EFFECTS OF MODIFIED SUB-SURFACE DRIP ON LETTUCE CROP ESTABLISHMENT, SOIL MOISTURE AND DRAINAGE

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ABSTRACT

The effects of a modified and conventional subsurface drip (SDI) on lettuce crop establishment, soil moisture and drainage were examined in a sandy soil at Richmond, NSW. In two field experiments, modified SDI gave a small but significant increase in percentage lettuce establishment and substantially greater plant fresh weight two weeks after transplanting (20% increase overall). The improved crop establishment and growth were related with more uniform wetting of soil surface and higher soil water content after irrigation, which averaged 22% in Modified SDI compared with 19% in conventional SDI. In a glass house study with 35 cm deep pots, a constant 6 kPa soil suction (applied via tension table in the bottom of each pot) and constant irrigation (4 mm/day), the modified SDI and more frequent irrigation (four/day) resulted in reduced drainage and improved surface soil water content.

INTRODUCTION

Irrigation in the Australian vegetable industry has traditionally been dominated by the use of surface irrigation. Increasing pressures on water availability, plus the potential yield increase through improved control of soil and plant water relationships, and the benefits of reduced labour, fertilizer and pesticide cost (Camp *et al.* 2000) have raised vegetable grower interest in alternative irrigation application techniques, including sub-surface drip irrigation systems (SDI) (Cornish *et al.* 2005). Surface irrigation leads to nutrient rich runoff and drainage. These problems are more evident in Sydney's intensive horticulture area (Cornish and Hollinger 2002). The farmers in the Sydney region do not use any form of irrigation scheduling or soil water monitoring (Cornish *et al.* 2005).

In intensive vegetable production lettuce is grown from seedlings and purchased from nurseries (Dimsey and Vujovic 2005). Seedling establishment using SDI may be poor due to wetting pattern, crop type, soil properties and drip tape depth (Harris, 2005). The seedling establishment stage is the one of most critical stage of lettuce crop and 'transplant shock' is common (Titley 2000). This paper considers if modifications to SDI can improve the establishment of lettuce which SDI depends on capillary water movement from buried emitter to seedlings, evaporation, soil texture, structure and hydraulic conductivity of soil. Bed shape, number of tapes per bed and tape depth can also be important when establishing with SDI (Burt and Style 1994).

To counter the problems of poor crop establishment, Welsh *et al*. (1995) introduced a new technique for manipulating the wetting pattern of SDI using an impermeable membrane to transform the point source of water in drip lines to a broad band source from which capillarity draws water upward and outward. However, attempts to use capillary root zone irrigation (CRZI) to improve seed germination of English spinach were unsuccessful (Charlesworth and Muirhead 2003). It appears that further research is needed to reduce the technical barriers to SDI including system design, drip tube placement depth and system management, which will depend greatly on local soil and climate conditions and constraints.

The CRZI product was modified and re-introduced under a new trade name as Kapillary Irrigation Subsurface System (KISSS™). The hypothesis supporting this paper was that the impermeable layer creates a small temporary water-table from which the upward flux of water is increased. More research is still required for crop establishment, soil moisture and drainage. The experiments reported here compared the modified SDI (KISSS™) and conventional with respect to surface soil water and crop establishment and growth, using lettuce transplanted into sandy soil. A glasshouse experiment quantified the effect of both types of SDI on the components of the water balance under controlled conditions which reported only drainage here.

MATERIALS AND METHODS

Location of study and soil

The experiments were undertaken at the University of Western Sydney Hawkesbury (UWSH) Campus at Richmond, 64 km west of Sydney, NSW. The soil type was Clarendon sand, a freely draining coarse sand brownish grey in colour to a depth of 75 cm overlying a light grey and yellow brown sandy clay (Aiken 2004) with low permeability.

Field experiment design

Experiments were conducted in autumn and spring 2007. In autumn the treatments were two drip tape types (T1-Modified SDI, T2-Conventional SDI) and three irrigation frequencies (1, 2 and 4 times per day designated as I1, I2 and I4) with a crop factor of 0.4 used to determine irrigation requirements. Crop factor is a proportion of pan evaporation that estimates water use by a crop and is commonly used to schedule irrigation (Qassim and Ashcroft, 2006). Generally, crop factors rise with leaf area index (LAI), but a relatively high factor can be used for newly-planted crops to ensure establishment, and then lowered in line with LAI. The amount of water applied daily was determined by multiplying the previous day's Class 'A' pan evaporation by the crop factor. One suggested crop factor for SDI during the initial stage of lettuce is 0.7 (Gulik and Nyvall 2001; Howell and Meron 2007). In the spring experiment, an additional treatment compared two crop factors 0.4 (A1) and 0.8 (A2) under both drip types and the same three irrigation frequencies.

