FINAL REPORT

To:
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Lettuce: The use of novel irrigation techniques as a management tool to restrict nitrate uptake in winter crops

(PC 244)

April 2006

Commercial – In Confidence

Project Title: Lettuce: The use of novel irrigation techniques as a management tool to restrict nitrate uptake in winter crops (PC 244).

Project number:	PC 244
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The results and conclusions in this report are based on two carefully monitored experiments. The conditions under which this study was carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with the interpretation of the results especially if they are used as the basis for commercial product recommendations.

Authentication

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

Signature………………………………………………… Date………..………….

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Headline

The use of two systems of trickle irrigation did not reduce nitrate levels in a winter-harvested crop of protected butterhead lettuce when compared to the industry standard practice of overhead irrigation.

Background and expected deliverables

This work was initiated in response to current EU legislation concerning the maximum levels of nitrate in lettuce and in particular to provide support for a continued derogation offered to UK Lettuce growers.

The aim of the work was to assess the potential to manipulate the nitrate content in a winter crop of glasshouse butterhead lettuce by using trickle irrigation compared to the industry standard of overhead irrigation using sprinkler nozzles. This would allow irrigation to be applied more regularly and closer to harvest to give more uniform application of water.

Summary of project and main conclusions

Two trickle treatments were compared on lettuce planted on 13 September (harvested 1 November 2005) and 26 October (harvested on 28 February 2006). Standard use of trickle tape between every other row was compared to a ‘switched’ Partial Root Drying (PRD) regime with plants watered from one side only before switching to the other side after a specified period. The volume applied followed commercial practice (100%) and a reduced volume (80%) to identify whether withholding water could reduce crop nitrate levels.

Conventional overhead irrigation was compared to these trickle systems which allowed the water to be applied directly to the soil surface.

For all approaches water was applied according to plant size, soil moisture and target planting date. All trickle irrigation plots received the same total water volume to that applied to the overhead plots except it was divided into 2-4 smaller applications over a longer period.

The first planting received a total of 62 litres of water/m^2 for the 100% treatment. The crop was monitored for nitrate levels on 2 dates plus at harvest on 1 November 2005. Soil mineral nitrogen was also determined at 4 weeks after planting and 2 weeks later at harvest. At harvest 5 samples containing 10 heads of lettuce per sample were taken from each plot ('W' pattern sampling) and were sent to the laboratory for nitrate analysis.

The second planting received a total of 30 litres of water/m^2 for the 100% treatment. The crop was monitored for nitrate levels on 4 dates plus at harvest on 28 February 2006. Soil mineral nitrogen was also determined at 11 and 16 weeks after planting and also 2 weeks later at harvest. At harvest 5 samples containing 10 heads of lettuce per sample were taken from each plot ('W' pattern sampling) and were sent to the laboratory for nitrate analysis.

The main conclusions from the work were as follows:

- In lettuce from both planting dates crop nitrate levels did not exceed the EC limit, but was higher in the second crop harvested in late February 2006.
- Trickle tape irrigation did not reduce the nitrate levels in the lettuce at harvest when compared against overhead irrigation (the industry standard).
- Partial Root Drying (PRD) achieved by using alternating lines of trickle tape did not affect lettuce nitrate levels at harvest.
- Commercially acceptable lettuce crops were produced when grown with only 80% of the water applied to the commercial standard.
- Disease levels were very low with negligible deterioration of the lower leaves for all irrigation treatments.
- Soil mineral nitrogen levels at harvest were high where trickle drip lines and 80% water were used. This is probably due to less leaching and could enable lower nitrogen rates to be applied before planting.
- Variation in the nitrate levels in the 5 samples of 10 lettuces taken at harvest ranged from 93-922ppm in the first crop and 318-1045ppm in the second crop despite careful management and uniform water application.
- There was no correlation between nitrate levels in the heads and the soil mineral nitrogen levels at harvest.

Financial Benefits

Extensions to the present EU derogation on nitrate levels in lettuce are based on the premise that research into ways of reducing those levels is pursued. Commercial winter glasshouse lettuce (butterhead) production is estimated at being worth £21 million per annum. An improvement in the ability to conform to the EU regulations will have significant financial benefits whilst maintaining the status of the UK lettuce industry as a leader in the provision of quality, safe food with due consideration to sustainable practice.

Action points for growers

- High quality crops can be produced with trickle irrigation using 20% less water as an alternative to overhead irrigation.
- If adopting this technique, it is advisable to use overhead irrigation to help establishment after planting and follow with trickle irrigation which can be used right up to harvest.
- Different methods of irrigation did not reduce nitrate levels in the harvested lettuce crop however, trickle irrigation with reduced water volumes lead to increased soil nitrogen levels. This indicates there is the potential to reduce rates of nitrogen fertiliser application with this irrigation system.

SCIENCE SECTION

Introduction

Despite voluntary adherence to the code of good agricultural practice (GAP), the UK Lettuce industry currently has no proven system that can guarantee nitrate levels in the harvested crop will be below those given in EC regulation number 563/2002, (see Table 1).

Table 1: Summary of maximum levels in European Commission Regulation (EC) No. 563/2002.

Product	Harvest Period	Maximum nitrate levels mg/ kg fresh product
Spinach (Fresh)	1st November - 31st March	3000
	1st April – 31st October	2500
Lettuce (protected and open-grown lettuce)	1st October – 31st March	4500
	1st April – 30th September	3500

The derogation awarded to UK Lettuce growers was reviewed in January 2005 and the Commission agreed to extend this based on evidence that codes of practice were currently applied, that UK growers have ongoing difficulties in keeping nitrate below the maximum levels and that there are current or planned investigations to help identify ways to lower these levels (FSA update, July 2005). Exceedances of nitrate concentration in lettuces mainly occur after periods of low light levels, particularly in the winter. Low rates of photosynthesis in these instances result in slower plant growth that does not appear to be matched by a decrease in nitrate uptake from the soil.

