Improved efficiency of nutrient and water use for high quality field vegetable production using fertigation.

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Keywords: fertigation, *Lactuca sativa*, nutrient efficiency, water efficiency, shelf life

Abstract

Drip-based fertigation may improve the application efficiency of water and nutrients while maintaining or improving marketable yield and quality at harvest and post-harvest. Two plantings of lettuce (*Lactuca sativa*) were grown in the UK, with six N treatments and two methods of irrigation and N application. The conventional overhead irrigated treatments had all N applied in the base dressing with irrigation scheduled from SMD calculations. The closed loop treatments had nitrogen and irrigation delivered via drip automatically controlled by a sensor and logger system. The work established that water content in the root zone can be monitored in real time using horizontally oriented soil moisture sensors linked to data logging and telemetry, and that these data can be used to automatically trigger drip irrigation for commercially grown field vegetables. When the closed loop irrigation control was combined with fertigation treatments, lettuce crops were grown with savings of up to 60% and 75% of water and nitrogen respectively, compared to standard UK production systems. However, excess supply of N through fertigation rather than solid fertiliser was more detrimental to marketable yield and post harvest quality highlighting that care is needed when selecting N rates for fertigation.

INTRODUCTION

New developments in the areas of soil moisture and pore water conductivity measurement technology provide new opportunities for adapting and developing systems to deliver precise control of root zone moisture and nutrient supply with maximum efficiency. UK vegetable growers are slowly increasing the use of drip tape, in response to legislative requirements to demonstrate efficient irrigation water application and reduce the agricultural impact on water courses (Knox and Weatherhead, 2005). The capability to control irrigation and hence fertigation allows growers to manipulate nutrient supply in response to crop need and soil conditions with potential to improve yield and post harvest quality with reduced water and nutrient inputs.

Fertigation can improve nutrient use efficiency by a) supplying nutrients and water precisely avoiding excess concentrations of fertiliser in the soil and consequent leaching, and b) adding nutrients only to a wetted volume of soil, where roots are active and taking up nutrients efficiently (Bar-Yosef, 1999). However, the benefits of fertigation in field crops have been reported mainly in arid or semi-arid crop production (e.g. McPharlin et al., 1995; Silber et al., 2003) where the incidence of rainfall is limited and soil organic matter, and hence the organic nutrient pool, is often quite low. In contrast, the soils used for growing field vegetables in the UK are generally of a moderate to high organic matter content and are sporadically but frequently wetted with rain. These conditions may limit the benefits of fertigation over a solid fertiliser with or without overhead irrigation.

The aim of this work was to a) develop a closed loop irrigation system suited to UK production and b) test the hypothesis that using this system, lettuce crops could be grown with reduced water and fertiliser inputs whilst maintaining yield and quality.

MATERIALS AND METHODS

The trial was undertaken at Warwick HRI, Wellesbourne, UK. The soil was a deep permeable coarse sandy loam of the Wick series (Whitfield, 1974). Green Batavia lettuce (*Lactuca sativa* 'Noisette') was purchased from a commercial plant raiser (Hillgate nurseries, Terrington St Clement, Norfolk) for two planting dates T1(10 May 2006) and T2 (29 June 2006). Plants in 42 mm peat blocks were transplanted by hand in 1.83 m wide beds at spacings of 0.33 m between rows and 0.35 m up a row. Each plot consisted of four rows of plants across the bed with 15 plants in a row, giving 24 guarded heads in the middle two rows of the bed.

Experimental treatments

Both plantings of lettuce were grown with six N treatments and two methods of irrigation and N application. There were two replicate beds of each treatment. The industry standard treatment was irrigated overhead and had all N applied in the base dressing with irrigation scheduled from SMD calculations. The Closed loop treatments had N and irrigation delivered via drip.

Measurements of soil mineral N at planting were made at depths of 0-30, 30-60 and 60-90 cm to confirm the SNS index and aid interpretation of the responses to nitrogen in the experiments. The residual mineral N level at planting was 83 and 139 kg ha^{-1} N to 90 cm for the T1 and T2, respectively. The current recommended rate of additional N for these crops was 150 kg N ha^{-1} for T1 and 25 kg N ha^{-1} for T2 (MAFF, 2000). The six N treatments of 0, 25, 50, 75, 100 and 150 kg ha^{-1} N, were supplied as NH_4NO_3 (Kemira, Chester, UK). The water source was from an on-site reservoir. The amount of water applied was recorded using an in-line water meter. Crops were harvested when mature, six weeks after transplanting, and marketable yield (t ha^{-1}) was estimated from head weights of Class I product (OECD, 2000) for each replicate plot. Post harvest quality of processed leaf was assessed using a commercial protocol (Bakkavor Ltd, unpublished) where quality deterioration was scored on a 0-3 scale subjectively for processed (chopped and bagged) leaf every 2 days over a 14 day period. Analysis of variance (ANOVA) was performed on yield and post-harvest quality data using Genstat (10th Edition) (Lawes Agricultural Trust, Rothamstead, UK).