Both experiments were laid out in a randomised complete block design with eight replications for the autumn experiment and four replications for spring. Beds were 6 m long and 1 m wide. SDI tapes were installed in each bed at a depth of 15 cm (Schwankl *et al.* 1990) with lateral spacing of 30 cm. Both drip tape types used identical 1.6 L h^{-1} emitters at 50 cm spacing.

General agronomic management ensured conditions were favorable to plant growth. Weeds were controlled before field preparation by spraying glyphosate (at 1.15L/ha). Compound fertilizers at 100 kg/ha (12% nitrogen, 5.2% phosphorus and 14.1% potassium) were incorporated 3 days prior to transplanting. Insecticide (Entrust® at 60 g/ha) was applied as necessary during plant establishment.

Commercially produced Cos lettuce (*Lactuca sativa*) seedlings were transplanted at 30 cm spacing between plants and rows giving three rows of lettuce per bed. Total rainfall of 4.6 and 1mm were received during the two-week establishment period of the autumn and spring experiments respectively.

Measurements included crop establishment and plant fresh weight in both seasons are presented here. The crop establishment was assessed on 14 days after transplanting (DAT). The total plant population was counted and converted into percentage establishment. Lettuce fresh weight was measured at 14 days after treatments commenced and expressed as g/plant. Volumetric soil moisture content was measured with a Theta probe (model of ML-2x a Delta T-Device). In the autumn trial, measurements were taken at 10 cm depth two times randomly from the bed immediately after irrigation. In the spring trial, measurements at 5 cm depth were made from the centre of the drip line and both sides of the drip line before irrigation.

Glasshouse experiment

Pots were 50 X 35 X 30 cm and contained 25 cm depth of soil above a tension table made of silica flour. The tension table was connected to hanging water column with a burette to indicate the suction in the table. The experimental apparatus consisted of a water inflow (irrigation) placed below the soil surface and outflow (drainage) system connected to the base of the pot below the tension table. By regulating the rate of irrigation and measuring drainage, evaporation from the bare soil surface could be calculated. Soil water content and potential were measured, but not reported.

To aim was to quantify drainage under steady-state conditions under a constant rate of irrigation and daily evaporative demand, with no plants presents. There were two treatments: soil types (2) and drip tape types (2), with two replicates. These treatments were compared under a succession of different irrigation regimes (irrigation rates and frequencies/day). The soil was saturated from the bottom prior to imposing a new irrigation regime and subsequently equilibrated to maintain -60 cm suction. The outflow (drainage) following irrigation was collected and weighed until steady-state was reached. The irrigation rate was a fixed proportion of E_{pan} (4mm/day) in the glasshouse, which was measured daily.

Statistical analysis of data

The crop establishment data were calculated as percentage data that needed to be transformed as square root transformation (Steel and Torrie, 1960). Analysis of variance (ANOVA) was conducted on data from both experiments using MiniTab *ver.* 14.

RESULTS

Crop establishment

In both autumn and spring, the mean establishment rate for modified SDI (KISSS™) (100% and 99%) was significantly greater than the conventional SDI (93%, $p<0.01$), (97%, $p<0.05$) respectively (Table 1). In neither season there was no significant difference between irrigation frequencies. There was no significant difference due to crop factor in the spring experiment.

Table1. The effects of tape types, irrigation frequencies and crop factor on establishment (%) of lettuce (sampling at 14 days after transplanting)

IF (irrig./ day)	**Autumn**			**Spring**				
	M.SDI	C.SDI	Mean IF	M.SDI 0.4 C.F.	M.SDI 0.8C.F.	C.SDI 0.4 C.F.	C.SDI 0.8C.F.	Mean I.F.
One	100	93	96	98	99	97	98	98
Two	99	92	96	98	98	96	96	97
Four	100	96	98	99	100	96	97	98
Mean of tape	100*	93	NS	99*		97		NS
Mean of C.F.	-			0.4 C.F. = 97		0.8 C.F. = 98^{NS}		
Tape type x I.F.	NS			NS				
Tape type x C.F.	-			NS				

* Significant at P<0.00, NS-not significant

Soil moisture

In the autumn experiment, the modified SDI system had greater soil water content than conventional SDI after irrigation, measured in both the first and second week after irrigation treatments commenced (Table 2). Increased irrigation frequency increased soil water content regardless of SDI system.

