The Potential of Sub-surface Drip Irrigation for Annual Forage Production to Increase the Productivity of the Northern Victorian Dairy Industry

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ABSTRACT

Dairy farming systems in northern Victoria are changing in response to competition for water. The comparatively low water productivity of conventional perennial pastures compared to annual forage species is driving adaptation of the forage base as producers seek to limit their reliance on purchased feed and control overall feed costs. When used with annual crops grown in complementary rotations, sub-surface drip irrigation (SSDI) has the potential to deliver higher economic water efficiency than border check or sprinkler irrigation.

Uncertainty frequently impacts crop selection, sowing and fertilizer application. Fluctuations in water allocations could be managed more effectively if SSDI is used on a proportion of the effective milking area to help guarantee limited production without wasting time and money. More effective land and water management could also result from the base level production of home grown feed around which other forage options can be selected on a season-by-season basis depending on total water availability.

The industry has funded research into sub-surface irrigation for dairy pastures. This confirmed that prospects were sound, achieving both water savings and productivity gains but these were offset by high capital cost and the need for attention to detail. Lack of irrigation water compromised the research effort but contributed to technological innovation. Economic modelling indicated that the employment of sub-surface drip irrigation for grazed pastures was questionable but flagged the potential of the technology for forage production.

Research on sub-surface drip irrigation for forage production and rotational cropping to serve the dairy industry has not been subject to the same degree of scrutiny as pastures despite the appeal. For the purposes of simulation APSIM was employed to simulate a range of high intensive annual forage rotations under multiple cropping arrangements. Results showed that maize-based annual forage systems can produce over 25t DM/ha/year using 500mm or less water with high precision irrigation. Conventional perennial pastures produced 15t DM/ha/year, however in practice, actual on-farm irrigation water use by dairy pasture systems exceed 800mm/season under border-check irrigation, which is the predominant method of irrigation.

1.0 Acknowledgement

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2.0 Introduction

Border check irrigation (BCI) has served dairy farms in the Goulburn Murray Irrigation district for over 100 years. Water applied using this system supported the growth of annual and perennial pastures yielding a cost effective production system. Centre pivot, bike move and fixed sprinkler systems can also be found but these are not common and only a handful of growers employ subsurface systems to support dairy production in the region.

Over the last thirteen dry years the lack, together with the cost, of irrigation water has compromised prospects for the growth of perennial ryegrass/clover pastures, forcing farmers to evaluate alternative land uses and irrigation systems. There is increased reliance on annual crops and pastures whilst lucerne is more common.

Sub-surface drip irrigation (SSDI) is an alternative to BCI and has been evaluated for both crop and pasture production. It is also commonly used for urban irrigation. For the past four years a research program studying SSDI for dairy pastures has been conducted by the Department of Primary Industries (DPI) Tatura and the University of Melbourne/Monash University through Uniwater. Funds for this program were provided by a range of agencies including the Department of Sustainability and Environment (DSE), Dairy Australia and the Geoffrey Gardiner Dairy Foundation.

Preliminary results indicate that SSDI can be used for watering grazed pastures but, given the capital cost of the system, it will be essential to achieve water savings and improvements in dry matter production to justify the installation costs and to achieve pay back in the shortest time possible. It is also recognised that a high standard of irrigation management will need to be achieved and the return of wet conditions could compromise system performance through pugging and compaction.

SSDI is commonly used in regional tomato production and is becoming more popular in horticulture and viticulture where returns can justify the relatively high installation costs. In the case of row crop production the pay back for capital cost recovery is longer but the experience is limited to a few regional growers and there is a critical need to evaluate the technology for a rotational cropping system.

This paper presents some of the findings of grazed pasture research on SSDI with data on crop simulations. Simulation generates performance targets for comparison with actual crop production records from four farms employing SSDI technology. The purpose being to highlight the potential of the technology for forage crop production and to extend the findings of the technology for irrigating grazed pasture.

3.0 Background

The Northern Irrigation Region of Victoria produces approximately 26% of Australia's milk .The value of the dairy production and dairy processing industries in the region is around $2 b per annum, and the farm-gate profits for dairy producers are around $325 million per annum, the largest of all the irrigated agricultural industries in northern Victoria .

