons for the lower irrigation water requirements include:

- a shorter period of time when irrigation is required
- irrigation of crops does not commence until a number of weeks after pasture startup time
- the conservation of some spring rainfall in the soil that can be used by the crop over the summer
- crop water usage is lower in the seedling and early growth stages.

v) Opportunities for "once-off" or occasional irrigations

Trial results indicate that summer forage crops such as turnips can, in some years, effectively utilise "once-off" applications of irrigation water or other occasional irrigations during their growing season to boost the final yield of the crop.

At Ecklin in 2000/01, one off 50 mm applications of irrigation water were applied to a turnip crop (cv. Barkant) at a range of stages in the growth of the crop. Best responses to the "once-off" irrigations occurred at 8-10 weeks after sowing when the turnip bulbs were developing rapidly. A 50 mm irrigation at this stage lifted crop yield by 1.2 t DM/ha over the dryland crop (Table 11). This response was equivalent to a WUE of 2.4 t DM/ha.ML for the applied water. "One-off" irrigations early in the growth of the crop gave much lower responses. These results are consistent with Tasmanian findings that the best responses occur if the irrigation is applied as the turnip bulbs are starting to fill.

Irrigated millet crop at Wollaston trial site January 2004

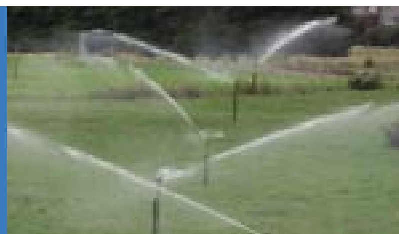


Table 11. The effect on yield (t DM/ha) and water use efficiency (t DM/ha/ML) of a "once-off" 50 mm application of irrigation water to a dryland turnip crop at a range of growth stages - Ecklin 2000/01

Crop Growth Stage (weeks after sowing)	Increased Yield over Dryland (t DM/ha)	Water Use Efficiency of Response (t DM/ha/ML)
0 - 6	0.1	0.2
6 - 8	0.5	1.0
8 - 10	1.2	2.4
10 - 12	1.1	2.1

The response of dryland perennial pasture to such "one-off" applications will, in our experience, be considerably less. Therefore, these results suggest that where irrigation water supplies are very limited or unreliable, and where summer feed is required, such applications to summer crops would be an effective use of the water.

A. Downsides of irrigating summer forage crops

Although there can be advantages in using irrigation water on summer forage crops rather than on perennial pasture, there are downsides that need to be considered.

i) Costs and time required to establish forage crops
Costs of establishing turnip crops in our recent studies, using current contractor, fertiliser, seed and chemical costs, was an average of $576/ha. The cost of re-establishing a perennial pasture after the crop was an additional $250/ha. Clearly, ploughing in a good irrigated perennial pasture to grow an irrigated summer forage crop will not be economical, even though there might be some advantages in WUE. However, if a pasture has deteriorated and requires renovation, the sowing and irrigation of a summer forage crop as part of the renovation process can be cost effective and could give some WUE advantages.

ii) Feed availability over the irrigation season
An irrigated perennial pasture will grow and produce forage all year with a relatively constant supply over the irrigation season if properly managed. Summer forage crops on the other hand do not have feed available for grazing for extended periods during their establishment and growing periods. While it is possible to stagger the sowing and grazing times, and use species or varieties with different maturity and grazing times, feed supply will often be more variable and more difficult to manage with irrigated forage crops than irrigated pasture.

iii) Quality of the herbage grown
Summer forage crops can vary greatly in the nutritive quality of their herbage. Any decision to grow irrigated summer forage crops should consider their nutritive quality as well as the WUE and other characteristics.

Irrigated perennial ryegrass-white clover pasture produces a high quality forage with good metabolizable energy (ME), crude protein (CP) and fibre (NDF) levels making it ideal for lactating or growing stock. The brassica forage crops such as turnips and Hunter typically have comparable to better herbage quality than irrigated pasture (Table 12). Values can vary depending on factors such as nitrogen fertiliser use and stage of maturity. These C3 (temperate species) forage crops are therefore capable of producing feed of high nutritional value and can replace other high quality feeds such as bought in concentrates. However, the C4 (tropical species) crops such as millet produce only moderate quality herbage. The lower metabolizable energy content and higher neutral detergent fibre content of the millet herbage will limit its potential for lactating dairy animals, unless it is used to replace other high fibre feeds such as hay or silage.

