EFFECT OF IRRIGATION MANAGEMENT ON NITRATE MOVEMENT UNDER A DRIP IRRIGATED LETTUCE CROP

K.J. Althaus, L.M. McKeering, A.D. McHugh and S.R. Raine

National Centre for Engineering in Agriculture and Cooperative Research Centre for Irrigation Futures
University of Southern Queensland, Toowoomba, AUSTRALIA

ABSTRACT
Irrigation management practices have a significant impact on the leaching of nutrients and salts within a soil profile. Crops such as lettuce, which are highly dependent on irrigation water for their effective growth and high quality yield, are particularly susceptible to high levels of nutrient leaching below the root zone. To ascertain the effect of irrigation management on nitrate movement soil, water and solute data was collected from a sprinkler and drip irrigated field of lettuce grown on a Ferrosol. This work has shown that deep drainage did occur during the season and that nitrate did leach below the root zone. Substantial spatial and temporal variations in nitrate and EC in the soil solution were observed which appear to be related to the pattern of water movement associated with the irrigation applications. Significant differences in nitrate concentration and EC were also found depending on the type and depth of placement of soil solution extractor used.

Keywords: Nitrogen, lettuce, irrigation management, leaching

INTRODUCTION

Irrigated agriculture in Australia accounts for approximately 70% of total water usage with 13% of this water being utilised in horticulture and viticulture (Australian Government Department of Agriculture, Fisheries and Forestry 2008). Vegetables are a major contributor to irrigated agriculture production in Australia. The value of the Australian lettuce industry is approximately $174 million per year (AUSVEG 2007) with southern Queensland being a significant lettuce producing region. Lettuce has traditionally been irrigated with solid set sprinkler irrigation systems (Barraclough and Co 1999) but with recent water shortages there has been an increased adoption of drip irrigation systems.

High quality lettuce production requires the close management of both fertiliser and water inputs. Lettuce plants stress at low soil moisture tension values (~20 kPa) but are sensitive to waterlogging Hence, lettuce is often grown on soils with good surface and internal drainage. The plants have a small root volume which rarely exceeds 15cm depth. Lettuce is harvested in the vegetative stage and high soil nitrogen levels are required until the day of harvest. Inadequate nitrogen results in stunting, yellow leaves and restricted head formation. Thus, lettuce irrigation is often characterised by high frequency, small volume irrigations to maintain the shallow root zone in a moist condition. The introduction of drip irrigation has also provided the opportunity to apply soluble nitrogen fertiliser in the irrigation water to maintain high levels of soil nitrogen in the root zone throughout the season. However, the combination of high soil moisture and nitrogen levels and well drained soils for extended periods of time raises concerns over the potential for nitrate leaching from the root zone into local groundwater systems. It also seems likely that the potential for nitrate leaching will be a function of the irrigation application system, fertigation strategy and irrigation management applied. However, there is little reported work on the movement of nitrogen under these conditions. Hence, this paper reports on a field trial conducted to evaluate nitrate movement under a fertigated commercial lettuce crop using drip irrigation.

MATERIALS AND METHODS

Field layout and agronomy

This trial was conducted on a commercial lettuce crop grown on the eastern Darling Downs. The soil at the site is a Red Ferrosol (Isbell, 1996) and the site had been used to grow lettuce for a period in excess of 10 years. An electromagnetic survey of the field was conducted using an EM38 (Geonics Ltd., Ontario, Canada) to select four monitoring plots with consistent soil properties. The plots were part of a commercial field which was cultivated into beds (1.2 m wide) separated by 0.4 m furrows. Four rows of five week old lettuce seedlings were transplanted onto each bed on the 28/1/09. The site was irrigated until the 20/02/09 using a solid set sprinkler irrigation system consisting of ISS Rainsprays sprinklers on 0.4 m risers. The sprinklers were arranged in a rectangular pattern with 9 m spacings along the laterals and an 8 m lateral spacing. Irrigations after the 20/2/09 were applied using a drip irrigation system. Two rows of drip tube with 0.4 m emitter spacing (2.3 L/hr/emitter) were installed 80 cm apart on the surface of the beds (Figure 1). Irrigation water was supplied from a local bore and urea was dissolved in the irrigation water and applied during both the sprinkler and drip irrigation events. Irrigation and fertigation was scheduled and recorded by the grower, based on observation of weather, crop and soil conditions. Weather data was collected throughout the trial using a weather station located adjacent to the trial site. Daily evapotranspiration for a reference crop (ET_0) was calculated using the FAO Penman-Monteith equation (Allen et al. 1998, eq. 6).