Growth is currently constrained by the costs and availability of resources (land, water, labour) and uncertainty regarding future climatic conditions. Dairy farmers face a challenge to maintain the economic viability and resilience of their businesses under difficult climatic conditions, likely shortfalls in irrigation water allocations, and increased costs of production. While global dairy production continues to rise, Australian dairy producers are confronted with modest milk prices and increased feed and fertiliser costs.

Water for irrigation has become limited due to persistent and recurrent droughts during the last five years. As the largest agricultural water user (~60% water allocated for irrigated agriculture in Victoria, ABS, 2006), the dairy industry is affected more by water shortages than other rural industries in northern Victoria. Large reductions in water allocations for irrigation have restricted the ability of dairy farmers to produce home grown feed, forcing farmers to purchase more feed from off-farm, at higher cost compared to home-grown feed, to fill feed gaps. Increased reliance on purchased feed increases the costs of production and the business risk of dairying in the region.

Climate change predictions of the CSIRO indicate that the availability of irrigation water in the Goulbourn-Broken region may decrease by a further 15 – 45% due to reduced rainfall. Shifts in seasonal rainfall patterns and increased inter-annual variability in rainfall are also expected. In addition, demand for water by other users (environment, urban etc) continues to increase. Thus, the irrigated pasture based dairying in Northern Victoria is currently under pressure to increase the production of high quality home grown feed with less water, reduce overall costs of production, and maintain profitability.

4.0 Irrigation Systems

The majority of irrigators in the region use border-check irrigation (BCI). While surface irrigation can theoretically be as water efficient as other irrigation methods, the current efficiency of surface irrigation systems on farms in the region is comparatively low. Improvements in on-farm irrigation efficiency and water productivity are needed to improve the profitability of dairy systems. New irrigation technologies, and associated farm management adaptations, offer one route toward improved water efficiency.

Border check irrigation attracts critics and stalwart supporters. Research and practice indicates that when flow rate, gradient, soil type, crop and drainage rate are matched, the system can be very efficient under the criteria of water use and energy. Sprinkler systems require less soil disturbance and landforming than BCI but are reliant on pumped reticulation and can suffer from wind disturbance. Fixed sprinkler systems have limited flexibility for cropping or resowing of pasture whilst the passage of travelling irrigators can be impeded by wet soil. All systems have advantages and disadvantages and experience indicates that the matching of the system to the crop, soil type, terrain and experience of the irrigator is critical.

Sub-surface drip irrigation (SSDI) delivered via underground tape is one of the most efficient methods of irrigation available. It has been practiced in many parts of the world for the last four decades, mainly for irrigating row crops. SSDI has significantly improved yields, yield quality, water use efficiency, and nutrient use efficiency of over 30 crop species compared to other irrigation systems in the United States of America (Camp, 1998, Camp and Lamm, 2008 Camp et al, 2000). Australian research and extension is drawing from this research (Devasiratham, 2009 and Harris, 2005).

5.0 Farm Production

Research has been directed toward determining the potential of SSDI for irrigation of perennial pasture in Victorian dairy systems (e.g. Wood and Finger 2006). As perennial pasture has historically constituted 60% or more of the total annual diet of cows this became a priority as relatively cheap water used to fully irrigate perennial pastures has been the foundation of highly profitable dairy systems. Benchmark data from approximately 165 farms in the region show that, for ‘average’ farms, the proportion of pasture in the total diet of dairy cows declined from 0.59 in 2005/06 to 0.45 in 2006/07 to 0.33 in 2007/08 (Table 1). At the same time, the average cost of all feed consumed increased from $228 to $306 and then $385 per tonne DM in the respective years. Operating profit for ‘average’ farms varied from $1,169/ha in 2005/06, to -$300/ha in 2006/07, to $510/ha (at an adjusted milk price of $4.20/kg milk solids) in 2007/08. Top 10% farms fared comparatively better (Table 1), but the same trends of declining home-grown feed consumption and profit, and increasing total feed costs, are evident.

