FINAL REPORT

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Protected lettuce: to assess the effects of soil nitrogen levels, trickle irrigation and light levels on nitrate accumulation in winter crops (PC 263)

May 2007

Commercial – In Confidence

Project Title: Protected lettuce: to assess the effects of soil nitrogen levels, trickle irrigation and light levels on nitrate accumulation in winter crops (PC 263)

Project number:	PC 263
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The results and conclusions in this report are based on two carefully monitored experiments and sampling at commercial sites. 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 rate of nitrogen fertiliser applied to the soil (30, 75, 100 and 200ppm) did not affect the nitrate content of a winter crop of protected butterhead lettuce. All samples were below the EC limit of 4500ppm.
- The use of trickle irrigation or shading did not affect nitrate levels in the crops at harvest.
- In commercial lettuce crops there was no correlation between soil nitrogen levels and nitrate levels in the crop at harvest with some lettuce samples exceeding the EC limits.

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 undertake research for a continued derogation offered to UK Lettuce growers.

The aim of the work was to determine the effects of various agronomic inputs on the nitrate content in glasshouse butterhead lettuce. Firstly, by studying the effect of nitrogen fertiliser rates and whether there is a correlation of fertiliser rate with crop nitrate at harvest. Secondly, if there was an effect of irrigation strategy on nitrogen uptake and soil nitrogen levels at harvest by using trickle irrigation compared to the industry standard of using overhead irrigation using sprinkler nozzles. Thirdly, to determine the effect of shading to reduce light levels in the 1, 2, 3 and 4 week period prior to harvest to assess if this would have a significant effect on crop nitrate levels at harvest.

The results should provide robust data to allow growers to make informed agronomic decisions to reduce the risk of crops exceeding the permitted nitrate levels. Winter lettuce crops are most at risk from high nitrate content due to the slower growth rates, more variable ambient light levels plus shorter day light periods between October and March.

Summary of project and main conclusions

In a glasshouse trial, at the Stockbridge Technology Centre, lettuce was planted on 2 October 2006 into soil where nitrogen fertiliser had been applied to achieve 30, 75, 100 and 200ppm nitrogen. Conventional overhead irrigation was compared to a trickle system with soil moisture levels monitored using specialist equipment in both glasshouses. All plots received the equivalent quantity of water. Soil samples were taken 2.5 weeks before harvest and at harvest, with crop nitrate levels determined by laboratory analysis at harvest on 18 December. At harvest 3 samples of lettuce from each plot were sent for nitrate analysis.

The results showed no effect of soil nitrogen levels on the nitrate content of the lettuce at harvest. Even where soil levels had been increased to 200ppm the lettuces were below the EC limit of 4500ppm. Soil nitrogen levels did increase as the rate of nitrogen fertiliser was increased. Soil nitrogen levels decreased by 50% in the 2 ½ weeks before harvest.

The second trial looked at the effect of shading with soil nitrogen levels increased to 100ppm following the Good Agricultural Practice guidelines. The shading treatments involved suspending either 1 or 2 layers of non-woven fleece (18g/m^2) to create a 15 or 30% reduction in light levels. These were applied to the crop at 4, 3, 2 or 1 week before harvest (15, 22 or 29 January and 5 February). At harvest 3 samples from each plot were sent for laboratory nitrate analysis.

The results showed no effect of shading treatment on nitrate levels in the heads at harvest with some samples exceeding the 4500ppm EC limit. The reasons for the lack of effect are unclear and require further study. Light levels in the 4 weeks before harvesting were generally good but they were very poor during December.

Sampling of lettuces from commercial growers between January and March 2007 was undertaken to provide additional data. Soil samples were taken 3-4 weeks before harvest and at harvest for determining nitrogen levels. There was no correlation between soil nitrogen levels and nitrate levels in the crop at harvest. However, sampling of commercial lettuce crops showed that 5 of the 6 samples exceeded the EC limits, where pre-harvest soil nitrogen levels were similar to the 100ppm treatment in the STC trial. Also, despite low soil nitrogen levels at harvest of only 30ppm for one crop, it was still 1400ppm above the EC limit. More work is therefore required to clarify the relationship between nitrate fertiliser application and nitrate levels of winter lettuce crops.

Financial benefits

The work has again highlighted the high variation in nitrate levels between samples from the same plot and this variation has reduced treatment effects. Therefore growers need to closely follow the current Code of Good Agricultural Practice to minimise the risk of crops exceeding the EC levels.