Nitrate uptake into the xylem of plants is a process that requires energy and it has also been shown that nitrate itself can stimulate its own uptake (Taiz & Zeiger, 1992). Once inside the plant cell, nitrate is converted to ammonia before assimilation into organic compounds. The enzyme that is responsible for the initial conversion of nitrate to nitrite is nitrate reductase (NR). This enzyme is therefore extremely important in the prevention of accumulation of excess nitrate in the vacuoles of plant cells. Genetic or environmental factors that decrease NR activity will affect the levels of nitrate accumulated in leaves.

HDC report, PC 88, highlighted that there was a great deal of variation in nitrate levels within heads of the same cultivar of lettuce and that there were no obvious differences between cultivars tested. The timing of harvest did not affect nitrate levels, even on sunny days. However, there was a tendency for lower nitrate residues in lettuce after bright days compared to levels after overcast days.

Byrne *at al* (2001) looked at the distribution of nitrate within the plant and found that lettuce heart contained the least nitrate (2880 mg/kg), surrounding leaves 4703 mg/kg and outer leaves 6000 mg/kg. This agrees with work in other areas and highlights the importance of removing older leaves as a means of decreasing nitrate in the product at point of sale.

An HDC-funded project, PC 245, commissioned in summer 2005 looked at the effect of spectrally modifying plastics on the nitrate content of baby leaf and lettuce at harvest. The project evaluated a range of photo-selective plastics covering Haygrove tunnels to identify whether nitrate content at harvest could be reduced by propagating lettuce in these structures before planting in the field. A second study looked at the potential of using these covers post planting to reduce nitrate content following standard glasshouse propagation. Results showed that the nitrate content of Lollo bionda plants at harvest was not affected by the film cover material used during propagation prior to field planting. Nitrate levels in butterhead lettuce propagated under glass and then planted in 5 tunnels covered with a range of photo-selective plastics were not affected by the post-planting regime.

Objectives

The aim of this work was to establish if irrigation strategies could be used to reduce nitrate content at harvest. Two planting dates were used to cover the winter growing period. The irrigation techniques were overhead, as a commercial standard, compared to two methods of trickle tape irrigation which were applied at volumes which were 100% or 80% of that used in commercial practice.

Materials and Methods

Trial details

Site

The trial was undertaken at Stockbridge Technology Centre, Cawood, Selby, North Yorkshire, YO8 3TZ. The crops were grown in venlo glasshouses with a 3.3m ridge height with a floor area of 148m^2.

Treatments

A. Planting date

1. 13 September 2005
2. 26 October 2005

B. Irrigation techniques

1. Overhead irrigation using 4 lines of sprinkler nozzles (1 line per 3.2m bay)
2. Trickle tape using 1 line between every other row of plants
3. Trickle tape using lines between every row but only using every other row at any one time to create a Partial Root Drying (PRD) zone

C. Quantity of irrigation

1. 100% of required amount – based on size of crop, weather conditions and crop growth stage
2. 80% of required amount

Details (summarised in Table 2)

Butterhead lettuce, cultivar 'Wynona', were sown into peat blocks on the 22 August and 28 September and propagated in a standard glasshouse. Fertiliser was added to each glasshouse based on soil analysis, to standardise the level to 100ppm as recommended by the Good Agricultural Practice guidelines, except for Crop 2 where two guard areas received nitrogen fertiliser to increase the level to 75ppm.

Table 2: Pre-planting N levels and amount of nitrogen fertiliser applied to each glasshouse.

Crop	Treatment	Soil analysis (0-30cm) (ppm NO_3)	Amount of ammonium nitrate applied (g/m^2)
Crop 1	Overhead	6.7	71.5
	Trickle	7.1	71.8
Crop 2	Overhead	56.3	33.6
	Trickle	15.8	64.8

Lettuce were planted on 13 September and 26 October at a spacing of 20 x 20cm, with 2 replicates of each treatment. Each plot for the trickle and PRD treatments had 12 rows of plants with 27 plants in each row. For the overhead treatments each plot comprised 12 rows of plants with 55 plants in each row with replicates situated in adjacent bays of the glasshouse.

The overhead plots received overhead irrigation as per commercial practice with each application being 10, 12 or 15 minutes in duration. The trickle irrigation plots received small bursts of overhead irrigation for the first few days after planting to aid establishment and to avoid the peat blocks from drying out. Thereafter they received all the irrigation through the trickle tape.

After each period of overhead irrigation the quantity of water applied was calculated and this same volume was then applied to the trickle plots, usually as a minimum of 2 smaller applications, over several days. The trickle tape plots had drip lines in every other row and these were used for each application. For the trickle plots where a Partial Root Drying (PRD) regime was being used the trickle tape was laid down between every row with alternate lines used for each cycle. The duration of each cycle varied according to the irrigation applied and the crop growth stage. For the 80% treatments the duration of each period of irrigation was reduced on a pro rata basis.

Records and assessments

Plant vigour

Lettuces were regularly assessed for vigour to determine if any of the treatments affected the rate of plant growth and plant habit.

Interim leaf nitrate analysis

Lettuces were cut, weighed and tested for nitrate content using the hot water extraction method developed in HDC Project PC 218. This was based on 6 plants per plot.

Leaf nitrate analysis at harvest

Trials had previously shown large head to head variation in the nitrate content of lettuces. In order to minimise this variation 5 samples of 10 heads were taken from each plot at harvest in a 'W' pattern. These were weighed and sent to NRM Laboratories for analysis.

Soil mineral nitrogen assessments

Soil samples from 0-20cm were taken from each plot part way through each crop and also at harvest. These samples were sent to Lancrop Laboratories for analysis.

Glasshouse Environmental Monitoring

The number of sun hours and radiation levels were monitored throughout the trial. The data are presented in Appendix I.