Table 1 Pasture contribution to total diet, average feed cost, and operating profit, for ‘average’ and top 10% farms in northern Victoria 2005/06 – 2007/08. Source: Red Sky (http://www.redskyagri.com)

	Pasture as proportion of total diet	Average cost of all feed ($/t DM)	Operating profit ($/ha)
Average farms			
2005/06	0.59	228	1,169
2006/07	0.45	306	(330)
2007/08*	0.33	385	510
Top 10% farms			
2005/06	0.56	211	2,377
2006/07	0.52	265	965
2007/08*	0.43	353	1,040

* Milk price adjusted to $4.20/kg milk solids (cf. $4.40 in 2005/06, $4.23 in 2006/07)

Downward pressure on the proportion of the total diet comprised by home-grown feed has come from insufficient irrigation water allocations to sustain the growth of perennial pastures through summer. Farmers have responded to this by reducing the proportion of farm area sown to perennials and using more annuals, such as annual pastures which require irrigation water only at the start (autumn) and end (mid to late spring) of their growing season. High-producing summer crops such as maize have also become more prevalent, as farmers have sought ways of growing high tonnages of feed that can be conserved as silage

The farmer-driven adaptation of the forage base and the growing interest in irrigation technology both derive from growing competition for water. It is in this context that irrigation technology such as SSDI may present a viable option for some farm businesses. While the results of the research into SSDI applied to perennial pasture appear to be negative in terms of economic viability of the technology it may complement forage crops better than it does perennial pasture.

6.0 Previous Research

Although irrigated pastures receive nearly 50% of the total water used by agriculture in Australia (ABS 2007), limited research information is available on the use of sub-surface drip irrigation for pastures or forage crops. A recent analysis conducted by DPI clearly indicated that the use of SSDI with perennial pastures is not economically attractive (Heard et al. 2009), mainly because the increases in yield of perennial pasture (>4 t DM/ha additional pasture consumed) required to generate an acceptable return on the high up-front establishment costs of SSDI have not materialised. Wood and Finger (2006) found that SSDI led to about 1 t DM/ha per year extra pasture consumption compared to surface irrigation (18.4 t DM/ha/year compared to 17.4 t DM/ha/year), although this was achieved with 2 ML/ha less water. Heard et al. (2009) concluded that an additional 2.8 t DM/ha consumed annually from perennial pasture irrigated with SSDI, using 2 ML less water, and coupled with high water ($350/ML) and purchased fodder ($400/tonne DM) costs would be needed to recoup the investment on SSDI establishment costs (c. $9,000/ha, depending on quality of tape installed, distance between tapes, emitter spacing etc.

Fieldwork for a large DPI Victoria project is now complete and the data is now being assessed whilst a website is being developed by Dr. Amjed Hussain of DPI Tatura. This presents findings of both the DPI project and the complementary University of Melbourne project. Both projects suffered from dry conditions and constraints on irrigation water availability but this limitation forced the DPI researchers to effectively employ SSDI for pasture germination whilst the University's project was forced to rely on a stock water system for reticulation, thus reducing the capital and operating costs and improving stock water quality through filtration.

Whilst the DPI project concentrated on pasture productivity and water use on two small scale farm SSDI systems the Uniwater project studied water quality and emitter clogging potential, soil compaction and conduit damage under grazing and the relative performance of three types of SSDI conduit at the Dookie Dairyfarm. Some of the University research findings are presented below.