Overhead system (industry standard)

The overhead irrigation was applied using Nelson MP rotator sprinklers. Meteorological data were collected from a met station approximately 200 m from the experiment. Total daily evaporation and rainfall data were used to run a simple Soil Moisture Deficit (SMD) model from which irrigation was scheduled. The model was based on Stanhill's equations (unpublished) and ran from an initial mean gravimetric SMD calculation taken at the time of transplanting. Irrigation was set to apply 10 mm at an SMD of 25 mm, until approximately two weeks before harvest when the soil was allowed to dry down, in line with commercial practice.

Closed loop drip system

Irrigation and fertigation was applied using pressure compensated 17mm Netafim RAM drip. Fertiliser was applied over 4 applications using Dosatron D1-16 proportional liquid feed injectors. An injection ratio of 1:64 was used, in combination with the variable dilutions of feed according to treatment, with an aim to apply in 3 mm of irrigation water. The system was flushed through with at least 1 mm of plain water following a fertigation event and between treatments. A single 'virtual' soil moisture sensor consisting of 4 Theta probes (Delta-T devices, Cambridge, UK) installed at a depth of 25 cm to measure a 30 cm transect under a single dripper mid-way within a plot was used to control drip irrigation for each experiment. Supplementary measurements were made using 'roaming' sensors of (a) the variation in soil hydraulic properties across all plots (fertigated and solid/overhead irrigated) at one point in time (b) the horizontal spread of the irrigation bulb in two fertigated plots. These measurements enabled us to assess the importance of (a) plot to plot variation in soil hydraulic properties and (b) dripper performance.

The dry threshold trigger value was set at a volumetric water content (vmc) of 0.18. This value is wetter than permanent wilting point (around 0.10 vmc for a sandy loam). Each irrigation event was 10 mm irrigation within the irrigation bulb which brought the water content up to field capacity (approximately 0.21 vmc). The irrigation was set to come on (when triggered) at 10:00 h and to come on only once per day.

RESULTS

Weather data

May was wet, June and July were dry but with significant rain events (>10 mm) every couple of weeks, and August was dry but with small rain events (<5 mm) every week or so. The soil used for each experiment was close to field capacity at the start of each experiment. In addition, the fertigated plots received a regular additional input of water (plus nutrients) every two weeks. The overall result of this was that the soil was not subject to severe prolonged drying during these experiments, apart from towards the end of each growing period and this can be seen from the volumes of rain water received by the crops (Table 1).

Closed loop system

The overall mean soil moisture content of all drip irrigated plots was measured using a 'roaming' sensor as 0.239 with a range from 0.210 - 0.270 at one time point following rain. The virtual sensor was installed in a plot with mean moisture content of 0.236, showing that the plot was representative of the experimental area. Dripper performance was consistent in the two plots monitored; the mean bulb diameter was 32.2 cm with a range from 30 –40 cm. This information was used in estimating the volume of water to be applied to restore the water content in the irrigation bulb to the wet threshold, and it was encouraging to see how uniform this was along the drip lines. It is interesting to note that the UK Department for Environment, Food and Rural Affairs (DEFRA) in their irrigation guidelines (DEFRA, 2003) recommend that lettuce is irrigated with 25 mm at a soil moisture deficit of 25 mm. In this work we were drip irrigating with 10 mm at 10 mm deficit.

Crop trials

The average yield for the first transplanting was lower than the later transplanting with a mean of 20.5 t ha^{-1} (T1) compared to 22.7 t ha^{-1} (T2). Yield data was variable and neither the rate of N nor interaction between N and application method (solid vs fertigation) was significant. In both transplantings the treatment means for the solid fertiliser treatments were variable in response to increasing N rates (Fig. 1 and 2) and did not fit a quadratic equation well (R^2 = 0.13 and 0.36 for T1 and T2, respectively). However, the fertigation treatments responded more consistently. The response of T1 to N rates supplied by fertigation was best described by the equation $y = -0.003x^2 + 0.494x + 5.155$ ($R^2 = 0.85$) with a maximum yield obtained from the fitted line at a rate of approximately 75 kg added N ha^{-1}; the equivalent of 158 kg ha^{-1} available N. With solid N maximum yield appeared to be given with a similar amount of N. The response of T2 to fertigation was best described by the equation $y = -0.002x^2 + 0.299x + 14.78$ ($R^2 = 0.96$) with a maximum yield obtained from fertigation at a rate of 25 kg N ha^{-1}; equivalent to 164 kg ha^{-1} available N. With solid N maximum yield was achieved with 100 kg/ha added N equivalent to 240 kg ha^{-1} available N.