Statistical Analysis

Analysis of variance was undertaken on the raw data set obtained for each crop at harvest. Comparisons were made between means based on the least significant difference (LSD) and a 95% confidence interval was used for all analyses.

Results

The results for each planting date are presented separately.

Planting 1 (13 September).

Establishment after planting was excellent but two short bursts of overhead irrigation were required on the trickle plots to avoid the peat blocks from drying out. This was only considered necessary for the first 2 days due to the sunny weather. The irrigation applied to the 100% treatments is presented below.

Table 3: Dates of irrigation, duration and quantity applied.

Date	Overhead 100%	Quantity (l/m^2)	Drip 100%	Quantity (l/m^2)
13 Sept	10 mins	5.87	5 mins #	3.3*
14	12 mins	7.04	5 mins # + 30 mins*	3.3* +4.4*
19	12 mins	7.04	Variable ##	8.95
21	12 mins	7.04	½	3.52
22	-		½	3.52
23	12 mins	7.04	½	3.52
24	-		½	3.52
25	10 mins	5.87	½	2.94
26	-		½	2.94
29	10 mins	5.87	½	2.94
30	-		½	2.94
2 Oct	12 mins	7.04	½	3.52
3	-		½	3.52
11	15 mins	8.8	1/3	2.93
17	-		1/3	2.93
26	-		1/3	2.93

overhead to aid establishment

* all trickle plots (100 and 80%)

variable duration to correct for each treatment

Note - PRD changed over to cycle 2 on 27 September and back to cycle 1 on 11 October.

The total quantity of water applied to the 100% treatment was 61.6 litres per m^2. The final watering to the trickle plots was made closer to harvest than was normally possible for overhead treatments due to the need to avoid wetting foliage.

The results for the interim assessments on the growing crop are presented in Tables 4 & 5 and the results at harvest presented in Table 6.

Table 4: Results of assessment carried out 4 weeks after planting (13 October).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	113	4871	4138	4505
Overhead 80%	107	4886	5186	5036
Trickle 100%	90	4604	5036	4820
Trickle 80%	89	4472	4880	4676
PRD 100%	104	4655	4883	4769
PRD 80%	101	4943	4435	4689

The results show that mean head weights were lower for the trickle irrigated plots. Nitrate levels were generally similar for all treatments but with some variation between the replicates.

Table 5: Results of assessment carried out 6 weeks after planting (24 October).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	187	4968	4041	4505
Overhead 80%	175	4057	4860	4459
Trickle 100%	159	4416	4407	4412
Trickle 80%	151	4736	3834	4285
PRD 100%	168	5579	4489	5034
PRD 80%	142	4472	3978	4225

The results show that mean head weights were slightly lower for the 80% treatments. Nitrate levels were generally similar for all treatments but again with variation between the replicates.

Table 6: Results at harvest (1 November).

Treatment	Mean head weight (g)	Mean nitrate content	Mean nitrate content	Mean nitrate content	% samples >3000ppm

		(ppm) Rep 1 #	(ppm) Rep 2 #	(ppm)	(3500ppm)
Overhead 100%	219	2982	2958	2970	30 (10)
Overhead 80%	214	2816	3104	2960	30 (10)
Trickle 100%	190	3220	3175	3198	60 (30)
Trickle 80%	187	3608	3013	3311	80 (30)
PRD 100%	183	3740	3141	3441	90 (40)
PRD 80%	183	3507	2937	3222	70 (20)
SED (59df)				177	
LSD (5%)				354	
				(NS)	

mean of 5 samples, each comprising 10 heads from similar locations in the plot

At harvest the lettuces were of excellent quality with only slight deterioration of the lower leaves which were in contact with the soil. This was similar for all treatments despite using the trickle lines close to harvest. Mean head weights were similar for the 100 and 80% treatments. There was no significant effect of the irrigation treatment on the nitrate content in the heads at harvest. This was due to large variation between the 5 samples from each plot and the 2 replicates for the PRD treatments and the trickle at 80%. Variation between the highest and lowest results for each plot ranged from just 93ppm to 922ppm despite careful harvesting and sampling from adjacent locations in each plot. All results were below the current maximum level of 4500ppm.

The results for each individual sample are presented in Appendix II.

The results for the soil mineral analysis are presented in Tables 7 and 8.

Table 7: Soil mineral N results on 13 October (4 weeks after planting).

Treatment	NH3 ppm	NO3 ppm	kg/ha N	Range
Overhead	0.8	149	300	281-318
100%	0.9	213	428	387-469
Overhead 80%	2.1	172	349	331-367
Trickle 100%	1.5	177	356	329-383
Trickle 80%	1.1	129	261	187-334
PRD 100%	1.6	127	257	231-283
PRD 80%				

The results show that despite raising the soil nitrogen levels to 100ppm at planting the levels of nitrogen after 4 weeks were at least 27% higher. There was large variation between the 2 replicates for some of the treatments. For the overhead irrigation treatments the soil nitrogen levels were higher in the 80% irrigation treatment. For the trickle and PRD treatments the results were similar for both the 100 and 80% treatments.

Table 8: Soil mineral N results at harvest on 1 November.

Treatment	NH3 ppm	NO3 ppm	kg/ha N	Range
Overhead 100%	0.4	129	259	247-271
Overhead 80%	0.7	146	294	289-299
Trickle 100%	1.0	122	247	243-249
Trickle 80%	1.2	140	283	233-332
PRD 100%	0.8	92	185	181-189
PRD 80%	1.6	107	218	195-241

At harvest soil mineral nitrogen levels were still well above the original target level at planting. The soil mineral levels were higher at harvest for all the 80% irrigation treatments. This could have been due to less nitrogen being leached through the soil by the reduced volumes of water applied to the crop.

Planting 2 (26 October).

Establishment after planting was excellent but several short bursts of overhead irrigation were required on the trickle plots to avoid the peat blocks from drying out. This was only considered necessary for the first 5 days due to the sunny weather. The irrigation applied to each 100% treatment is presented below.