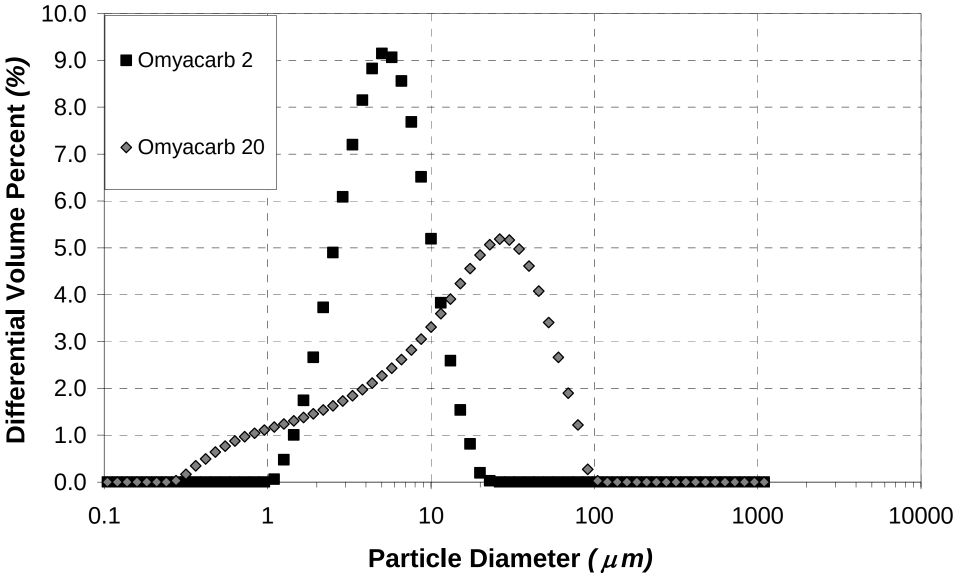

Figure 1 Particles in Water and Clogging Potential

Even particles in regional groundwater could compromise system performance and filtration is essential. Figure 1 indicates that particles less than 300 micron could clog emitters and if allowed to pass into the conduit, deposition would result. Regular system flushing is essential to remove accumulated silt and clay which is carried in the turbid channel water of the region. Clogging however is inevitable and periodic flushing with acid is an undesirable result.