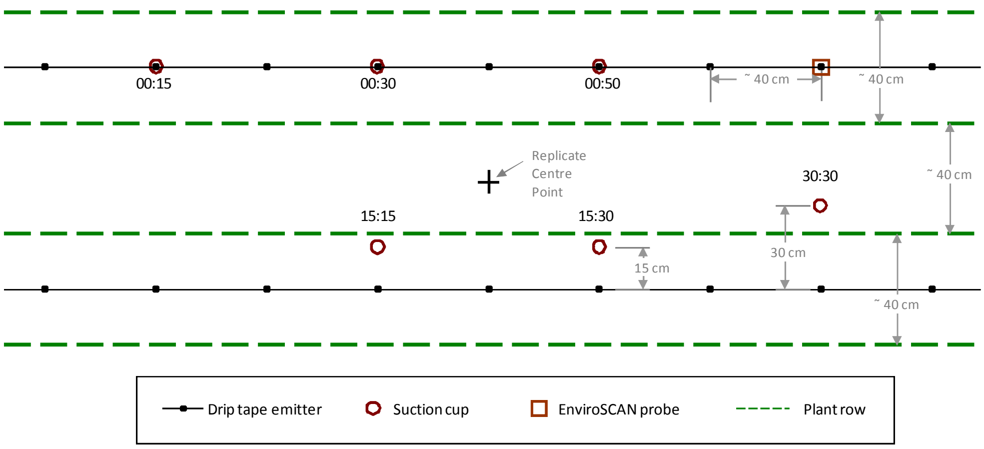

Figure 1 Plan view of the plot layout showing location of drip tape and sensors

Soil moisture and nutrient monitoring

Pre-plant and post-harvest soil core samples were taken at depth ranges of 0-10 cm, 10-20 cm, 20-30 cm, and 30-50 cm. The soil core samples were used to obtain pre- and post-season soil moisture, bulk density, nitrate, ammonium and electrical conductivity (EC). Enviroscan (Sentek, Adelaide) capacitance probes were located in each plot adjacent to a drip emitter and measured soil moisture changes with the soil profile at 0.1 m increments up to a depth of 0.5 m.

Ceramic soil suction cup samplers were used to extract soil solutions at various combinations of depths (ranging from 15 to 50 cm) and distances (0 to 30 cm) from the drip emitters (Figure 2). Two types of samplers were used, the SoluSAMPLER™ (Sentek, Adelaide) and Model 1900 Soil Water Sampler (ICT International, Armidale). Both suction cups were installed at similar locations relative to the drip emitters and the same suction (~20 kPa) was applied for the same period (typically 24 hours) with each cup. The Model 1900 is a large volume sampler with a capacity of >1000 mL. The Sentek (Adelaide) SoluSAMPLER is a low volume sampler with a capacity of 70-75 mL. Two of the monitoring plots were installed with the SoluSAMPLER and the other two plots had the Model 1900 samplers installed. Soil solution samples were extracted at two or three day intervals throughout the season and the nitrate concentration and electrical conductivity measured.