Post harvest quality

The quality after processing differed markedly between N sources in the first transplanting. Increased levels of N fertigation were associated with a decrease in the overall quality of processed leaves (Fig. 3). In contrast, increased rates of solid N fertiliser improved post harvest performance up to 80-100 kg ha^{-1} additional N (160-180 kg ha^{-1} available N). There was no decline in quality at rates higher than this. Transplanting 2 showed that increasing the rate of N through fertigation gave a variable response in quality of processed leaves (Fig. 4). A clearer response to N rate was observed with the solid N with the best overall score being achieved at the highest rate.

Water use

Overall, the closed loop irrigation control system used less water than a standard overhead irrigation system managed by SMD calculations. The early transplanting used 1.1 mm more water with the closed loop system, equivalent to an additional 7% of irrigation volume (Table 1). However, the difference in water can be accounted for by the additional water needed to apply the fertigation treatments (approximately 4 mm per fertigation event) when an irrigation treatment was not necessary. The later crop showed a more marked reduction in applied water through closed loop irrigation compared with the overhead system with 26.6 mm less water applied equating to approximately 40% of the water applied using the standard system.

DISCUSSION

The water content in the root zone can be monitored in real time using horizontally oriented soil moisture sensors linked to data logging and telemetry, and these data can be used to automatically trigger drip irrigation for semi-commercially grown lettuce. The system coped well with the intermittent rain received by both plantings, preventing irrigation when SMD calculations would require irrigation. Water was not saved in the first transplanting as rain maintained soil water at levels above which irrigation was needed in any quantity and the need to fertigate meant that additional irrigation water was applied using the drip system. However, in the dryer second transplanting, particularly in the last 4 weeks of growth the drip system applied less than half the water of the standard system. The only technical limitations to the wider use of this fully automated approach is that the water supply to the relay valve would need to be pressured in anticipation of an irrigation event, or else be timed to coincide with the irrigation window (10:00 h every day with this system).

The marketable yield response suggested that the optimum rates of N with fertigated treatments could be lower than those from solid fertiliser combined with overhead irrigated treatments. The fitted responses of both transplantings indicated that the optimum rate of available N with drip-fertigation was between 155 and 165 kg N ha^{-1} .With solid treatments the optimum rates of N were similar to drip-fertigation in T1 but higher at 240 kg N ha^{-1} for T2. This may be explained by a more precise placement of N in the root zone. The precision of application may also explain why the yield response to the solid N treatments is less consistent than that of the drip-fertigation. Another factor in the variable response to the solid application is that the heavy rainfall may have led to a proportion of the solid fertiliser being leached away from the root zone of plants, particularly early in the crop cycle.

The shelf life of processed leaf responded independently of marketable yield. The transplantings gave different patterns of response. The addition of N through drip-fertigation reduced quality in the first transplanting and there was a suggestion that it improved quality slightly in the second transplanting. However, adding N as solid fertiliser did not reduce quality in either transplanting. The most obvious difference between T1 and T2 was the amount of rainfall. The leaching of solid N by heavy rainfall could also explain the poor response to solid N rate in both transplanting. The dryer conditions towards the end of T2 may explain the different response between the plantings. There was more consistent rainfall in the first transplanting which could have interacted with higher N levels to reduce shelf life: a similar response was observed by Hilton et al. (2008). This effect may have been more marked with the drip-fertigation supplying N to the roots at regular time intervals compared to the solid fertiliser crop where heavy rain may have leached the N away from the surface soil layers. Further work is required in the area of post harvest quality in response to available N.

CONCLUSIONS

Water content in the root zone can be monitored in real time using horizontally oriented soil moisture sensors linked to data logging and telemetry, and these data can be used to automatically trigger drip irrigation for commercially grown field vegetables. When the closed loop irrigation control was combined with fertigation treatments, lettuce crops were grown with savings of up to 60% and 75% of water and nitrogen respectively, when compared to standard UK production systems. However, excess supply of N through fertigation rather than solid fertiliser was more detrimental to marketable yield and post harvest quality highlighting that care is needed when selecting N rates for fertigation.