Table 12. Typical feed quality values for irrigated turnip, Hunter and millet forage crops compared to a perennial ryegrass-white clover pasture. Ecklin and Wollaston trial sites (2000/03)

	Metabolizable Energy (MJ/kg DM)	Crude Protein (% DM)	Neutral Detergent Fibre (% DM)
Turnip	13.7	18	24
Hunter Brassica	12.0	20	28
Millet	9.5	15	62
Pasture	11.5	20	47

9. Coping with reduced irrigation water supplies

Irrigation can still be managed effectively even when water supply is limited or unreliable.

South west Victorian irrigators, who are reliant on water supplies from streams and other surface diversions, regularly face the problem of reduced and unreliable irrigation water supplies. A combination of low stream flows during dry seasons, together with the requirements of stream flow management plans will result in water volumes of less than licence allocation for the season. A more difficult problem to manage is the unreliability of supply of this water. Changes in the volume of irrigation water available from week to week can play havoc with irrigation scheduling and lead to major reductions in yields and water use efficiency of irrigated pastures and crops.

Some factors to consider and possible strategies for coping with reduced irrigation water supplies are:

a) Where less irrigation water is available, but its supply is reliable

- *Pasture or forage crops?*
  Irrigated summer forage crops can have a higher water use efficiency (i.e. produce more feed per megalitre of water) than an established irrigated perennial pasture. However, as outlined in Section 8, it is usually not economic to plough up a pasture and sow a forage crop unless the pasture is degraded and in need of renovation. Other factors such as the period of feed availability, the herbage quality and the method of feeding the crop also need to be taken into account before moving water from pasture to forage crops.

- *Don't delay startup in spring*
  Perennial pasture is very sensitive to late irrigation startup. Once the pasture plants are water stressed at the start of the irrigation season, growth rates drop rapidly and it takes a number of weeks for the pasture to recover and get back to its normal growth rate (see Section 5). From a water use efficiency viewpoint, it is preferable to start irrigating pasture at the optimum time and finish irrigating earlier in the summer/autumn.

  If it is not possible to start irrigating pasture at the optimum time in spring, irrigation water is likely to be more efficiently used on summer forage crops midway through their growing period (see Section 8).

- *Fully irrigate or partially irrigate pasture?*
  A common response to reduced irrigation water supplies is to continue to irrigate the same area of perennial pasture, but apply less water per hectare. Our trials in the south west, together with results from other parts of the state clearly indicate that it is far more efficient to fully irrigate a smaller area of pasture with its full requirement of water (see Section 6) than to under-irrigate a larger area of pasture. Shallow rooted perennial pasture is particularly sensitive to drought stress. Where less water is applied, growth rates drop quickly and less feed is grown per megalitre of water applied.

  Irrigated summer forage crops appear to behave differently. Our results indicate that the best water use efficiency and hence the most additional feed grown per megalitre of irrigation water on forage crops is where the crop is partially irrigated (see Section 8).

- *Use the water for autumn startup?*
  In some circumstances, a late summer-early autumn start to irrigation could be an option for irrigators with limited water. No trials on this strategy have been conducted in the south west, but work in north east Victoria is relevant. This work suggests that the timing of the first irrigation is important. Depending on the autumn break, irrigating at the start of March may not produce a lot more feed than not irrigating at all. The best responses and water use efficiencies were found for an early February startup time. If irrigating from a dam, high summer evaporation rates will significantly reduce the volume of water available for late summer/autumn startups. Typically around 600 mm can be lost from dams over the summer by evaporation.

- *Use best pasture management techniques*
  Good pasture management has been found to substantially improve the yield and water use efficiency of irrigated pasture. Two of the key pasture management areas (Section 7) are:
  a) Grazing Management
  Avoid excessively short grazing rotation lengths. Ryegrass should be at least at the 2 leaf stage. Avoid excessively hard grazing – by making sure residues are at least 4 cm height. If strip grazing, back fence previously grazed areas.