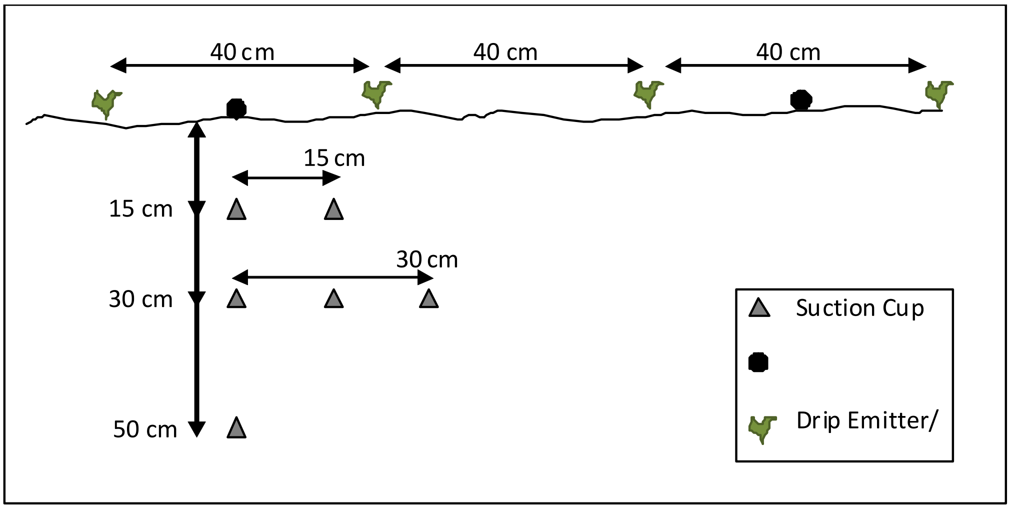

Figure 2 Diagrammatic representation of soil profile through beds showing the position of drip emitters and the soil suction cup samplers

RESULTS AND DISCUSSION

Water and fertiliser applications

The potential evapotranspiration for the crop season was 232 mm and the total volume of water applied during this period was 294 mm. A total of 101 mm of irrigation water was applied through sprinkler irrigation and a further 134 mm of water was applied through the drip irrigation. During the trial it rained a total of nine days, applying an average of 6.5 mm on each occasion (Figure 3a). There was slightly higher depths of irrigation water applied by the individual drip irrigation events compared to the sprinkler irrigation events (Figure 3a). However, the fertiliser application rates were substantially higher on a wetted area basis for the drip irrigation events (Figure 3b). A total of 93 kg/ha of nitrogen was applied through fertiliser applications during the trial. A further 21 kg/ha of nitrogen was applied due to the concentration of nitrogen (30 mg/L) present in the bore water supply, creating a total of 114 kg/ha of nitrogen applied throughout the season. It is interesting to note that approximately one-sixth of the total nitrogen was applied in the last week before harvest. There is some debate (Huett and Dettman 1992; Doerge, *et al.* 1991) as to the effectiveness and level of uptake at this late stage. If this nitrogen is not taken up by the plants it will remain in the soil, susceptible to leaching until it is utilised by the next crop.

Water movement within the soil profile

The EnviroSCAN data (Figure 4) shows that soil moisture throughout the soil profile was high for the majority of the season. Extraction occurs primarily within the surface layer (0-10cm) of the soil profile and increases as the season progresses. Later in the season some minor extraction occurred from the 20 cm and 30 cm depths. Anecdotal observations of rooting depths of lettuce plants suggest that roots typically only extend to a maximum of 15 cm. Hence, some of the water extraction in the 20 cm to 30 cm depths may be attributed to water extraction in the surface layer creating a soil matric gradient which moves water up through the profile. Continuous high moisture observations at 40 cm and 50 cm depth and spiking associated with irrigation and rainfall events at these depths suggests that there is deep drainage occurring due to both rainfall and irrigation events throughout the season.

Effect of soil solution sampling methodology on nitrate measurement

Considerable differences between the different suction cups were observed in both the volume of soil solution extracted and the measured nitrate concentrations (Table 1). Generally, smaller volumes were measured using the SoluSAMPLER. The largest volumes extracted using the Model 1900 was 174 mL while the largest using the SoluSAMPLER was only 25 mL. However, the difference between the average nitrate concentrations measured with the different cups varied according to sampling location in the profile. At 15 cm depth, the Model 1900 cups measured substantially lower average seasonal nitrate nitrogen levels (i.e. 252 – 313 mg/L) than the SoluSAMPLER (455 – 548 mg/L) (Table 1). However, at 50 cm depth, the average seasonal nitrate nitrogen level for the SoluSAMPLER was