Table 9: Dates of irrigation, duration and quantity applied.

Date	Overhead 100%	Quantity (l/m^2)	Drip 100%	Quantity (l/m^2)
26 Oct	3 mins	1.76	2.6 mins#	1.76
27	2 mins	1.17	2 mins#	1.35
28	1 min	0.59	1 min#	0.67
31	10 mins	5.87	1/3	1.88
1 Nov	-		1/3	1.96
2	-		1/3	1.96
5	10 mins	5.87	1/3	1.96
6	-		1/3	1.96
7	-		1/3	1.96
23	-		¼	2.2
24	15 mins	8.8	-	
25	-		¼	2.2
28	-		¼	2.2
12 Dec	10 mins	5.87	¼	2.2
19	-		1/3	1.96
16 Jan 2006	-		1/3	1.96
1 Feb	-		1/3	1.96

overhead irrigation used to aid establishment

Note - PRD changed over to cycle 2 on 9 November, back to cycle 1 on 12 December and back to cycle 2 on 9 January 2006.

The overall quantity of irrigation applied to the crop at 100% irrigation was 30 litres/m^2. This was less than for the first crop as the soil was wetter at planting following flooding to reduce soil nitrate levels.

The results for the interim assessments on the growing crop are presented in Tables 10 – 13 and the results at harvest presented in Table 14.

Table 10: Results of assessment carried out 6 weeks after planting (7 December).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	19	4107	4195	4151
Overhead 80%	19	4006	4575	4291
Trickle 100%	23	3679	4367	4023
Trickle 80%	21	3673	4123	3898
PRD 100%	23	4532	3919	4226
PRD 80%	21	3946	3884	3915
OH 100% -75ppm	17			4123
OH 80% -75ppm	14			3593

Plants were first assessed at 6 weeks after planting so that nitrate levels could be monitored throughout the whole growing period. The heads had not developed to any great extent. Nitrate levels were similar for all treatments, with large variation between the 2 replicates for some of the treatments.

Table 11: Results of assessment carried out 11 weeks after planting (12 January 2006).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	79	5162	5544	5353
Overhead 80%	71	4640	5073	4857
Trickle 100%	80	5546	5825	5686
Trickle 80%	78	6039	5586	5813
PRD 100%	83	5647	4846	5247
PRD 80%	71	5307	5886	5597
OH 100% -75ppm	58			5167
OH 80% -75ppm	63			5494

The mean head weights were similar for all main treatments and lower for the 75ppm treatments but these plots were in the outside bays of the glasshouse.

Nitrate levels in the heads were again variable between the 2 replicates with no apparent treatment effect.

Table 12: Results of assessment carried out 14 weeks after planting (1 February 2006).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	109	5141	5145	5143
Overhead 80%	105	4923	5284	5104
Trickle 100%	111	4635	4904	4770
Trickle 80%	118	4821	4346	4584
PRD 100%	126	4515	4838	4677
PRD 80%	104	5825	4856	5341
OH 100% -75ppm	99			4945
OH 80% -75ppm	108			4785

The mean head weights were generally similar for all treatments with no consistent effect.

The nitrate levels in heads were generally lower than at the assessment 2 weeks earlier and were similar for both replicates, except for the PRD at 80% treatment.

Table 13: Results of assessment carried out 16 weeks after planting (14 February 2006).

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)
Overhead 100%	148	5603	5954	5779
Overhead 80%	131	6163	5707	5935
Trickle 100%	136	6211	6112	6162
Trickle 80%	137	6240	5989	6115
PRD 100%	144	6290	6060	6175
PRD 80%	131	5760	6529	6145
OH 100% -75ppm	130			6153
OH 80% -75ppm	128			5507

The mean head weights were overall similar for all treatments but with a slight reduction in head weight where 80% irrigation was used.

The nitrate levels in the heads were higher than at the previous assessment taken 2 weeks earlier. Variation between the 2 replicates was not as high as seen previously, except for the PRD at 80% irrigation.

Table 14: Results at harvest on 28 February 2006.

Treatment	Mean head weight (g)	Mean nitrate content (ppm) Rep 1	Mean nitrate content (ppm) Rep 2	Mean nitrate content (ppm)	% of samples >3500ppm (4000ppm)
Overhead 100%	198	3448	3560	3504	50 (20)
Overhead 80%	185	3344	3553	3449	40 (0)
Trickle 100%	190	3548	3654	3601	50 (10)
Trickle 80%	187	3716	3615	3665	70 (10)
PRD 100%	194	3671	3875	3773	80 (40)
PRD 80%	181	3763	3608	3686	50 (10)
SED (59df)				221	
LSD (5%)				442 (NS)	
OH 100% -75ppm	172			3472	67 (0)
OH 80% -75ppm	166			3239	33 (0)

At harvest the quality of the lettuce was excellent with negligible deterioration of the lower leaves. The mean head weights were slightly lower for the 80% treatments. Mean nitrate levels in the lettuces were uniform between the 2 replicates and were well below the EC maximum limit. There were no significant differences between the treatments. There was no obvious reduction in nitrate levels from only increasing soil nitrogen levels to 75ppm rather than 100ppm.

The results for each sample are presented in Appendix II.

The results for the soil mineral analysis are presented in Tables 15 - 17.

Table 15: Soil mineral N results on 12 January 2006 (11 weeks after planting).