- *Fertiliser use*
  Ensure that the irrigated pasture is adequately supplied with phosphorus, potassium and sulphur fertiliser. In trials nitrogen fertiliser application rates of between 25 and 50 kg N/ha after each grazing were found to optimize improvements in yield and water use efficiencies.

b) Where supply is also unreliable

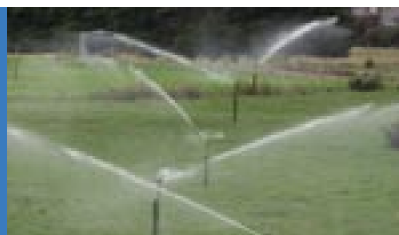
Where the volume of irrigation water available per week may vary from full entitlement to a total irrigation ban (e.g. streams with irrigation rosters), efficient use of water becomes more difficult. In these situations it is important that decisions on any changes are made early in the season to allow time for any changes to be effective. Such decisions will often have to be made with incomplete information - try to assess at the start of the season the amounts and reliability of irrigation water supplies.

Also consider:

- *A balance between irrigating perennial pasture and summer forage crops.*
  One of the biggest limitations of irrigating perennial pasture is that it is particularly sensitive to missed irrigations (see Section 6). When scheduled irrigations are delayed or missed, the plants go into partial water stress and growth rates decline. As a result, total pasture yields decline and the water use efficiency of the applied irrigation water is reduced. If the stressed pasture is then fully irrigated, there is still a lag period before pasture growth rates are back to normal. In comparison, summer forage crops appear to be more tolerant of missed irrigations. In addition, our research suggests that summer forage crops can respond favourably and profitably to once-off irrigations in the mid to latter phases of their growth period (see Section 8). A possible strategy may therefore be to irrigate a core area of perennial pasture with the irrigation water supply that is reasonably secure. Additional, less secure water may be better applied to summer forage crops in an opportunistic manner.

- *Be careful of poisoning risks with some of the tropical (C4) forage crops.*
  The tropical grass forage crops, such as sorghum, sudax and maize, are attractive options because of their high water use efficiency and the ability to produce high yields of forage. However, with some of these crops, such as the sorghums, there is a risk of stock poisoning from prussic acid. Potentially dangerous levels of prussic acid can develop when these crops are water stressed. Some other crops in this group, such as maize, are particularly sensitive to water stress at certain growth stages.

- *Carrying water over for an "autumn start" irrigation.*
  In some circumstances, it may be possible to stop irrigating during the summer and carry over the saved water to the autumn. Such water can be used as an "autumn start" irrigation onto pasture - that is, to create an early autumn break. However, if the water is stored in a dam or other surface storage, the high evaporation losses and the subsequent reduction in the volume of water available in the autumn need to be considered.



Appendix A: Use and care of tensiometers

What is a tensiometer?

A tensiometer is an instrument that can be used to measure the availability of water in the soil for plant use. They are simple, easy to use and relatively inexpensive.
In irrigated pasture management they are a particularly useful aid for:
a) Determining when irrigation should commence at the start of the season and throughout the season, and
b) Monitoring how effective the irrigation is in meeting plant requirements.

It is important to note that tensiometers are only an aid to making irrigation management decisions. The irrigator shouldn't rely on tensiometer readings alone, but should also use his own experience and other aids such as weather data to assist in decision making.

How does a tensiometer work?

Tensiometers consist of a rigid plastic tube with a porous ceramic tip at one end. The tube is filled with water that usually has some colouring dye and methylated spirits (5 – 10%) added. Some tensiometers have a built in vacuum gauge while others have an electronic vacuum gauge that can be transferred from one tensiometer to another.

When the tensiometer tube is filled with the water solution and installed in the soil, water can move in and out through the ceramic tip. As the soil dries, water moves out of the tensiometer and creates a vacuum in the tube that is then measured on the vacuum gauge. If the soil continues to dry out the vacuum reading increases. When water is added to the soil, water will move back into the tube through the tip and the vacuum reading will decrease.

The vacuum reading on the tensiometer is, in fact, a direct measure of the force or suction that a plant root has to exert to extract water from the soil. It does not measure the actual water content of the soil, but rather the difficulty the plant has in extracting water from the soil. As a result, the reading is comparable between different soil types.

Where to place tensiometers?

A number of tensiometers, preferably at least three or four should be installed across the irrigated area. It is essential that the sites chosen be representative of the soils and the pasture of most of the area and that they receive the same irrigation treatment. When located in grazed pasture, the tensiometer will need to be protected from damage by stock. If a protective cage is placed over the tensiometer, ensure that the pasture around the tensiometer is kept at the same height as the rest of the paddock.

What depth?