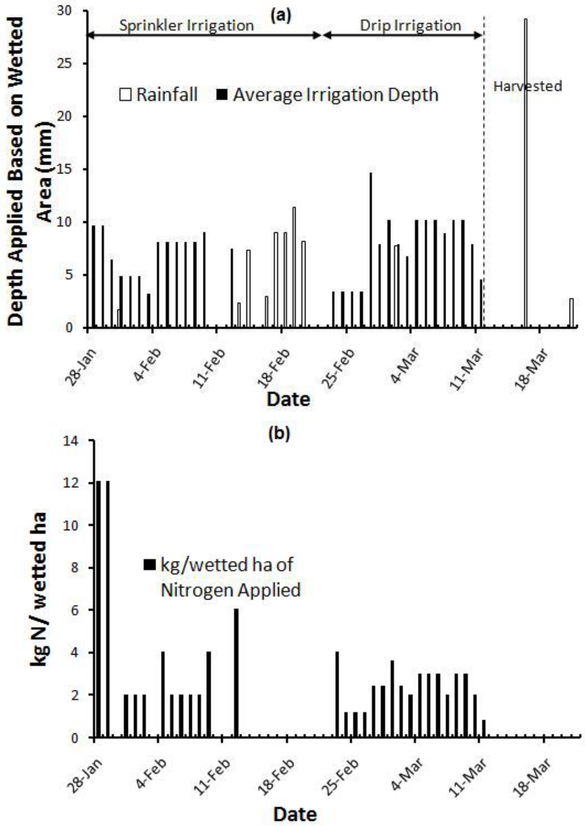

Figure 3 (a) Rainfall and irrigation application and (b) fertigation application for the trial lettuce crop on the eastern Darling Downs, Queensland.

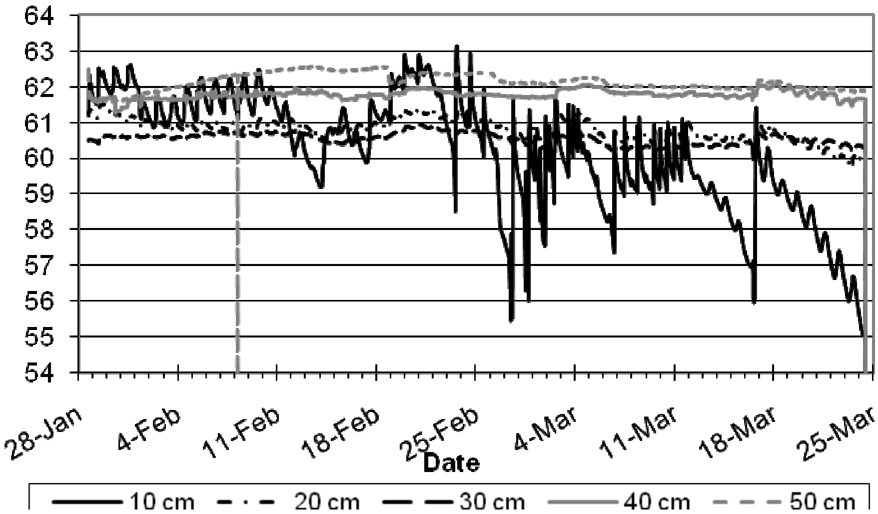

Figure 4 Relative soil moisture change for a sprinkler and drip irrigated lettuce crop on the eastern Darling Downs, Queensland.

approximately 100 mg/L less than that measured using the Model 1900, however this was not regarded as substantial. Differences at 30 cm depth were also negligible, however the substantial differences found at a depth of 15 cm. appear to occur during early growth stages and diminished after the beginning of substantial plant growth and the change to trickle irrigation. Good soil contact around the SEC solute samplers is hard to maintain compared to the Sentek solute samplers, especially under shallow installations, due to wind vibration and handling during solute sampling. Therefore it is possible that gaps between the SEC solute samplers and the surrounding soil allowed preferential flow of irrigation (sprinkler) and precipitation down toward the SEC ceramic cups, resulting in a difference in soil solute concentration. Preferential flow may only be part of the reason for the apparent differences as it is also likely to be function of the relative pore size from which the soil solution is being extracted, but this is not corroborated at other depths. However, the implications of this finding in relation to bypass pathways within the root zone and the impact on the potential for using soil suction cups for measuring plant available nitrate and deep drainage require further investigation.

Table 1 Average nitrate concentrations extracted from the Model 1900 Soil Water Sampler and the SoluSAMPLER in a field trial lettuce crop on the eastern Darling Downs, Queensland.