Action points for growers

Continue to adhere to the Code of Good Agricultural Practice and in particular follow the advice on monitoring soil nitrogen levels and keeping glass clean.

SCIENCE SECTION

Introduction and Objectives

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 EC regulation number 563/2002.

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 within heads of the same cultivar 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 than after dull weather.

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

A HDC-funded project, PC 245, commissioned in summer 2005 looked at the effect of spectrally modifying plastics on the harvest nitrate content of baby leaf and lettuce. 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 was not affected by the post-planting regime.

Another HDC-funded project, PC 243, commissioned in summer 2005 looked at the effects of irrigation method and partial root drying on crop nitrate levels at harvest using 2 planting dates in the autumn. The results showed that high quality lettuce could be produced by using trickle irrigation and where 20% less water was applied there were higher residual soil nitrogen levels. Neither the irrigation method nor using 20% less water affected the nitrate levels in lettuce at harvest. Levels were below the EC limit but there was considerable variability, up to 1045ppm between sub-samples of lettuce harvested from the same plot.

Objectives

The aim of this work was to identify the effects of soil nitrogen fertiliser rates and irrigation strategy on crop and soil nitrate levels at harvest and in a second trial to determine the effect of reduced light levels in the 4 weeks prior to harvest.

Trial details

Site

The trials were 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.

Part 1: Determining the effect of nitrogen fertiliser rates and irrigation strategy on crop and soil nitrate levels at harvest.

<u>Treatments</u>

A. Nitrogen fertiliser rates

1. 30ppm
2. 75ppm
3. 100ppm (current recommendation in GAP guidelines)
4. 200ppm

B. Irrigation techniques

1. Overhead irrigation using sprinkler nozzles (1 line per 3.2m bay)
2. Trickle tape using 1 line between every other row of plants

<u>Details</u>

Butterhead lettuce, cultivar RZ 42.23, were sown into peat blocks on the 12 September and propagated in a standard glasshouse. The levels of soil nitrogen on 7 September were very low and ranged from 7.4 – 14.7ppm NO3 in one glasshouse (trickle irrigation) and 3.7 – 9.4ppm NO3 in the second glasshouse (overhead irrigation). Nitrogen fertiliser was added to each glasshouse based on soil analysis, to increase the levels to the required treatment level. For the 2 highest rates 50% of the fertiliser was applied pre-planting and the rest applied on 19 October (17 days after planting). The nitrogen fertiliser used was ammonium nitrate.

Lettuces were planted on 2 October at a spacing of 20 x 20cm, with 4 replicates of each treatment. Each plot had 12 rows of plants with 13 plants in each row.

The overhead plots received overhead irrigation as per commercial practice with each application being 10, 12 or 15 minutes in duration. For the trickle irrigation plots they received overhead irrigation 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 overhead irrigation the quantity of water applied was calculated and this was then applied to the trickle irrigated plots as 4 smaller applications over several days. The trickle tape plots had drip lines in every other row and these were used for each application.

<u>Records and assessments</u>

Plant vigour

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

Leaf nitrate analysis at harvest

At the main harvest three boxes of 10 heads were cut from each plot and sent to NRM Laboratories for analysis. Each set of 10 heads was harvested from a discrete area of the plot and all 10 heads within each sub-sample were adjacent to each other.

Soil mineral nitrogen assessments

Soil samples from 0-30cm were taken from each plot part way through the growing period 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. Comparisons were made between means based on the least significant difference (LSD) and a 95% confidence interval was used for all analyses.

Part 2: Determining the effect of shading on crop nitrate levels at harvest.

<u>Treatments</u>

A. Shading treatment

1. No cover
2. 15 % reduction achieved using a single layer of non-woven fleece
3. 30 % reduction achieved using 2 layers of non-woven fleece

B. Duration of covering

1. 4 weeks prior to harvest (applied 15 January 2007)
2. 3 weeks prior to harvest (applied 22 January 2007)
3. 2 weeks prior to harvest (applied 29 January 2007)
4. 1 week prior to harvest (applied 5 February 2007)

Details

Butterhead lettuce, cultivar RZ 42.23, were sown into peat blocks on the 27 September and propagated in a standard glasshouse. Fertiliser was added to each glasshouse based on soil analysis, to increase the soil level to 100ppm. The levels of soil nitrogen on 7 September were very low 11.9 ppm NO3.