For irrigated pasture in south west Victoria, we have found that a depth of 20 cm was the most suitable for determining startup time. Tensiometers can also be installed at 30 cm depth in pasture, but the readings are slower to respond. It is recommended that tensiometers not be installed at depths of less than 15 cm.

How to install a tensiometer

Prior to installing, the ceramic tip must be pre-soaked in water for at least 24 hours to fill all the pores with water. In some cases, the tensiometer may also have to be pumped according to the manufacturer's directions to remove any further air bubbles.

The aim when installing a tensiometer is to maximize contact between the ceramic tip and the soil. On most soils, this is best done by augering a hole to the required depth using a T bar screw auger of the same or slightly narrower diameter than the tip of the tensiometer. Pour some water down the hole to lubricate the sides and slide the tensiometer in to the required depth. A cover should be placed over the above ground parts of the tensiometer to protect it from sunlight.

Tensiometer

Reading tensiometers

Tensiometers should, if possible, be read at the same time each day, preferably before the heat of the day.

Tensiometer gauges have a scale reading from 0 to 100 kilopascals (kPa). A tensiometer can operate effectively between 0 and 80 kPa.

For a tensiometer installed at 20 cm depth in irrigated perennial ryegrass-white pasture, the optimum levels of soil moisture for pasture growth are between 10 and 30 kPa (Table 13). At 35 kPa and above, the plant starts to experience increasing difficulty in extracting water from the soil and growth rate starts to decline. Prolonged periods with readings less than 5-8 kPa indicate that the pasture is waterlogged.

Table 13. Interpretation of readings of tensiometers installed at 20 cm depth in irrigated perennial ryegrass-white clover pastures

Tensiometer Reading (kPa)	Interpretation - effect on pasture growth
0 – 5	Saturated soil. Plants suffering from lack of oxygen in the root zone
8 – 10	Soil at 'field capacity'. The free water has drained away leaving a good proportion of air to water in the soil.
10 – 30	Optimum soil moisture range of the unrestricted growth of pasture.
35	The 'refill point' – the point where pasture plants start to suffer from reduced soil water availability.
40 – 80	The plant experiences increasing difficulty in extracting soil water leading to reduced growth rates.
80 - 100	The tensiometer is at the limit of its working range. It will suck air and will need to be refilled with water. In some cases, the tensiometer will need to be removed, pre-soaked again and re-installed in the soil.

Tensiometer maintenance

Tensiometers are vulnerable to damage and need to be protected from the grazing animal and other hazards. In grazed pastures it is usual to place a small weldmesh or similar pasture cage over the tensiometer to prevent it being knocked or trodden on. Pasture inside the cage should be cut just before cows are put into the paddock or any other harvesting takes place. This reduces the chance of cows pushing the cage over and keeps the pasture under the cage as the same growth stage as the rest of the paddock.

Tensiometers should be checked at least twice per week. If there is an air gap of more than 2 cm in the top of the water column, it should be topped up. The drier the soil, the more often the column will need topping up. Rapid drops in the water level are often caused by leaking rubber seals that need to be replaced.

When not in use over the winter period, tensiometers should be removed from the field and put into storage. Tensiometers are vulnerable to damage if the water in the tube freezes during frosts.

Further information:
Department of Primary Industries, Information Note Series:
Note number AG0298: "How to use tensiometers."

Appendix B: The use of water budgets for irrigation scheduling

Accurate irrigation scheduling requires a reliable estimate of the water losses (*evapotranspiration*) from the pasture and the contribution that any rainfall has made. Such estimates can be made by keeping a *water budget*.

The first requirement of a *water budget* is to be able to collect actual *evaporation (E)* results. Some weather recording stations measure evaporation and, in some districts, the daily evaporation rates are published in the press. If this information is not available, then evaporation needs to be measured by some means. Some automatic weather stations are able to calculate evaporation, but their accuracy needs to be checked periodically. A more simple and practical method is to measure the evaporation from an evaporation pan (see Appendix C).

The *evapotranspiration* (ET), or the amount of water lost by the pasture can be estimated by:

Evapotranspiration = Evaporation x Crop Factor

We have found a *crop factor* of 0.8 to be suitable for irrigated perennial pasture over the summer period. In other words, perennial pasture loses water by evapotranspiration at a rate of approximately 80% that of the evaporation from an evaporation pan.