		Distance From Emitter (cm) : Depth (cm)					
Type of Suction Cup		0:15	0:30	0:50	15:15	15:30	30:30
Model 1900	Volume (mL)	50	30	50	37	38	24
	Nitrate (mg/L)	313	330	312	252	351	427
SoluSAMPLER	Volume (mL)	17	13	9	16	14	11
	Nitrate (mg/L)	548	308	223	455	299	435

Nitrate movement within the soil profile

Pre-plant nitrate nitrogen was 13 mg/kg in the surface layer and 23 mg/kg at 30-50 cm. However, during the season the surface nitrate nitrogen increased to 27 mg/kg while the nitrate nitrogen in the 30-50 cm horizon decreased to 13 mg/kg (Table 2). The nitrate nitrogen concentration in the top 30 cm of the soil profile and directly under the drip emitter was initially 400 to 550 mg/L (Figure 5). At a distance of 15 cm from the drip emitter the concentration was only slightly lower with a concentration range of 300 to 500 mg/L (Figure 5). As the season progressed these values were observed to decrease significantly and most notably at a greater rate after the switch from sprinkler to drip irrigation. The reduction was observed to follow a period of rainfall and no fertiliser application (Figure 2). The soil solution data (Figure 5) and soil moisture data (Figure 3) showing movement of water at depth suggests that the presence of in-season rainfall was a significant cause of nitrate movement through the profile. However, it should be noted that at depths and distances away from the drip emitter wetted zone, the nitrate concentrations remained persistently high. This suggests that this area may have been drier prior to the rainfall events and likely suffered less drainage and nitrate loss. This confirms that the nitrate movement within the soil profile is highly dependent on water movement.

Table 2 Soil chemical analysis for soil growing a lettuce crop on the eastern Darling Downs, Queensland.

		Depth			
		0-10cm	10-20cm	20-30cm	30-50cm
Ammonium Nitrogen	Pre-Plant	0.99	0.97	0.9	0.6
(mg/kg)	Post-Harvest	1.13	0.51	0.78	0.57
Nitrate Nitrogen	Pre-Plant	13	19	21	23
(mg/kg)	Post-Harvest	27	15	18	13
Electrical Conductivity	Pre-Plant	0.13	0.16	0.19	0.23
(dS/m)	Post-Harvest	0.25	0.23	0.19	0.15

Changes in electrical conductivity within the soil profile

The soil solution EC patterns throughout the season appeared to mirror the change in soil solution nitrate (Figure 6). At the start of the field trial the electrical conductivity within the soil profile ranged from 0.13 dS/m in the top 10 cm to 0.23 dS/m in the 30-50 cm depth (Table 1). Throughout the trial reasonably high values of EC were observed within the soil solutions extracted (Figure 6). The EC in the surface layer is lower than at depth confirming the accumulation of salts with depth due to crop water extraction and salt movement as irrigation and rainfall moves within the profile. There is greater variation directly under the emitter than at 30cm away from the emitter suggesting that the wetter soil moisture conditions in this area contribute to the salt movement, particularly during periods of rainfall. During the trial the EC was lower, with average root zone soil water EC below 2 dS/m at a distance of 15 cm from the closest emitter (Figure 6). At the emitters, the average root zone EC in the soil water was below 2.8 dS/m throughout the trial, with average EC at 15 cm depth remaining below 2.6 dS/m (Figure 6). Based on the work of Maas and Hoffmann (1977), this would have resulted in only a very small (if any) yield loss due to salinity, because the soil solution extract threshold EC for lettuce under steady state conditions is commonly reported to be 1.3 dS/m with a 25% yield loss occurring at 3.2 dS/m. However, this data shows substantial variation in soil EC within the root zone with this variation occurring both spatially at any point in time and temporally as a consequence of irrigation, fertigation and rainfall inputs. The impact of this variation on crop production is not known and requires further investigation.