Treatment	NH3 ppm	NO3 ppm	kg/ha N	Range
Overhead 100%	0.5	100	200	166 - 234
Overhead 80%	0.5	116	232	218 - 244
Trickle 100%	1.0	160	320	308 - 330
Trickle 80%	1.1	216	432	358 - 506
PRD 100%	0.8	207	414	276 - 550
PRD 80%	0.7	232	464	414 - 516
OH 100% -75ppm	0.5	85	170	
OH 80% -75ppm	0.4	99	198	

Soil nitrate levels were lower in the overhead irrigated treatments but the residual nitrogen levels prior to fertiliser application were much lower than in the glasshouse used for the trickle treatments. Soil nitrogen levels were lower still where the soil levels were only raised to 75ppm instead of 100ppm in the main trial. Soil nitrogen levels were higher for all the 80% irrigation treatments and this is probably due to less leaching of the nitrogen fertiliser through the soil profile.

Table 16: Soil mineral N results on 14 February 2006 (16 weeks after planting).

Treatment	NH3 ppm	NO3 ppm	kg/ha N	Range
Overhead 100%	1.0	84	170	111 - 226
Overhead 80%	1.1	103	208	195 - 218
Trickle 100%	1.3	93	188	168 - 211
Trickle 80%	1.3	196	394	275 - 513
PRD 100%	1.0	147	296	291 - 298
PRD 80%	1.1	118	238	224 - 253
OH 100% -75ppm	0.6	59	120	
OH 80% -75ppm	0.7	121	243	

In mid February the soil mineral nitrogen levels were generally still above the target level at planting. There was large variation between replicates, despite being in adjacent bays in the glasshouse.

Table 17: Soil mineral N results at harvest on 28 February 2006.

Treatment	NH3 ppm	NO3 ppm	kg/ha N	Range
Overhead 100%	1.6	48	100	85 – 114
Overhead 80%	1.3	56	114	111 – 116
Trickle 100%	1.0	66	133	99 – 168
Trickle 80%	1.0	109	221	197 – 245
PRD 100%	3.1	53	113	94 – 132
PRD 80%	1.6	116	236	212 – 260
OH 100% -75ppm	0.9	38	78	
OH 80% -75ppm	1.2	72	147	

Soil mineral nitrogen levels decreased in the 2 weeks before the crop was harvested. Levels were lower for the overhead irrigation treatments and where 100% irrigation had been applied to the trickle treatments. Soil mineral nitrogen levels on the plots where the pre-planting soil nitrogen levels had only been increased to 75ppm were similar to those on the equivalent 100ppm plots.

Discussion

The uptake of nitrogen by plants is a complex process and as demonstrated by this project is subject to high sample to sample variation. Despite careful attention to detail and careful preparation of samples, particularly at harvest, the head to head variability was often greater than differences between the treatments. This was highlighted in the range between the highest and lowest samples within one plot exceeding 1000ppm.

Nitrate manipulation in the crop

In this trial all samples at harvest were below the EU limit of 4500ppm. Levels were higher in the second crop harvested in late February following a prolonged period of very low light levels.

There was no consistent effect of irrigation system or quantity of water applied on the nitrate levels in the crop at harvest. Head to head variation in nitrate content is known to be high and this was also the case in both planting dates with large differences between the replicates and between samples within each replicate. Any differences between treatments were masked by this variation.

The use of Partial Root Drying (PRD) achieved by using different sets of drip lines did not have a consistent effect. This was probably due to the small distance between the drip lines due to the close spacing between the plant rows. There was insufficient differential in the moisture content between the different sides of the plants to have a significant effect in the second crop where detailed soil moisture measurements were taken (Appendix III). The graphs show that for the PRD treatments at both 80 and 100% the maximum difference in soil moisture between the ‘wet’ and ‘dry’ side of the plant was only 7%.

Water use efficiency

The trial has demonstrated that high quality crops can be produced by using trickle irrigation as an alternative to overhead irrigation and also by using 20% less water. Overhead irrigation has several disadvantages in that disease development can be encouraged by the increased humidity and moisture on the foliage. Applications can only be applied up to a certain growth stage to avoid water resting in the semi-mature heads. Trickle irrigation can be used to apply water on a ‘little and often’ basis and can be used much closer to harvest as the water is applied directly to the soil surface. However, overhead irrigation may still be required to help establishment after planting.

Although in this trial an identical quantity of water was applied to each irrigation system it should be possible to apply less to the crop grown with trickle as the grower can respond more quickly to the prevailing weather conditions. Applying water more regularly should enable plants to grow more uniformly and avoid soils from becoming excessively wet.

There was a concern that the lower leaves in contact with the drip lines might deteriorate more rapidly than those grown with overhead irrigation but this was not observed. The emitters in the drip lines were facing downwards and so the upper surface of the drip lines remained dry.

The trial has also identified that water volumes can be reduced from standard practises without compromising crop yield. There is probably scope to reduce this further when used in conjunction with accurate soil moisture deficit recording equipment.

Nitrogen leaching

Trickle irrigation should reduce fertiliser leaching as more frequent applications of lower volumes of water should avoid nutrients from being leached though the upper soil profile. This was not observed probably due to the same overall quantity of water being applied to each irrigation system. However, in both trials the soil mineral nitrogen levels were higher for the 80% irrigation regime indicating that more nitrogen was present in the top 20cm. This could potentially allow for reduced base applications to be used and requires further study to reduce production costs and to reduce environmental contamination.

Correlation between crop and soil nitrate levels

The mean crop nitrate levels at harvest for each crop were plotted against the soil mineral nitrogen levels. These are presented in Figures 1 and 2.

Figure 1: Crop nitrate levels plotted against soil mineral nitrogen levels at harvest – Crop 1.