Table2. Effect of tape types and irrigation frequency on volumetric water content (v/v %) during crop establishment stage in autumn 2007 (after irrigation)

Tape type	First week after treatment commenced			Second week after treatment commenced		
	Irrigation frequency day^{-1}			Irrigation frequency day^{-1}		
	1	4	Mean	1	4	Mean
M.SDI	0.192	0.246	0.219*	0.180*	0.251	0.215
C.SDI	0.175	0.201	0.188	0.164	0.204	0.184
Mean	0.183	0.223**		0.172	0.228**	

*, ** Significant at P<0.05, 0.01 respectively

In the spring experiment, volumetric soil water content responded to crop factor, tape types and irrigation frequencies (Table 3). In this trial, soil water was measured just before irrigation. The modified SDI had higher volumetric soil water content (mean 0.045) than conventional SDI system (0.039). Higher soil water content was obtained in the treatment with the modified SDI and four irrigations per day (0.077).

Table3. Effect of tape types, crop factor and irrigation frequency on volumetric water content (v/v %) at crop establishment stage (before irrigation)

IF (irrig./day)	M.SDI 0.4	M.SDI 0.8	C.SDI 0.4	C.SDI 0.8	Mean IF	Mean C.F. x I.F. 0.4	Mean C.F. x I.F. 0.8	Mean Tape x IF M.SDI	Mean Tape x IF C.SDI
One	0.016	0.026	0.013	0.038	0.023	0.015	0.032	0.021	0.025
Four	0.049	0.088	0.038	0.067	0.060	0.045	0.077	0.049	0.053
Mean C.F. x Tape	0.032	0.057	0.026	0.053					
Mean of tape type	0.045*		0.039						
Mean of C.F.	0.4 C.F.= 0.029		0.8 C.F. = 0.054*						
Mean of I.F.	**								
Mean of C.F. x tape types	***								
Mean of C.F. x I.F.	*								
Mean of tape types x I.F.	*								
Mean of C.F. x tape types x I.F.	*								

*, **, *** Significant P< 0.00, 0.002, 0.05 respectively

Table4. Effect of tape types difference between emitter positions on volumetric soil moisture content (v/v %) during spring at crop establishment (before irrigation)

Position	Tape X Position M.SDI	Tape X Position C.SDI
One side of drip line	0.045	0.038
Centre of drip line	0.044	0.041*
Other side of drip line	0.045	0.038
Means of tape types	NS	*

* Significant at P< 0.00; NS- not significant

Tape type significantly affected soil moisture at different positions in the bed relative to the drip tape. The conventional SDI had higher soil water content over the drip line (0.041) than either side (0.038) (Table 4). The modified SDI had uniform soil water content.

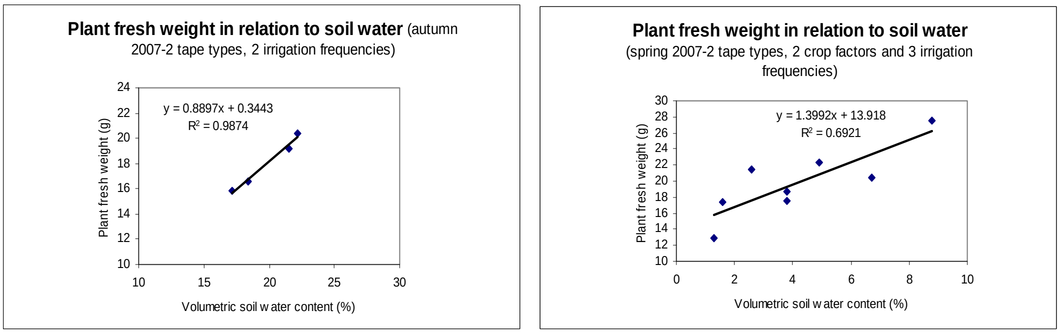
Plant fresh weight

In both experiments, plant fresh weights were greater at the end of the two week establishment period. The differences in fresh weight were substantial, with the

M.SDI system recording increases over the C.SDI of 16% and 25% in the autumn and spring experiments, respectively (data not shown).

Over all treatments, there was a strong relationship between surface soil water content, measured either before or after irrigation, and plant fresh weight at the end of the establishment period (Fig. 1).

Fig1. Plant fresh weight response to volumetric soil water content during both seasons



Drainage

Steady-state drainage in the pot experiment was significantly (P<0.001) less for modified SDI (1.4mm/day,) than conventional SDI (1.8mm/day). More frequent irrigation (4/day) gave reduced drainage (P<0.001).