The estimated pasture water loss or evapotranspiration sometimes has to be adjusted for any *rainfall* (R) that has occurred over the same period. Not all the rain that falls will be effective as a proportion of it will evaporate and not add to the soil moisture reserves. We disregard the first 3 mm of each rainfall event.

Therefore:

Effective Rainfall = Actual Rainfall – 3 mm

Table 14. An example of a water budget for use on a centre pivot irrigator on a five day irrigation interval

Day	Measured Evaporation (mm)	Evapo-transpiration[1] (mm)	Measured Rainfall (mm)	Effective Rainfall[2] (mm)	Soil Water Balance[3] (mm)
1	- Pasture Irrigated -				
2	8.0	6.4			- 6.4
3	5.5	4.4	6.0	3.0	- 7.8
4	6.0	4.8			- 12.6
5	4.5	3.6			- 16.2
6	6.0	4.8			- 21.0
Total	**30**	**24**	**6**	**3**	**- 21.0**

[1] *Evapotranspiration* is calculated by multiplying the *evaporation* by the *crop factor* of 0.8.
[2] *Effective rainfall* is estimated by subtracting the first 3 mm from each rain event.
[3] *Soil water balance* is kept by keeping a cumulative total of the *evapotranspiration* since the last irrigation less the *effective rainfall*.

Therefore, the estimated irrigation requirement for this period is 21 mm.

Note: In some situations where high salinity irrigation water is being used, or where the system does not apply the water uniformly, an additional 10 – 15% of water should be applied.

Appendix C: Using evaporation pans

If evaporation figures for the district are not available from newspapers or some other source, then it is worthwhile installing your own evaporation pan. If installed and used correctly, an on farm evaporation pan will provide accurate and up to date figures of the evaporation on your farm. This information, when used together with the rainfall in a water budget (Appendix B), will enable accurate irrigation requirements to be calculated. Measuring evaporation requires a regular but small time commitment. The benefits however are well worthwhile.

Types of evaporation pans

"Class A Pan"

The accepted standard pan for measuring evaporation throughout Australia and overseas is known as the "Class A" pan. This is a circular galvanized tank 1.2 m in diameter containing water 0.25 m deep. The pan sits 15 cm above the ground on a slatted wooden frame and is usually covered with netting to prevent birds or animals affecting the water level.

The pan is filled with water up to a standard mark, usually being 5 – 10 cm from the top. This mark usually being the top of a steel rod placed vertically in the middle of the tank. A "stilling well" – a circular sheet metal cylinder 15 –20 cm in diameter - is usually placed around the steel rod to reduce the effect of wind when reading the pan. Every day, at the same time, the pan is refilled with water up to this standard mark. By recording the volume of water that had to be replaced and knowing the surface area of the pan, the depth of the water replaced in millimeters can be calculated. This depth of water is the millimeters of evaporation, less any rainfall that has occurred over that time period.

"Mini-pans" or "Evaporimeters"

While the "Class A" pan will give the most accurate results, evaporation can also be measured on farm using smaller home made "Mini-pans" or "Evaporimeters". These "Mini-pans" can be made from either the bottom of a 200 litre steel drum or a plastic "Cherry Barrel".

Various designs have been produced, but all operate on the same principle.
We have found the plastic 200 litre "Cherry Barrel" design to be the most reliable.
To make one:

- Cut the drum exactly in half and clean up any rough edges on the bottom section to make the pan
- Cut a V notch about 5 cm down from the lip of the pan
- Fix a length of tape with millimetre markings either below the notch or on a central rod. (Alternatively, the volume of water to refill the drum to the notch or mark can be measured).

To set up the pan:

- Place the pan on cement blocks or pieces of timber (e.g. A wooden pallet) to allow air circulation under the pan
- Place wire mesh over the pan to prevent birds or animals drinking from it,
- Locate the pan in a typical open pasture situation, preferably in an irrigation paddock, and protect it from animals or other interference.

Note:

"Mini-pans" overestimate the amount of evaporation when compared to a standard "Class A" pan. In our experience a "Mini-pan" made from a 200 litre plastic "Cherry Barrel" will overestimate evaporation by approximately 15% and one made from the bottom of a steel 200 litre drum will over estimate evaporation by up to 40%.

If possible, a "Mini-pan" should be calibrated against a standard "Class A" evaporation pan.