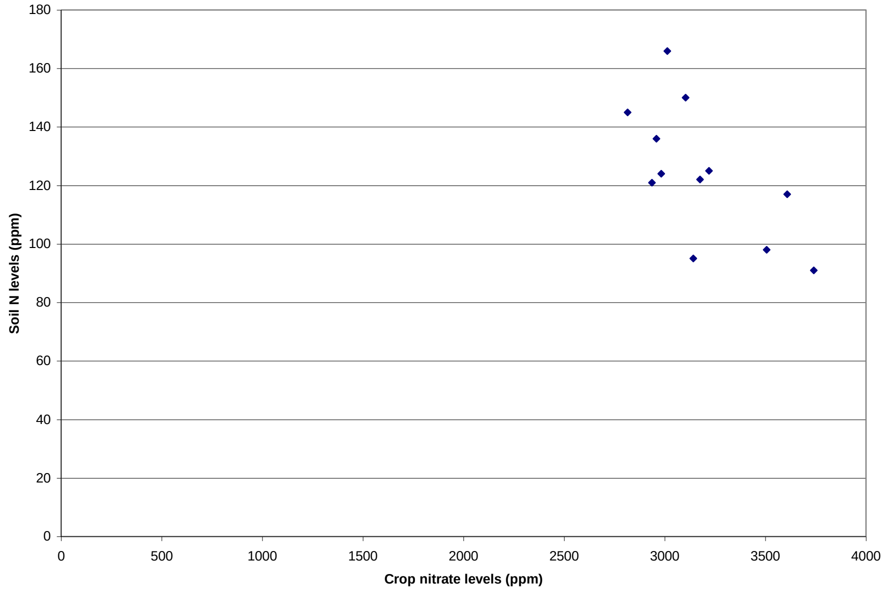
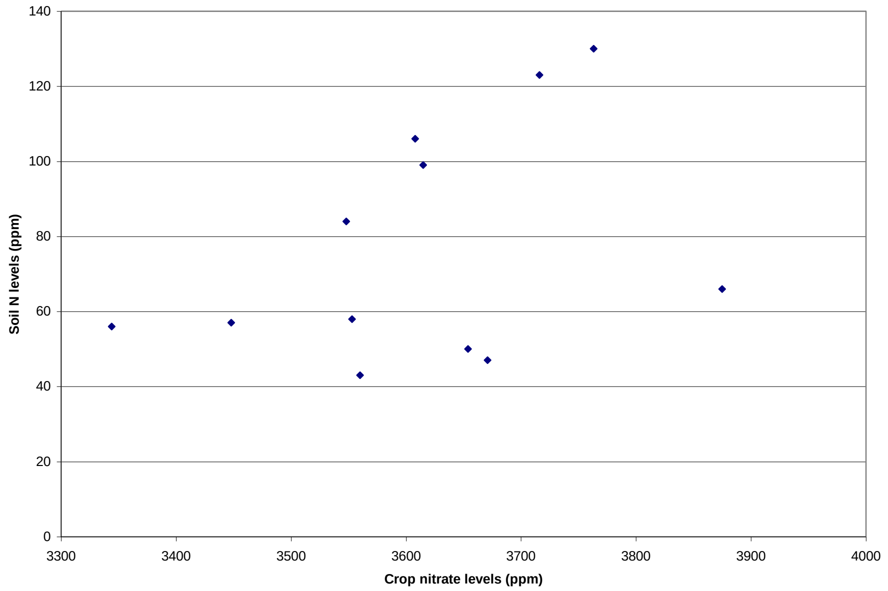


Figure 2: Crop nitrate levels plotted against soil mineral nitrogen levels at harvest – Crop 2.



There was no correlation between nitrate levels in the heads and the soil mineral nitrogen levels at harvest.

Conclusions

1. High quality lettuce crops can be produced by using trickle irrigation rather than relying on overhead sprinklers. Water could be applied closer to harvest and the foliage always remained dry. However, trickle systems would be more expensive to install.

2. Trickle irrigation could allow crops to be grown with less water but accurate soil moisture monitoring equipment would be required to optimise plant growth. In outdoor salads, crop performance was improved by allowing soils to dry between irrigation applications.

3. No irrigation treatment examined in this project reduced the nitrate content of the crop at harvest.

4. Partial Root Drying (PRD) treatments did not create a large difference in soil moisture content between the ‘dry’ and ‘wet’ side. This was probably due to the close inter row spacing.

5. Crops grown with trickle irrigation with reduced water volumes increased residual soil nitrogen levels at harvest. Thus there is the potential to use lower rates of nitrogen fertiliser to reduce nitrogen levels in the soil at harvest.

6. There was no correlation between crop nitrate levels and soil nitrogen levels at harvest.

Recommendations

Further work should be undertaken to:

1. **Evaluate the potential to further reduce and optimise water usage for lettuce grown using a trickle system –** this is potentially a very important area of work to demonstrate that growers are using irrigation water to maximum effect. Water for both agricultural and horticultural uses could be restricted in certain geographical areas where lettuce is currently grown due to increasing demand by the public and other industries.

2. **Evaluate the effect of different soil mineral nitrogen rates on the nitrate content of lettuces and soil nitrogen levels at harvest** – further work is required to demonstrate to the EU Regulators that growers are continuing to look at practical methods to reduce crop nitrate levels. The current derogation has been granted on the understanding that growers improve their knowledge of nitrate accumulation by the crop. There is a need to understand better the effect of soil nitrate levels prior to planting on nitrate levels in both the crop and that remaining in the soil at harvest.

3. **Evaluate the effect of different shading regimes and the plants response to periods of lower light in the 2-3 week period before harvest** – growers need to know what the effects of reduced light levels and day length are on crop nitrate levels. There may be a simple correlation that could be used to determine nitrate residues under various light level scenarios. Growers could then decide on the feasibility of using mobile lighting rigs to increase light levels in the days leading up to harvest.

TECHNOLOGY TRANSFER

The results of this work were disseminated at the Lettuce Technology Group meeting held at STC on 8th November 2005.

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Appendix I: Radiation and number of sun hours.