Table5. Effect of drip tape type and irrigation frequency on steady-state drainage (mm/day)

I.F.	**Soil type**				I.F. x Soil		I.F.x Tape		Mean of I.F.
	Sand		S.loam						
	Tape type				Sand	S.loam	M.SDI	C.SDI	
	M.SDI	C.SDI	M.SDI	C.SDI					
1/day	1.4	1.9	1.3	1.9	1.5	1.6	1.4	1.9	1.6
2/day	1.5	1.8	1.6	1.8	1.7	1.7	1.5	1.8	1.7
4/day	1.1	1.5	1.1	1.4	1.3	1.3	1.1	1.4	1.3*
Mean of tape									
KISSS™	1.4*								
C.SDI	1.8								
Mean of soil									
Sand	1.6 NS								
S.Loam	1.6								

* Significant at P<0.001; NS-not significant

DISCUSSION

Overall performance

Although SDI has advantages over conventional drip, seedling establishment is often poor compared with other irrigation methods. Supplementary surface irrigation is usually required, resulting in wasted irrigation water via either runoff or drainage (Harris, 2005). Both of the field experiments reported here show that modifying SDI with an impermeable layer and geotextile fabric has the potential to improve surface soil water, plant establishment and early growth. A major reason for the improved overall performance was the superior wetting pattern of the modified SDI. The glasshouse experiment shows that these advantages can be achieved with reduced drainage and therefore with higher upward flux.

The modified SDI system resulted in better survival of the transplanted seedlings. The difference was numerically small at an average of 99% for modified SDI and 95% for conventional SDI, but it indicated a superior environment for establishment in the modified SDI system. This is supported by the average 20% greater plant fresh weights found in modified SDI over both experiments at the end of establishment period. A further advantage of the modified system was that plants were more uniform.

If the differences present at the end of establishment period (15 DAT) were carried through to maturity, this would mean earlier harvest, more uniform sizes and harvest dates, offering significant advantages for marketing (Bogle and Hartz 1986). With plants harvested in the vegetative stage, it is usual for early to continue through until harvest. Whilst delaying harvest of smaller plants may result in more comparable plant weights, this is undesirable as it increases the duration of harvest and harvest costs. In some plants, a delay will mean plants progress into reproductive development and are not harvestable.

The improved establishment and growth in the modified SDI was very likely due to improved plant water status rather than any other factor, although only soil water was measured. Over all treatments, there was a good relationship between surface soil water and plant fresh weight (Fig. 1), and the modified SDI consistently gave higher soil water than conventional SDI at comparable irrigation frequencies and crop factors (irrigation amounts) (Table 2 and 3). The difference between tape types was greatest with the high irrigation frequency (4/day), in which soil water content was 5% higher than with conventional SDI.

Responses to crop factor and irrigation frequency

Plants responded to both increased crop factor (CF), that is increased irrigation amount, and irrigation frequency (IF). However, for every combination of CF and IF, the growth of plants with modified SDI was greater than with conventional SDI. To maintain an optimal soil water regime on sandy soils, short, frequent pulses of water were required (Ghali and Svehlik 1988). More frequent water application through SDI was also better in work reported by El-Gindy and El-Araby (1996) and Silber *et al*. (2003). Whilst the present results agree with the earlier findings on ‘pulse irrigation’, also showed that with a modified SDI either fewer pulses, or less irrigation water, may be used to achieve a similar results. Further work is needed to quantify this and develop management guidelines.

The data for soil water are consistent with the hypothesis that a fraction of the water applied each irrigation is retained in a temporary water table which forms along the drip tape of the KISSS^{TM} product (modified SDI), above the impermeable layer. This increases upward and lateral flux of water towards the soil surface, making it wetter after irrigation (Table 2) and for a period subsequently (Table 3) (Hillel 1971).

Water balance components

The greater the frequency of irrigation in a period of time, the more of the total irrigation water applied that is available for transfer from the water table to the soil surface for evapotranspiration, and the less is available for drainage. In the glasshouse experiment, the modified SDI had significantly less drainage than conventional SDI (Table 5). All treatments received the same irrigation amount (4mm/day) the modified SDI must have delivered more water to the surface for evaporation. The impermeable barrier considerably reduced the drainage and as shown in the field, improved the lateral spread and the upward flow of water to the soil surface. Comparable findings were discussed by Brown *et al.* (1996).

CONCLUSION

The modified drip tape system KISSS™, performed better than conventional SDI system in both seasons. For shallow rooted crops like lettuce, the modified drip tape (KISSS™) had positive effects on soil moisture and seedlings establishment and growth apparently by creating a localised water table which prolongs upward capillary water movement. These benefits can be achieved whilst reducing drainage losses. Frequent irrigation with KISSS™ provided additional water to the surface which would be an added advantage in sandy soil. Further work is needed to optimise irrigation rates and frequencies for different climate and soil type and to determine if the short-term benefit of reduced drainage is reflected throughout crop production.

Acknowledgements

Financial support provided by University of Western Sydney and CRC for Irrigation Futures are acknowledged. We also thank Irrigation Water Technology (IWT) for their support. The trade name (KISSS™) used in this paper belongs to IWT.

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