Lettuces were planted on 18 October at a spacing of 20 x 20cm, with 3 replicates of each treatment. Each plot had 6 rows of plants with 10 plants in each row.

The shading treatments commenced 4 weeks before the expected harvest date with non-woven fleece suspended 55cm above the soil to ensure adequate air movement over the crop. The fleece was allowed to drop down on all sides of the plot to ensure that all the plants in the plot received the correct shading treatment.

Records and assessments

Leaf nitrate analysis at harvest

At harvest three boxes of 10 heads were cut from each plot and sent to NRM Laboratories for analysis. Each set of 10 heads was harvested from a discrete area of the plot and all 10 heads within each sub-sample were adjacent to each other.

Glasshouse Environmental Monitoring

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

Statistical Analysis

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

Part 3: Sampling of commercial lettuce crops

The project also involved sampling commercial lettuce crops in late 2006 and early in 2007. This was to provide extra sets of data to allow any correlation between crop nitrate levels at harvest and soil nitrogen levels both at harvest and 3-4 weeks before harvest to be identified. This would provide additional information to support any interpretation of the results in Part 1.

Soil samples were taken prior to fertiliser application for each site unless the grower had already sampled the soil. These soil samples were sent to commercial laboratories. Growers applied their standard fertiliser rates and crops were planted. For one grower the lettuces were planted through white polythene mulch but the other crops were planted into bare soil. Soil samples were taken 3-4 weeks before expected harvest from a $2m^2$ area and sent for analysis. At crop maturity ten heads were harvested from this small area, trimmed and sent away for nitrate analysis. A further soil sample was also taken from the immediate area.

Results

The results for each trial are presented separately.

Part 1: Determining the effect of nitrogen fertiliser rates and irrigation strategy on crop and soil nitrate levels at harvest.

Establishment after planting was excellent with no differences between the nitrogen fertiliser treatments. All plots looked similarly vigorous. The irrigation applied to the crops is presented below.

Table 2: Dates of irrigation, duration and quantity applied.

Date	Overhead	Quantity (l/m^2)	Trickle	Quantity (l/m^2)
2 Oct	10 mins	5.87	10 mins #	5.87

16	15 mins	8.81	¼	2.2
20	-	-	¼	2.2
27	-	-	¼	2.2
9 Nov	-	-	¼	2.2
18	15 mins	8.81	¼	2.2
27	-	-	¼	2.2
1 Dec	-	-	¼	2.2
11 Dec	-	-	¼	2.2

overhead to aid establishment

The total quantity of water applied to both glasshouses was 23.5 litres per m^2. The final watering to the trickle plots was made closer to harvest than was possible for the overhead treatment due to the need to avoid getting the foliage wet.

The results for the interim soil nitrogen assessments taken from within the growing crop are presented in Table 3.

Table 3: Results of soil analysis carried out 2.5 weeks before harvest (1 December).

Treatment	NH3 ppm	NO3 ppm	Total N (kg/ha N)	Range
Overhead				
30ppm	1.9	41.5	130.2	111 – 146
75ppm	4.3	91.9	288.4	236 – 376
100ppm	42.5	138.6	543.3	403 – 718
200ppm	108.5	213.2	965.0	912 – 992
Trickle				
30ppm	3.3	62.7	197.9	58 – 465
75ppm	9.8	60.8	211.8	158 – 271
100ppm	72.9	131.9	614.2	371 – 785
200ppm	111.8	248.1	1079.5	907 - 1254

The results show, as expected, that as the rate of nitrogen fertiliser applied to the soil increased the levels of nitrogen in the soil increased accordingly. The uniformity between the replicates was generally good but there were still instances for some treatments where there was extreme variation between the replicates. There was no obvious effect of irrigation strategy on soil nitrogen levels. The use of overhead sprinklers did not increase fertiliser leaching compared to where trickle irrigation was used where smaller amounts were applied on each occasion.

The harvest results are presented in Tables 4 and 5.

Table 4: Results at harvest for overhead irrigated plots (19 December 2006).