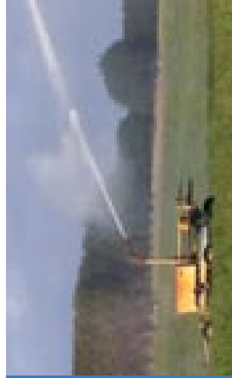
Further information:

Department of Primary Industries, Information Note Series:
Note number AG0293: "Construction of an evaporation pan for irrigation scheduling."

Appendix D: Irrigation methods – general comparison against key elements and considerations

Table 15. A general comparison of four different spray irrigation systems against a number of key elements and considerations for a 20 ha and a 40 ha scheme. Prepared with the assistance of Frank Mahony, Irrigation Engineer, Aquaflow Solutions Pty Ltd

	20 Hectare				40 Hectare			
Consideration	**Centre Pivot**	**Fixed Sprinkler**	**Long Lateral (van den Bosch)**	**Traveller**	**Centre Pivot**	**Fixed Sprinkler**	**Long Lateral (van den Bosch)**	**Traveller**
Rotation length - Heavy Soil	Excellent	Excellent	Good	Fair-Good	Good	Good-Excellent	Fair-Good	Poor
Rotation length - Light Soil	Excellent	Excellent	Fair-Good	Fair	Good	Good-Excellent	Fair	Poor
Uniformity	Good-Excellent	Good-Excellent	Fair-Good	Fair	Good-Excellent	Good-Excellent	Fair-Good	Fair
Capital Cost	Medium	High	Low-Medium	Medium	Low	High	Low-Medium	Medium
Operating Pressure	Low	Medium	Medium	High	Low	Medium	Medium	High
Pump Efficiency	Medium-High	Medium-High	Medium-High	Low	Medium-High	Medium-High	Medium-High	Low
Running Costs	Low	Medium	Medium	High	Low	Medium	Medium	High
Labour Requirements	Low	Low	Medium	Medium-High	Low	Low	High	High
Maintenance	Low-Medium	Low-Medium	Low-Medium	High	Low-Medium	Low-Medium	Low-Medium	High
Flexibility – Crops	Excellent	Excellent	Fair	Excellent	Excellent	Excellent	Fair	Excellent
Flexibilty – Other Areas	Poor	Poor	Poor	Excellent	Poor	Poor	Poor	Excellent
Site Constraints	Poor-Fair	Good	Excellent	Fair-Good	Poor-Fair	Good	Excellent	Fair-Good
Pasture Growth - Heavy Soil	Excellent	Excellent	Good	Fair-Good	Excellent	Excellent	Fair-Good	Fair
Pasture Growth -Light Soil	Excellent	Excellent	Good	Fair-Good	Excellent	Excellent	Fair	Fair



Appendix E: WISDAM

- WestVic Dairy Irrigation Scenario Decision Assistance Model

WISDAM, or the WestVic Dairy Irrigation Scenario Decision Assistance Model is a computer based decision support model developed to assist dairy farmers in south west Victoria make decisions regarding investment in irrigation.

WISDAM is a discounted cash flow model used to assess the economic and financial viability of various irrigation scenarios on a dairy farm. A discounted cash flow model discounts the value of money to be received or spent in the future back to what it would be worth in current dollar terms. WISDAM models a period of twenty years with year one being the year of initial investment. The model assesses the economic and financial viability of investment in irrigation by generating a range of measures including net present value, a benefit:cost ratio, a payback period and a peak debt level.

The model allows for the comparison of a range of irrigation scenarios for any one farm. It allows the user to choose from four different irrigation systems: travelling gun irrigator, fixed sprinkler, centre pivot and long lateral (van den Bosch). The user can assess just one system, or up to all four if required.

The user chooses the area to be irrigated and the anticipated improvement in productivity on this area. The user can specify productivity improvements as increased production per head, increased cow numbers or a reduction in the amount of supplements fed. Changes in any one or more of these variables can be recorded for each farm.

The WISDAM model consists of four spreadsheets in an Excel file for the inputting of data and presentation of results:

1) Current situation feedbase: This calculates an annual feed budget for the current farm situation without irrigation.
2) Feedbase with irrigation: Calculates a new feed budget incorporating the irrigation pasture.
3) Investment costs: Requires the user to specify capital as well as annual running costs associated with investment in the irrigation system.
4) Analysis results: Presents the results of the investment analysis for each irrigation system under investigation.

The WISDAM program and user manual are available for downloading from the WestVic Dairy website: www. westvicdairy.com.au