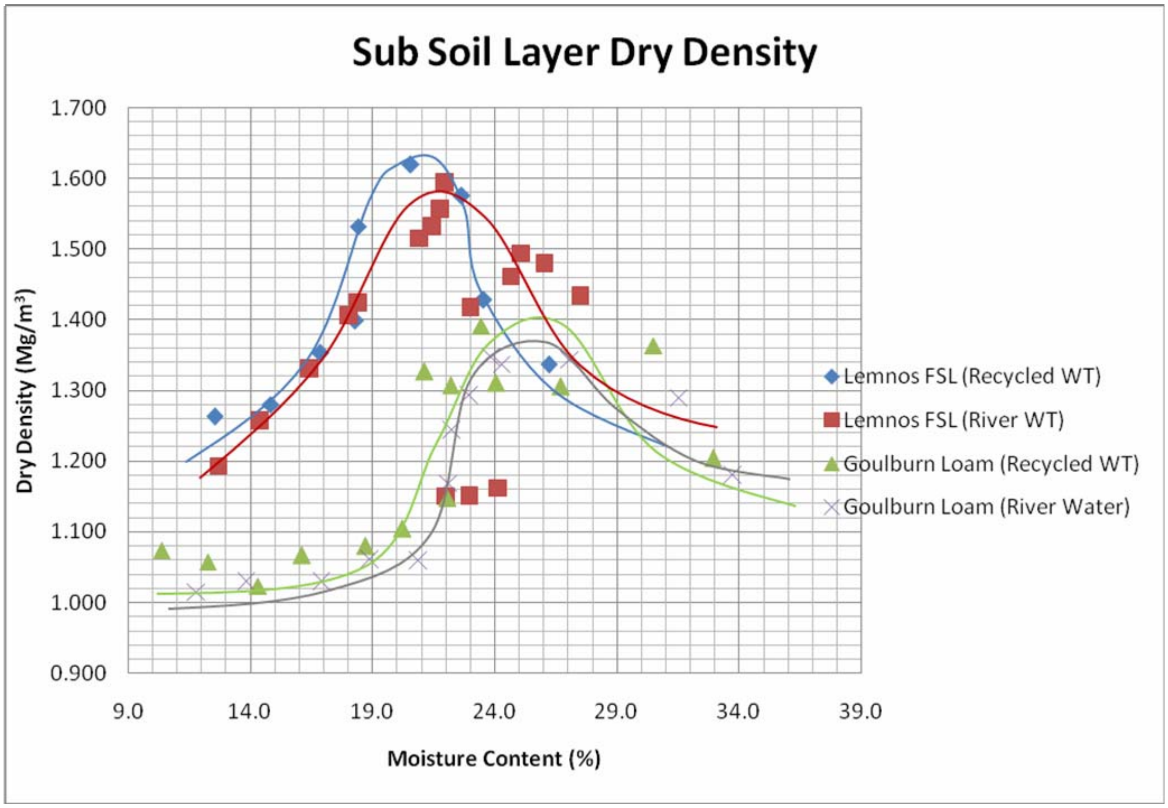

Figure 2 Results of Subsoil Compaction Tests

Figure 3 Wetted Annulus around SSDI Conduit

Figure 2 indicates that there is a well defined optimum moisture content(OMC) for two of the soils commonly irrigated for pasture and crop production in the region. In order to avoid pugging and compaction grazing needs to take place at OMC. Most irrigated soils in the region would display this compaction behaviour under animal traffic.
Figure 3 shows that in order to prevent root intrusion a wetted annulus must be maintained around the SSDI conduit**.** Root inhibitors are not recommended but can be used. The test plot site was destructively tested to reveal the performance of different SSDI systems with respect to clogging and root pattern. Research confirmed that different manufacturers products behaved differently with the same water, soil, pasture and animal traffic.

Knowledge gained from this research also appears in the DPI website. This includes the following recommendations:

- ✓ recommend installation of conduits in a pervious soil layer above a low permeability soil layer;
- ✓ prepare site prior to installation in an endeavour to reduce topsoil isotropy;
- ✓ match conduit and emitter spacing to soil type and crop;
- ✓ provide adequate filtration to remove coarse particles in irrigation water;
- ✓ select appropriate filters for the type of water to be applied;
- ✓ regularly flush lines to remove silt and clay escaping the filter system and deposited in -conduits;
- ✓ fix leaks as soon as they are found;
- ✓ check pressure drop across filters to ensure a satisfactory backwash;
- ✓ maintain a wetted annulus around emitters to limit root intrusion;
- ✓ ensure that stock are not permitted access under wet soil conditions or when leaks are contributing to saturated soil;
- ✓ observe non-uniform growth which could be associated with wet soil or clogged emitters.
- ✓ use existing farm pressure reticulation systems if possible to minimise capital and operating costs
- ✓ filtration systems could be used to improve stock water quality and milking shed cleaning water

7.0 Simulated Forage Production

Agricultural **P**roduction System **Sim**ulator (APSIM) was used to model two intensive annual forage cropping systems and three Northern Victorian commercial dairy forage producers were used as case study farms.
The soil used in the simulation was assumed to have the characteristics of Lemnos loam.

Agricultural Production System Simulator (APSIM)

The agricultural production systems simulator APSIM 6.1 (Keating et al. 2003) was used to simulate the performance of maize-brassica double cropping and maize- brassica field pea triple cropping systems. Agronomic criteria set up in simulations are described in Tables 3 and 4.

Simulated irrigation practice

Soil water balance module ‘Soilwat2’ calculates daily crop water balance and reports daily soil water deficit (among the other various out puts) for the user-defined effective root zone of the modelled crop. Irrigation module of the APSIM was set up to replaces the total soil water deficit automatically when the plant available soil water fraction reached 90% or less, however, irrigation frequency was set to two days. Although water balance module of APSIM has not specifically been designed to simulate SSDI, it effectively emulates SSDI process than surface irrigation application methods. Under field situations, achieving 100% irrigation efficiency may not be practical even under best managed with SSDI system, therefore, modelled irrigation efficiency was set to 95% allowing 5% water losses from the system.

Irrigation water availability was restricted to 1st September to end of April, which is the standard irrigation season for northern Victoria. For maize, over 85% of irrigation was used during the late spring and summer months.

Soil Type

Simulation used a Lemnos loam soil (Skene and Poutsma, 1962), commonly used for irrigated dairy pastures in Northern Victoria. This duplex soil is characterised by a 20 - 40cm lighter textured loamy A-horizon on a generally deep heavy textured medium to poorly drained subsoil. The soil has a capacity to store approximately 30 mm of plant available water in the profile to 100 mm depth.

Climate

Long term historical SILO climate data from for Dookie was used for the simulations. Results presented in this paper are based on 40 year climate data from 1960 to 2000 (Figure 4).