Treatment	Mean head weight (g)	Mean nitrate content (ppm)	Range	% samples >4500ppm (4000ppm)
30ppm	239	3313	2290 – 4818	8 (25)
75ppm	245	3455	2613 – 4353	0 (17)
100ppm	236	3655	2418 – 4911	8 (33)
200ppm	230	3380	2732 – 3897	0 (0)
SED (32df)	6.03	151		
LSD (5%)	12.3 (NS)	308 (NS)		

NS = not significant at 5%

Table 5: Results at harvest for trickle irrigated plots (19 December 2006).

Treatment	Mean head weight (g)	Mean nitrate content (ppm)	Range	% samples >4500ppm (4000ppm)
30ppm	213	3111	2484 – 3995	0(0)
75ppm	222	3372	2896 – 3848	0 (0)
100ppm	231	3487	2706 – 4477	0 (17)
200ppm	223	3500	2285 – 4260	0 (25)
SED (32df)	3.9	136		
LSD (5%)	8.0 (NS)	277 (*)		

NS = not significant at 5% * significant at 5%

There were no significant (P>0.05) differences in mean head weights between the nitrogen fertiliser treatments with all the lettuce considered marketable. Foliage colour was very good even where the lowest rate of nitrogen fertiliser had been used.

The mean nitrate content at harvest based on a total of 12 samples per treatment showed a trend effect with higher nitrate content obtained by increasing the rate of nitrogen fertiliser. There were significant differences (P>0.05) between the 30ppm treatment and the 2 highest rates. However, there was large variation between the lowest and highest results for each treatment despite careful harvesting and the lettuce being harvested from three small areas within each plot.

All samples were below 4500ppm nitrate except at the 2 highest nitrogen rates where some samples were over 4000ppm.

The results for the soil mineral nitrogen analysis are presented in Table 6.

Table 6: Soil mineral N results at harvest on 18 December (11 weeks after planting).

Treatment	NH3 ppm	NO3 ppm	Total N (kg/ha N)	Range
Overhead				
30ppm	2.8	14.9	53.0	40 – 60
75ppm	5.1	51.2	168.8	105 – 198
100ppm	24.3	88.8	339.5	253 – 427
200ppm	40.4	114.2	463.6	262 – 608
Trickle				
30ppm	2.7	13.7	49.4	29 – 75
75ppm	4.5	51.7	168.5	160 – 187
100ppm	35.1	94.1	387.5	329 – 442
200ppm	60.2	114.8	524.9	393 - 779

The soil nitrogen levels at harvest had significantly decreased in the 17 days since the previous sampling on 1 December.

A summary of the soil nitrogen levels for the treatments at both sampling occasions is shown in Table 7.

Table 7: Soil mineral N reductions between 1 and 18 December.

Treatment	Total N (kg/ha N) on 1 December	Total N (kg/ha N) on 18 December	% reduction
Overhead			
30ppm	130.2	53.0	59
75ppm	288.4	168.8	41
100ppm	543.3	339.5	38
200ppm	965.0	463.6	52
Trickle			
30ppm	197.9	49.4	75
75ppm	211.8	168.5	20
100ppm	614.2	387.5	37
200ppm	1079.5	524.9	51

The lettuces in their final 2 ½ weeks of growing significantly depleted the soil nitrogen levels. At the lowest application rate the levels were similar to the levels prior to fertiliser application.

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A series of bivarate Pearson's correlations were carried out on the nitrogen data and both the head weights and the nitrate content data. There was a positive correlation between nitrogen fertiliser treatments and soil nitrogen levels.

Part 2: Determining the effect of shading on crop nitrate levels at harvest.

The lettuce established well and was very uniform prior to applying the first shading treatments in mid January 2007.

The results for the crop nitrate levels at harvest on 12 February are presented in Table 8.

Table 8: Results at harvest (12 February 2007).

Treatment	Mean head weight (g)	Mean nitrate content (ppm)	Range	% samples >4500ppm (4000ppm)
<u>15% shading</u>				
4 weeks	186	4648	4402 – 5212	56 (100)
3 weeks	177	4452	4220 - 4597	56 (100)
2 weeks	185	4368	3959 – 5115	89 (33)
1 week	193	4160	3755 – 4783	11 (78)
<u>30% shading</u>				
4 weeks	196	4262	3986 - 4597	22 (89)
3 weeks	186	4327	3747 – 4663	44 (67)
2 weeks	191	4475	3888 – 4752	56 (89)
1 week	205	4292	3897 – 5035	22 (78)
Nil cover control	187	4384	3733 - 5434	28 (72)
Mean of 15% cover	185	4407		
Mean of 30% cover	195	4339		
Mean of 4 week trts	191	4455		
Mean of 3 week trts	182	4390		
Mean of 2 week trts	188	4421		
Mean of 1 week trts	199	4226		
SED (63df) for:				
comparing cover means	1.6	58		
LSD (5%)	3.2 (NS)	116 (NS)		
duration means	2.4	82		
LSD (5%)	4.7 (NS)	163 (NS)		
all treatment means	2.9	116		
LSD (5%)	5.8 (*)	231 (*)		