CROP 1

Date	Radiation (MJ/m^2)	Sun hours
13 Sept	14.63	7.6
14	13.50	8.1
15	2.37	0.0
16	13.24	8.2
17	12.40	4.5
18	12.90	6.6
19	12.68	6.0
20	11.40	6.0
21	10.75	4.0
22	13.64	7.9
23	6.40	2.5
24	14.50	9.1
25	11.18	5.1
26	5.53	0.5
27	12.63	6.2
28	8.45	3.5
29	10.44	6.5
30	5.97	1.6
1 Oct	11.38	7.9
2	9.86	4.5
3	3.67	0.0
4	4.08	0.1
5	8.11	3.2
6	1.81	0.0
7	2.94	0.0
8	1.82	0.0
9	3.74	0.8
10	7.61	3.9
11	4.82	1.0
12	4.06	0.3
13	3.29	0.1
14	3.17	0.0
15	3.18	0.0
16	7.73	5.2
17	1.86	0.0
18	3.73	0.1
19	3.44	1.0
20	6.73	3.5
21	2.40	0.4
22	1.47	0.0
23	2.72	0.1
24	1.59	0.0
25	5.31	3.0
26	4.01	1.5
27	7.34	6.5
28	3.67	1.0
29	4.77	2.5
30	2.58	0.6
31	2.79	1.5

1 Nov	6.39	5.4

CROP 2

Date	Radiation (MJ/m^2)	Sun hours	Date	Radiation (MJ/m^2)	Sun hours
26 Oct	4.01	1.5	11	3.03	5.0
27	7.34	6.5	12	3.25	1.5
28	3.67	1.0	13	2.11	2.6
29	4.77	2.5	14	2.24	0.8
30	2.58	0.6	15	2.36	0.2
31	2.79	1.5	16	1.73	1.5
1 Nov	6.39	5.4	17	2.81	3.9
2	3.74	1.5	18	1.82	1.2
3	2.19	0.4	19	2.90	4.2
4	1.66	0.2	20	1.00	0.0
5	4.08	2.0	21	0.88	0.0
6	1.97	0.6	22	0.73	0.0
7	5.33	4.9	23	2.27	3.2
8	2.07	0.2	24	2.67	4.2
9	5.19	4.4	25	2.25	2.2
10	1.43	0.0	26	1.47	0.6
11	1.76	0.6	27	2.50	3.1
12	4.42	6.0	28	2.70	0.0
13	5.18	6.4	29	3.04	0.0
14	2.06	0.3	30	0.42	0.0
15	4.12	4.6	31	1.36	0.0
16	4.96	6.1	1 Jan 2006	1.27	0.0
17	4.96	6.1	2	1.30	0.0
18	4.94	6.5	3	1.63	0.0
19	4.95	5.4	4	1.21	0.0
20	4.04	4.5	5	0.47	0.0
21	4.40	0.0	6	0.50	0.0
22	2.46	0.0	7	0.46	0.0
23	2.91	0.0	8	0.56	0.0
24	3.05	0.0	9	1.09	0.0
25	3.10	0.0	10	0.79	0.1
26	1.88	0.0	11	3.25	5.5
27	1.94	0.0	12	3.43	0.0
28	1.39	0.0	13	1.85	1.0
29	3.21	0.0	14	1.19	0.0
30	1.30	0.0	15	1.50	0.2
1 Dec	0.98	0.0	16	0.90	0.5
2	0.99	0.0	17	2.96	1.5
3	0.93	0.0	18	1.08	0.0

4	1.56	0.0	19	1.07	0.0
5	2.98	0.0	20	3.58	4.1
6	3.01	0.0	21	4.14	5.8
7	3.21	0.0	22	2.30	0.0
8	3.06	0.0	23	1.08	0.0
9	1.21	0.0	24	3.24	0.6
10	2.24	1.2	25	3.42	3.1

Date	Radiation (MJ/m^2)	Sun hours
26	3.40	3.0
27	2.30	0.6
28	4.85	7.1
29	2.59	0.1
01	3.34	0.6
31	1.66	0.0
1 Feb	1.26	0.0
2	1.47	0.0
3	0.82	0.0
4	1.43	0.0
5	1.19	0.0
6	1.24	0.0
7	3.91	3.2
8	6.34	7.9
9	2.72	5.6
10	3.03	0.0
11	1.61	1.2
12	3.31	0.0
13	4.24	1.1
14	4.22	2.2
15	5.66	2.1
16	7.29	4.4
17	8.55	5.0
18	7.44	6.9
19	7.12	4.4
20	7.13	6.6
21	4.59	1.5
22	1.88	0.0
23	2.20	0.0
24	3.52	0.5
25	5.20	1.9
26	4.27	0.4
27	5.71	2.2
28	8.20	5.5

Appendix II: Nitrate levels in lettuces at harvest.

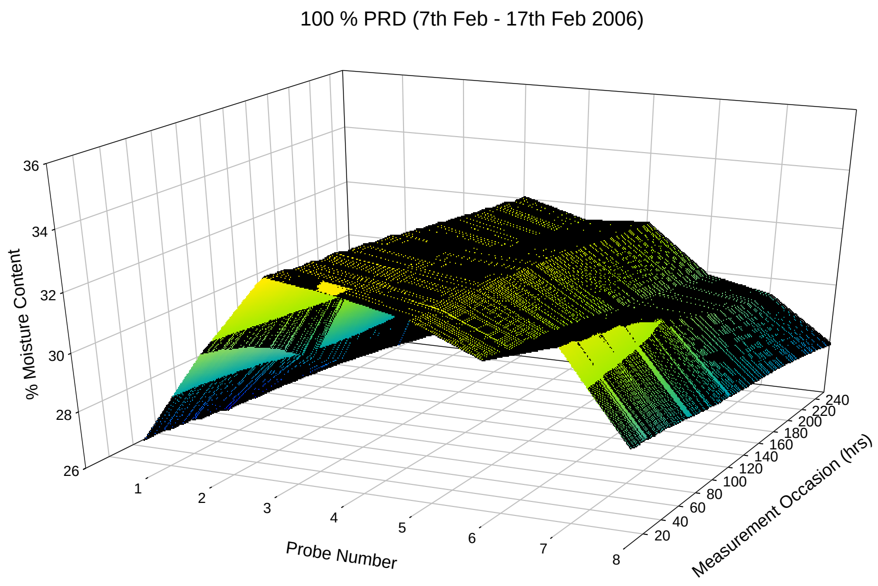
Table A: Nitrate levels in each of the 5 samples taken from each plot - Crop 1.