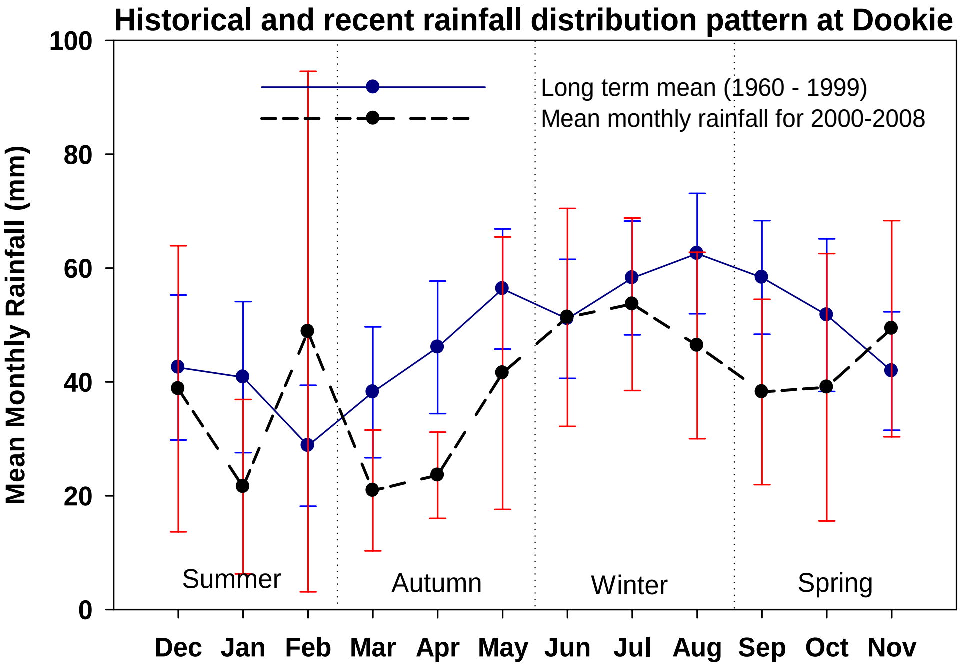

Figure 4 Monthly Trends in Rainfall at Dookie

Case Study Farms

Growers A, B and C have SSDI systems and all grow fodder for the dairy industry (their own or other dairies) in the Goulburn Valley, Victoria. The tabulated data is based on discussions with these growers, and calculations of the DM value of hay and silage produced from their SSDI blocks. The variations in yield are generally due to seasonal conditions and management (irrigation scheduling, weed control, pest control, adequate nutrition, correct harvesting time).

Table 2 SSDI Case Study Farms

Grower	**Location**	**Total land area (farm size) (ha)**	**Crop/Pasture**	**Area of SSDI (Ha)**	**Soil Type**	**Conduit Spacing (m)**	**Emitter Spacing (m)**	**Emitter Flow Rate l/hr**	**Comments** • **Years of experience** • **Comparison with other irrigation systems**
A 2008-2009	GMID	350	Lucerne	22	Loam	1	0.5	1.1	Lucerne planted Spring 2007 Stand reached peak production February 2009 (semi dormant variety reaches peak 18 months after emergence Huge ease of operation and higher WUE in comparison with flood irrigation
B	GMID		Maize	40	Loam	1.5	0.6	1.55	20 years experience with SSDI (tomatoes, legumes and cereals). SSDI itself doesn't guarantee success but makes it easier to farm, and gives more flexibility and more options, particularly in drought. n.b Maize was double cropped with barley in winter; barley yield was 6t/ha DM
B	GMID		Lucerne	100	Loam	1.5	0.6	1.55	
C	GMID		Lucerne	22	Loam	0.8	0.5	1.1	Lucerne planted 2006 High variability of yield – management by trial and error Ease of operation is a positive

Table 3 Agronomic/management rules used for three forage cropping systems simulated with APSIM