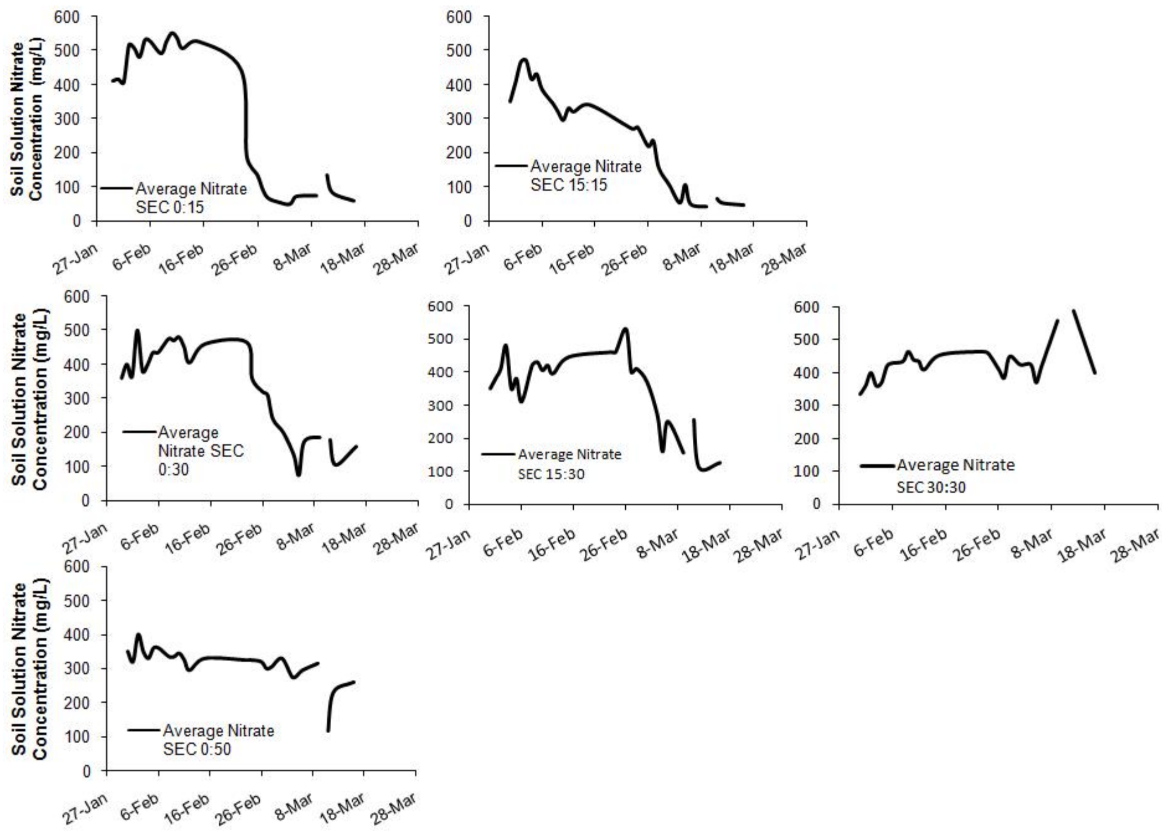

Figure 5 Nitrate concentrations collected from the soil profile using Model 1900 soil solution extractor during a lettuce crop on the eastern Darling Downs, Queensland. (Labels are horizontal distance in cm:depth in cm).