NS = not significant at 5% * = significant at 5%

Overall the mean head weights were similar for all treatments and head quality was very good. There was a significant (P>0.05) increase in head weight for the 30% cover treatment compared to the 15% and nil cover treatment but this result should be treated with caution.

The mean nitrate content values were all over 4000ppm even where no shading had been applied. Although there were was a trend with the nitrate content increasing with extended covering it was not significant. This was probably due to the variation between samples and confirms previous trials experience where sample to sample variability can mask main treatment effects.

The number of samples exceeding 4500ppm was generally higher for the 15% shading treatment but with no consistent effect of the length of covering.

Part 3: Sampling of commercial lettuce crops

The results for the six crops are presented in Table 9.

Table 9: Summary of soil nitrogen levels and nitrate levels in the heads at harvest.

Crop	**1**	**2**	**3**	**4**	**5**	**6**
Lettuce type	Butterhead	Curly	Butterhead	Butterhead	Butterhead	Curly
	(mulched)	(mulche	(bare soil)	(bare soil)	(mulched)	(mulched)
Soil results		d)				
Pre planting						
NH3 (ppm)	<1		<1	2.7	<1	<1
NO3 (ppm)	104	<1	46.7	11.9	80	80
Total (kg/ha)	312	104	140	14.6	240	240
		312				
Pre harvest						
Date	18 Dec		18 Dec	18 Jan	28 Feb	28 Feb
NH3 (ppm)	1.6	18 Dec	2.0	4.8	1.8	2
NO3 (ppm)	732	1.8	66.8	71.4	41.2	88.2
Total (kg/ha)	2202	151	206	229	129	271
		458				
Harvest						
Date	11 Jan		1 Feb	12 Feb	23 Mar	23 Mar
NH3 (ppm)	4.6	11 Jan	3.3	2.6	3.1	2.5
NO3 (ppm)	77	3.2	30.6	30.4	99.4	73.3
Total (kg/ha)	245	50.9	102	99	308	227
		162				
Crop nitrate						
(ppm)	5157		5985	4175(Lab 1)	4612	5405
		6081		4561(Lab 2)		

Crop samples 1 and 2 were planted less than 3m from each other but there was a large differences in the nitrogen levels in the soil at 3 weeks before harvest. The results for the curly lettuce are in line with the results obtained in Part 1 where soil nitrogen levels were increased to 100ppm. At harvest the soil nitrogen levels for both Crops 1 and 2 were generally similar to that obtained in Part 1 but with crop nitrate levels well above the EC limit.

For Crop 3 harvested on 1 February the soil nitrogen levels were low in mid/late December and had decreased by 50% between 1 February and harvest. However, the crop nitrate level was high despite low nitrogen levels in the soil at harvest.

For Crop 4 the soil sample taken on 18 January showed a soil nitrogen level which was similar to where soil levels had been increased to 100ppm in Part 1, with over a 50% reduction between 18 January and harvest on 12 February. Crop samples were sent to 2 laboratories and showed a 10% difference despite coming from alternate plant rows.

For Crops 5 and 6 the soil was sampled in late February and the lettuces harvested in mid/late March. The pre-harvest soil nitrogen levels were relatively low but the lettuce at harvest still exceeded the EC limit. The reason for the increase in soil nitrogen level between 28 February and 23 March is unclear.

Discussion

The uptake of nitrogen by lettuce plants is a complex process and trials looking at nitrate content are very liable to high sample to sample variation. Despite careful attention to detail, particularly at harvest, and careful preparation of samples the head to head variability was often greater than differences between the treatments and these generally masked treatment effects. This was highlighted in the range between the highest and lowest samples within one plot exceeding 2528ppm in the fertiliser trial and 1098ppm in the shading trial.

<u>Effect of nitrogen fertiliser</u>

In this trial almost all samples at harvest were below the EC limit of 4500ppm. The nitrate levels were probably low due to the good weather conditions experienced by the crop during October and November.