Parameter	Forage cropping system					
	Maize Brassica double cropping		Maize Brassica Fieldpea triple cropping			Lucerne
	Maize	Brassica	Maize	Brassica	Field Pea	
Variety	early maturing NSCM-41	A generic mid term	early maturing NSCM-41	A generic mid term	excel	Trifecta
Sowing date/window	15th and 30th Oct	20th Mar and 1st Apr	15th and 30th Oct	15th February and 30th April	15th May and 30th August	15 May 10 July
Planting density (plants/m2)	8	80	10	80	200	150 (at start)
Row spacing (cm)	15	15	15	15	30	25
Sowing depth (cm)	5	2	5	2	2	2
Fertiliser (N kg/ha as urea)						
@ sowing	200	100	200	100	100	None
1st top dressing (1st of Dec)	100	75 kg N/ha on 1st June	158	100 (around 30th May)	-	None
2nd top dressing (10th Jan)	100	75 kg N/ha on 1st August	158		-	None
Harvesting criteria	End of grain fill or by 15 March	Cut when dry matter reached 2500kg/ha and remove the crop by early Oct	Growth stage 9 or by 1st March	30th July	Complete harvest by 28th September	Cut at flowering
Cutting height (cm above ground)	5	5	5	5	5	5
Dry matter removal (%)	90	90	90	90	90	95

Table 4 Simulated and actual herbage yield, irrigation water use and water productivity of forage cropping systems.

System	Maize	Brassica	FP	Barley	Lucerne	Total	Irrigation volume (mm)	irrigation water Productivity (t/ML)
Modeled outputs								
Maize Brassica double cropping	19	6	-	-		25	461 (30)	5.4
Maize Brassica /Fieldpea triple cropping	16.8	5.8	2.6	-		25.2	483 (34)	5.3
Perennial forage cropping	-	-	-	-		24.6	587 (42)	3.6
Case study farms								
Case study A (2008-2009)	-	-	-	-	17	17	700	2.4
Case studyB -								
Maize/Barley double cropping	22	-	-	6	-	28	500-600	4
Lucerne	-	-	-	-	19-30	24.5	500-600	3.2 - 6
Case studyC Lucerne	-	-	-	-	20-30	25.0	700-900	2.2 – 4.2

8.0 Results of Simulations and Comparison with Case Study Farms and Published Data

Maize

Table 3 presents the data used and assumptions made in APSIM simulations whilst Table 4 presents mean biomass yields of three forage systems simulated using APSIM for 40 years. Results included individual biomass yields from each component in the system and also total biomass from the system modelled. Irrigated summer crop, maize produced an average biomass of 19t/ha and 16t/ha annually respectively for double cropping and triple cropping systems. Including the non-irrigated winter crop components in the systems, total biomass confirmed the potential for multiple forage cropping in the region.

The SSDI maize crop of Case study farm A produced 22t/ha dry matter biomass for the 2008/2009 season and producer indicated that he managed to obtain over 20t/ha consistently

The simulated results from APSIM and the biomass data from the case study farm B for maize are reasonably consistent with the previously reported data for irrigated maize. In a triple crop experiment at Camden, NSW, Garcia & Kerrisk (2008) reported a range in yield of 24-27 t/ha under micro-sprinklers with unrestricted irrigation. In addition, the same authors reported a simulated yield (derived using APSIM) of 25-27 t/ha (Garcia & Kerrisk, 2008) under climate at Camden, NSW. Greenwood et al. (2006) reported on-farm maize yield of 18 and 19 t/ha under border-check irrigation from a farm in North Eastern Victoria. On-farm maize biomass yields under centre-pivot spray irrigation as reported by Greenwood et al. (2006) ranged from 18 – 21.9t/ha.

Brassica and Lucerne

The simulated Brassica biomass was found to be quite variable(4.9-7.1 t/ha) whilst the total harvested biomass for lucerne resulted in average yield of 22 t/ha/year over the 40 year period simulated with APSIM. This yield was achieved with irrigation restricted to 1st September to end of April of the following year. These modelled lucerne biomass yields were within the range of actual biomass yields under SSDI reported from case study farms

Both simulated lucerne biomass yields and actual yields from case study farms compared favourably with the reported lucerne under irrigated conditions., border-check irrigated (BCI) lucerne produced 20.5 -26.1 t/ha from an on-station field experiment conducted on a Lemnos Loam soil at Kyabram (Greenwood et. al., 2006). Similarly, Lawson et.al (2004) achieved similar yields under BCI on field experiment conducted at Kyabram. This was conducted from 2004 – 2007and the results finally reported in 2008. Although the conditions may not be similar,the highest achieved yields from case study farm B and C under SSDI were nearly 4t/ha above the BCI irrigated lucerne at Kyabram. Greenwood(2003) had previously indicated that prospects for increasing dry matter yields from irrigated forage production were good.