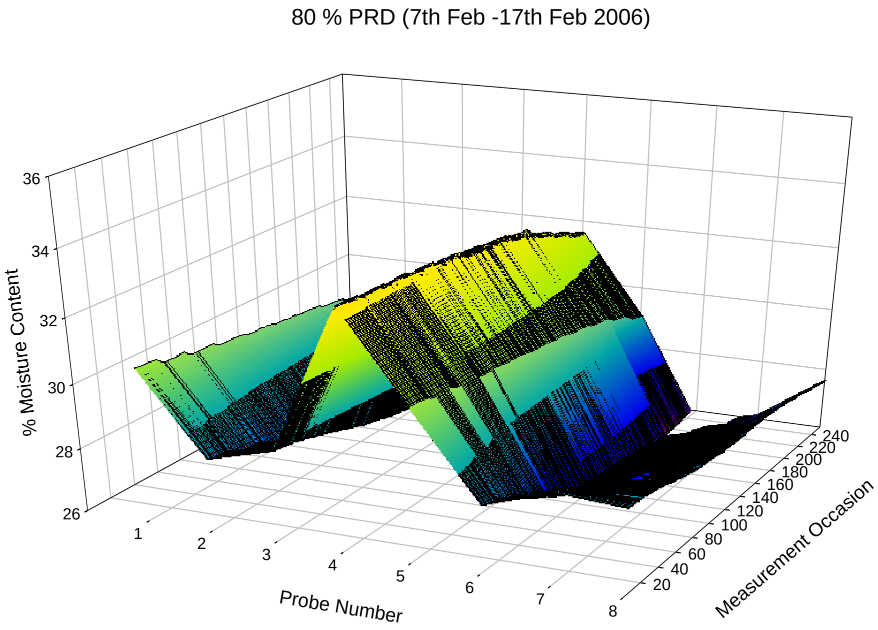
Treatment	Rep	A	B	C	D	E	Mean
Overhead 100%	1	3087	3521	2883	2741	2679	2982
	2	2963	2972	2910	3003	2941	2958
Overhead 80%	1	3122	2595	2879	2941	2542	2816
	2	3193	2905	3685	2976	2763	3104
Trickle 100%	1	2772	3193	2923	3565	3645	3220
	2	2963	3503	3122	3437	2852	3175
Trickle 80%	1	3875	3866	3454	3596	3251	3608
	2	2980	3149	2852	3047	3038	3013
PRD 100%	1	3401	3645	3618	3853	4181	3740
	2	3100	3051	3268	3383	2901	3141
PRD 80%	1	4034	3304	3698	3290	3211	3507
	2	2532	2945	3082	3277	2848	2937

Table B: Nitrate levels in each of the 5 samples taken from each plot - Crop 2.

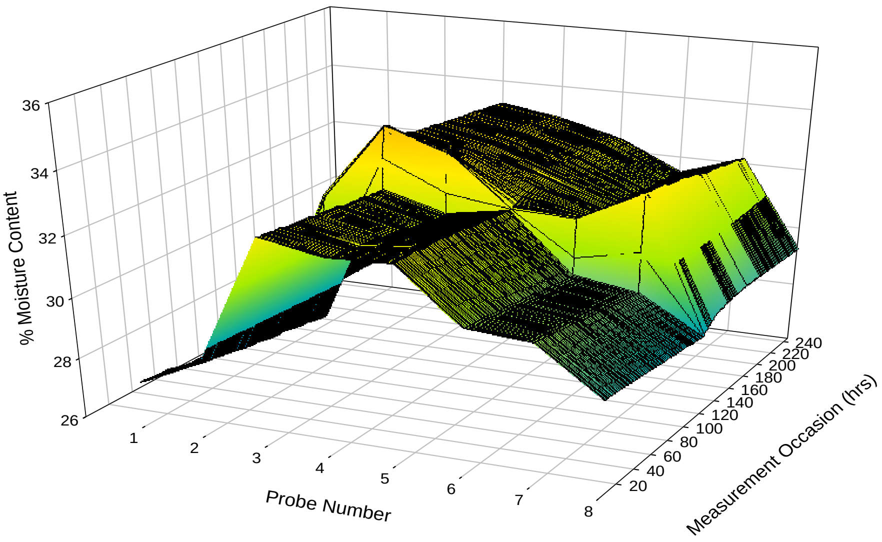
Treatment	Rep	A	B	C	D	E	Mean
Overhead 100%	1	3268	3893	3051	4181	2848	3448
	2	4136	3175	3202	3671	3618	3560
Overhead 80%	1	3693	3242	3499	3366	2918	3344
	2	3773	3361	3937	2998	3698	3553
Trickle 100%	1	3764	3888	3308	3401	3379	3548
	2	4105	3206	3667	3875	3419	3654
Trickle 80%	1	3401	3831	3840	3454	4052	3716
	2	3534	3437	3614	3755	3733	3615
PRD 100%	1	3933	4154	3525	3087	3654	3671
	2	4017	3893	4039	4017	3410	3875
PRD 80%	1	3472	3538	3995	4331	3481	3763
	2	3884	3428	3428	3330	3972	3608
Overhead 100% with 75ppm N		3915	2892	3609			3472
Overhead 80% with 75ppm N		3779	3561	3078			3239

APPENDIX III: SOIL MOISTURE LEVELS IN THE PRD TREATMENTS – CROP 2.





100 % PRD (27th Jan - 6th Feb 2006)



80 % PRD (27th Jan - 6th Feb 2006)