There was no consistent effect of nitrogen fertiliser rate on head weight or quality at harvest or on nitrate content. The colour and size of the lettuce grown in soil which had been increased to 30ppm was as good as where soil nitrogen levels had been increased to 100ppm. Even where soil nitrogen levels had been increased to 200ppm the plants did not take up this extra nitrogen and so nitrate content in the heads was similar to the other treatments.

There was an increase in nitrogen residues in the soil both 3 weeks before harvest and at harvest where higher rates of nitrogen fertiliser had been used. This result is to be expected but did not result in luxury uptake by the maturing crop.

<u>Water use efficiency</u>

The trial confirmed the results obtained in PC 243 that high quality crops can be produced by using trickle irrigation as an alternative to overhead irrigation. 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 to avoid the peat blocks from drying out.

In this trial an identical quantity of water was applied to crops grown using overhead and trickle irrigation systems. However, 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, particularly when using soil moisture monitoring equipment. Applying water more regularly should enable plants to grow more uniformly and avoid soils from becoming excessively wet.

Nitrogen leaching

Trickle irrigation should, in theory, reduce nitrogen fertiliser leaching as more frequent applications of lower volumes of water should avoid nutrients from being leached through the upper soil profile. This was not observed in this trial with generally similar results for both irrigation systems for all 4 rates of nitrogen fertiliser. However, due to the weather during October and November the crop grew faster than expected and matured several weeks earlier than expected. If the crop had been in the ground for longer and received more irrigation events there may have been a different result.

Effect of shading of nitrate content at harvest

Nitrate levels in the crop at harvest were higher than has normally been observed in trials at Stockbridge but with no consistent effect of either the level of shading or the duration of shading. Crops which receive lower levels of light and for a longer period of time would normally be expected to have a higher nitrate content as light levels are considered to be one of the main factors affecting nitrate accumulation in plants. In this carefully controlled trial there was only a very limited effect with no obvious increase in nitrate levels for the covered treatments compared to the non covered control.

One explanation might be that the plants were covered when they were semi mature and that the plants might be more affected by reduced light levels when they are at a younger stage and are less responsive closer to harvest.

Correlation between crop and soil nitrate levels in commercial crops

The sampling of commercial crops provided more data on soil nitrogen levels both pre and at harvest and nitrate levels in the crop at harvest. The results of the soil sampling 2-3 weeks before harvest generally confirmed the results obtained in Part 1 that growers had increased soil nitrogen levels to 100ppm before planting.

Unfortunately there did not appear to be any obvious correlation between ‘pre-harvest’ or ‘at harvest’ soil nitrogen levels and in-crop nitrate levels. For 2 crops soil nitrate levels at harvest were only 30ppm but there was over 1400ppm difference in crop nitrate.

Conclusions

1. The rate of nitrogen fertiliser had only a very slight effect on the nitrate content of lettuce at harvest even when applied to increase the soil levels to double those recommended in the Code of Good Agricultural Practice. High quality lettuce crops were produced even where soil levels had been increased to only 30 and 75ppm.

2. Overhead irrigation and trickle irrigation systems gave similar mean head weights at harvest. The nitrate content of the heads was similar for both irrigation methods. Soil nitrogen levels at 2 weeks before harvest and at harvest were similar within each nitrogen fertiliser treatment. There was no apparent effect on nitrogen fertiliser leaching by using smaller volumes of water but more frequently.

3. Using shading to simulate a 15 and 30% reduction in ambient light levels during a period of low natural light had no significant effect on the nitrate content in the lettuce at harvest.

4. Soil nitrogen levels for the commercial crops at 2-3 weeks before harvest could potentially be used to confirm that growers had applied nitrogen to increase soil levels to 100ppm. However, there was no obvious correlation between soil levels at harvest with nitrate levels in the crop 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. Crops planted in the winter could particularly benefit from trickle irrigation systems and could reduce pesticide use.

2. **Evaluate the effect of different shading regimes and the plants response to periods of lower light throughout different parts of the growing period** –

although the results obtained in this project showed little effect growers need further information on what the effects of reduced light levels and day length are on crop nitrate levels. A greater range of cover durations at different times of the year might enable a better understanding of how light affects nitrate content in plant material. Growers could then decide on the feasibility of using mobile lighting rigs to increase light levels in the days leading up to harvest.