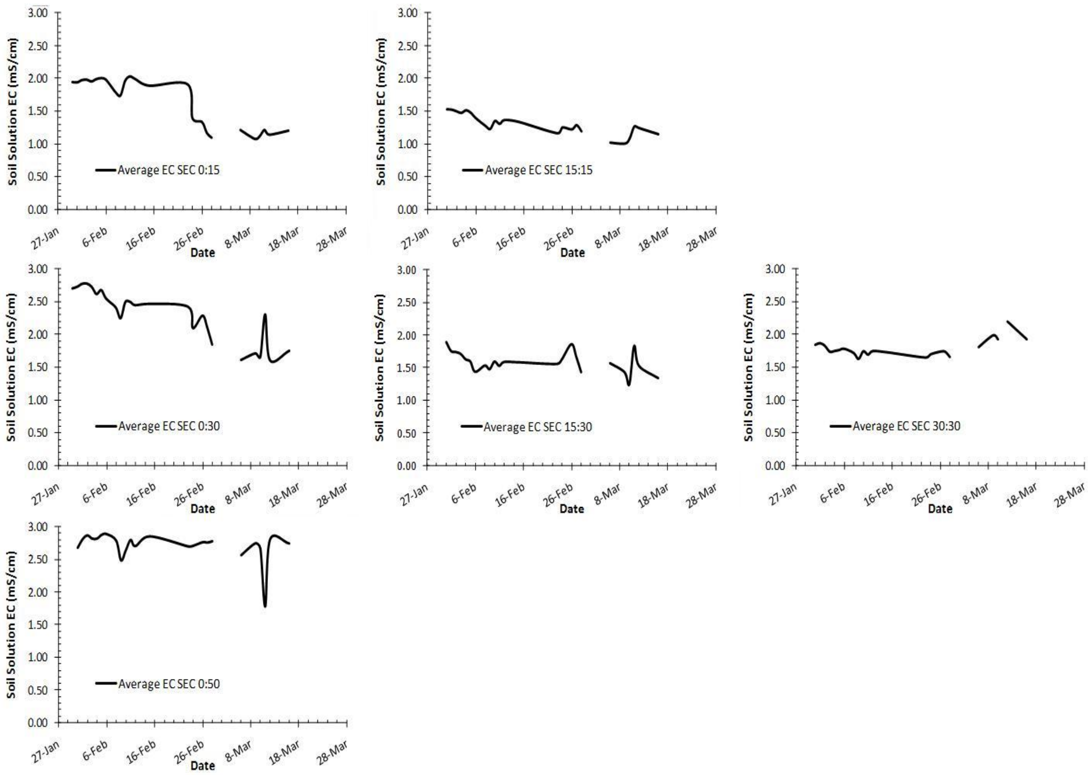

Figure 6 Electrical conductivity of soil solutions collected using a Model 1900 soil solution extractor during a lettuce crop on the eastern Darling Downs, Queensland. (Labels are horizontal distance in cm:depth in cm).

SUMMARY AND CONCLUSIONS

A field trial has been conducted on a commercial sprinkler and drip irrigated lettuce crop. This work has shown that deep drainage did occur during the season and that nitrate would have been moving out of the root zone. Substantial spatial and temporal variations in nitrate and EC in the soil solution were observed which appear to be related to the pattern of water movement associated with the irrigation applications. Hence, it would seem reasonable to suggest that the level of deep drainage and nitrate leaching would be influenced by the irrigation design and management practices as well as the in-season rainfall and soil physical conditions. The key to nitrogen management is minimising the amount of nitrogen and water in the soil, whilst ensuring adequate nitrate and water is available for plant growth. Currently a large amount of water and fertiliser is applied after transplanting, during a time when the plant roots are very shallow and plant requirements are small. Measurements suggest substantial nitrogen was lost to leaching before the plants had reached 20% ground cover.

The uptake of nitrogen by head lettuce during the week prior to harvest requires further investigation. Available research is conflicting as to whether nitrogen uptake during the week prior to harvest is negligible. During these trials, approximately one-sixth of the total nitrogen was applied during this period, if unused it is highly susceptible to leaching during the fallow period. However, further work is required to identify appropriate design and management practices under a range of conditions. Substantial differences were also observed between the soil solution nitrate and EC measurements obtained using difference soil solution extractors installed at shallow depths. The implications of these differences in terms of either the utility of the measurements obtained with either instrument and/or nitrate and EC movement requires further investigation.

ACKNOWLEDGEMENTS

The senior author gratefully acknowledges the National Program for Sustainable Irrigation, Land and Water Australia for providing a Summer Scholarship to conduct this field work. The collaboration of the farmers in providing access to the field site and assisting with the trial operation is also gratefully acknowledged. The use of product names in this report does not imply endorsement.

REFERENCES

Allen, RG, Pereira, LS, Raes, D & Smith, M 1998, '*Crop evapotranspiration – Guidelines for computing crop water requirements*', Food and Agriculture Organisation of the United Nations (FAO) Irrigation and Drainage Paper 56, Rome.

Australian Government Department of Agriculture, Fisheries and Forestry, last reviewed 08 October 2008, fact sheet – Horticulture

AUSVEG (2007) "Vegetable Spotlight - Lettuce." Retrieved 11/1/2008, from http://www.ausveg.com.au/assets/contentitems/public/6493/Lettuce-Commodity-Spotlight.pdf.

Barraclough and Co (1999) *Audit of water and irrigation use efficiencies on farms within the Queensland horticultural industry.* Barraclough & Company in conjunction with NCEA, Agtrans Research and B. Hearn. Sydney.

Doerge, TA, Roth, RL, & Gardner, BR. 1991, 'Nitrogen Fertilizer Management in Arizona', University of Arizona College of Agriculture, Tucson Arizona US.

Huett, DO & Dettmann, EB 1992, 'Nutrient Uptake and partitioning by Zucchini Squash, Head Lettuce and Potato in Response to Nitrogen', *Australian Journal of Agricultural Research*, vol. 43, pp. 1653-65.Isbell, R. F. (1996) *The Australian Soil Classification*, CSIRO Publishing, Melbourne.

Maas, EV & Hoffman, GJ 1977, 'Crop Salt Tolerence - Current Assessment', *Journal of the Irrigation and Drainage Division: Proceedings of the American Society of Civil Engineers*, vol. 103, No. IR2 June, pp. 115-134.