Irrigation Water Use and Water Productivity

Irrigation volumes and productivity data generated from APSIM simulations and the case study farms are presented in the Table 4 along with some previously recorded data from literature. As expected simulated irrigation water use by summer forage crop Maize under triple cropping was about 20mm higher than under the double cropping. However, maize under both multiple cropping systems used less than 500mm of irrigation per season, this included 5% losses added into the simulations. In reality, this kind of low irrigation volume would not be expected under on-farm conditions. However, highest recorded irrigation water use for maize crop at Case study farm B under SSDI was only 600mm (Table 4).

The annual average modelled irrigation water use by lucerne was 585mm. Actual irrigation volumes used by lucerne under SSDI on case study farms ranged from 500-900mm. Lower irrigation volumes (500-600mm) for lucerne reported from the case study farm could be attributed to experience of SSDI as the operator of this farm has over 15 years of experience.

The simulated results for maize from both models are reasonably consistent with observed data for irrigated maize. In a triple crop experiment at Camden, NSW, Garcia & Kerrisk (2008) reported a range in yield of 24-27 t/ha. In addition, the same authors reported a simulated yield (derived using APSIM) of 25-27 t/ha (Garcia & Kerrisk, 2008). In north eastern Victoria, a range of 19-22 t/ha was reported by farmers, and yields of 18-20 t/ha were reported by researchers (Greenwood et al. 2006).

9.0 System Costs

The data provided in Table 5 is based on discussions with the growers A,B,C and is based on system replacement value in 2009.The capital costs are separated into the cost of preparing the ground and the cost of materials and installation of the actual system. There is likely to be marked difference in costs between systems supplied by rival manufacturers. These are also influenced by the scale of the installation, access to power, filtration requirements, valve configuration, mode of installation, type of conduit and spacing of tapes.

Table 5 Cost Estimates for SSDI Systems from Case Study Farms

Case study	Crop/Pasture	Capital Cost ($/ha)	Operating Cost ($/ha)
1 2008-2009	Lucerne	$11,000 total $8,000 SSDI system	$1200
2	Maize	$7,000 (total) $5,000 (SSDI system)	$1200
2	Lucerne	$7,000 (total) $5,000 (system)	$1200
3	Lucerne	$8,000 (total) $7,000 (SSDI system)	$1300

10.0 Comments and Conclusion

Tomato growers in the GMID region employed SSDI in the 1990s to maximise the quality and quantity of their crops with reduced labour; it was also found that less irrigation water was required by comparison with furrow and sprinkler irrigation systems. Other factors contributing to this change included the avoidance of drainage problems and the ability to produce a number of crops in succession whilst achieving uniformity of quality. SSDI permitted access to irrigated blocks for planting, weed control and harvesting under continuous cropping.

As a result of the positive outcome for tomato production the technology has been gradually taken up for permanent plantings in horticulture, viticulture and for annual row and broadacre pulse, legume and grain crops. Growing interest in the technology for irrigating grazed dairy pastures resulted in the commissioning of research projects with DPI Tatura and the Uniwater; these projects demonstrated the feasibility of SSDI for application to perennial pasture and flagged a range of considerations which apply to the dairy industry.
Based on the results of industry experience, field research, survey and modelling there is the opportunity to use SSDI to improve the quality and quantity of dry matter with associated water saving. Monitoring the performance of existing systems and crop yields is essential to provide more accurate measures of spatial differences in production and water distribution to confirm the survey and modelling work.

Given the complexity of SSDI it is important that all agronomic factors and water quality impacts are accounted for in replicated experiments. There is some scepticism that positive outcomes are associated with the zeal of unique irrigators and a fortuitous alignment of conditions rather than the application of sound irrigation science with good irrigation management.

The use of water for irrigated agriculture needs to be justified on the basis of dry matter production levels per unit of water applied compared with dryland production systems. Typical ML/ha ratings are not effective measures of enterprise performance and ignore production levels.

Rather than concentrate on capital cost and operating cost comparison of a range of irrigation systems it is important to expand the range of parameters for consideration. Of particular interest are the merits of sub-surface fertigation to reduce nitrogen emission rates and the opportunity cost of time which could be realised through automation.

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