3. **Investigate the reasons for the high sample to sample variation in nitrate content –** there is very large variation between samples from small areas and this requires further study. The reasons might be due to harvest technique, natural variation between adjacent plants, differences between different parts of the plant eg leaf and mid rib or sample preparation where there may be more outer leaf or inner leaf material used.

TECHNOLOGY TRANSFER

- The results have been discussed with members of the industry and have been used to support the documents presented to EFSA in March 2007.
- HDC News Article (Sept 07).

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Appendix I: Radiation and number of sun hours.

PART 1

Date	Radiation (MJ/m^2)	Sun hours	Date	Radiation (MJ/m^2)	Sun hours
2 Oct	8.40	2.6	11 Nov	3.63	1.1
3	1.06	6.3	12	3.78	1.4
4	9.47	3.8	13	2.72	2.2
5	2.72	0.1	14	3.14	0.1
6	7.89	3.7	15	2.95	1.3
7	9.65	7.4	16	3.17	0.7
8	7.10	1.8	17	4.16	1.1
9	8.38	5.8	18	3.94	6.0
10	2.01	0.0	19	4.21	5.2
11	2.22	0.0	20	3.79	2.4
12	7.99	4.8	21	3.30	2.8
13	4.15	0.0	22	1.45	4.9
14	6.87	3.3	23	3.61	5.1
15	2.10	0.0	24	0.82	0.0
16	3.95	0.7	25	1.83	0.9
17	2.45	0.0	26	2.64	3.8
18	3.03	0.0	27	3.37	4.2
19	4.38	1.8	28	2.76	3.4
20	5.08	2.1	29	3.40	3.5
21	4.93	2.4	30	1.29	0.0
22	3.64	1.4	1 Dec	1.86	0.0
23	5.03	2.3	2	2.76	3.5
24	7.16	5.0	3	3.08	4.8
25	2.18	0.0	4	2.18	1.5
26	3.92	2.0	5	2.06	1.9
27	1.91	0.0	6	1.34	0.6
28	2.16	0.1	7	1.96	2.2
29	6.10	7.5	8	2.71	4.5
30	5.91	6.0	9	3.05	6.1
31	4.29	6.2	10	0.89	0.0
1 Nov	6.86	7.0	11	2.31	3.0
2	7.02	8.0	12	2.22	1.5
3	6.66	6.5	13	0.99	0.0
4	5.43	1.1	14	0.47	0.7
5	4.61	2.2	15	2.73	0.0
6	5.88	7.1	16	2.85	5.8
7	5.57	3.6	17	2.98	5.9
8	2.60	7.0	18	0.89	1.2
9	5.92	6.5	19	1.60	0.0
10	2.24	0.0			

Appendix II: Radiation and number of sun hours.

PART 2

Date	Radiation (MJ/m^2)	Sun hours	Date	Radiation (MJ/m^2)	Sun hours
19 Dec	1.60	0.0	19	3.49	2.5
20	1.52	1.0	20	3.54	4.0
21	2.50	0.0	21	2.70	1.1
22	2.95	0.0	22	4.61	6.5
23	0.59	0.0	23	4.54	5.1
24	0.46	0.0	24	3.20	0.8
25	0.66	0.0	25	4.67	5.5
26	0.86	0.0	26	3.34	0.6
27	1.97	1.1	27	3.96	5.2
28	0.85	0.0	28	2.30	0.5
29	0.39	0.0	29	4.25	0.0
30	1.29	1.0	30	2.30	6.0
31	1.50	0.0	31	2.25	1.0
1 Jan 2007	1.83	2.1	1 Feb	5.46	4.9
2	2.02	0.0	2	5.85	7.0
3	0.78	1.5	3	6.24	6.9
4	2.31	2.9	4	6.33	7.0
5	1.13	0.6	5	6.33	6.0
6	1.08	0.0	6	7.16	6.2
7	1.38	0.0	7	7.43	6.4
8	1.03	0.2	8	2.15	0.0
9	1.09	0.0	9	1.96	0.0
10	2.50	3.1	10	1.01	0.0
11	1.66	0.5	11	4.58	2.5
12	1.68	0.1	12	4.48	3.0
13	1.98	0.1			
14	3.62	6.1			
15	1.70	0.9			
16	1.22	0.0			
17	2.73	3.9			
18	1.74	0.6			