ACKNOWLEDGEMENTS

This work was funded by the DEFRA-funded project HortLINK HL0165LFV. We are grateful to Angela Hambidge and Jane Akehurst at Warwick HRI for their technical assistance, and to Lester Simmonds for inspiration.

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Tables

Table 1. Volume of water (mm) applied through irrigation or received from rainfall.

	Irrigation			Total water	
	Solid	Fertigation	Rainfall	Solid	Fertigation
Transplant 1	15.3	16.4	105.1	120.4	121.5
Transplant 2	46.9	20.3	103.1	150.0	123.4

Figures

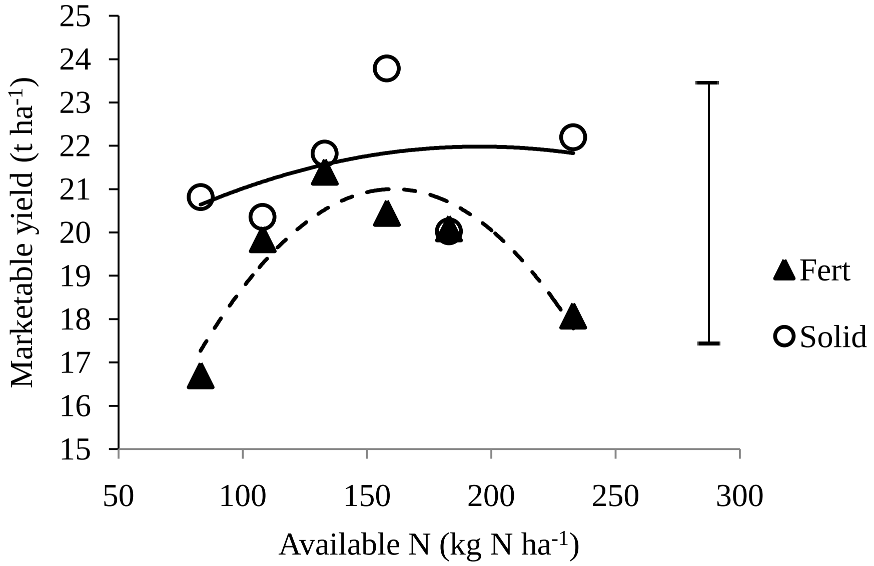

Fig. 1. Marketable yield of green batavia in response to available N (residual N to 90 cm plus added N) supplied either as soil incorporated solid fertiliser with overhead irrigation (Solid) or drip fertigation (Fert). Transplanting 1. Bar shows $LSD_{(5\%)}$ N x method.

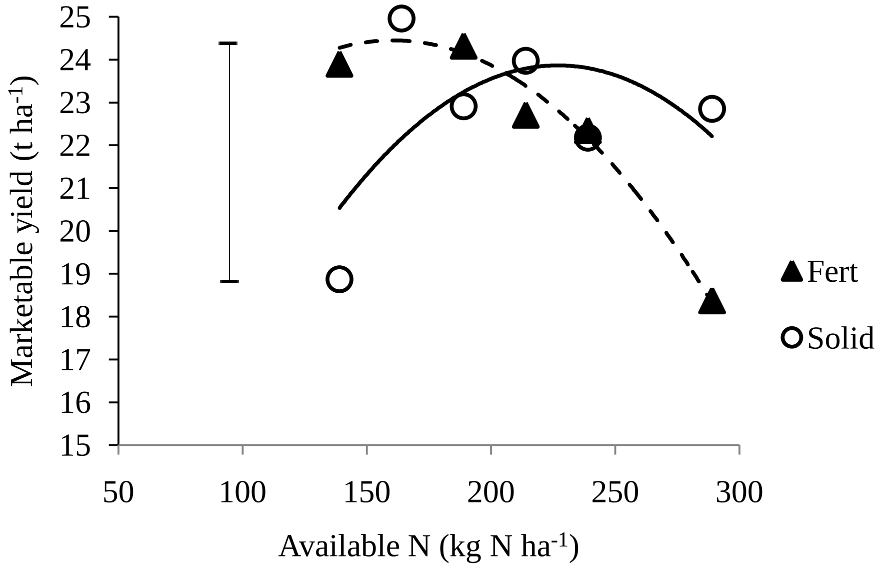

Fig. 2. Marketable yield of green batavia in response to available N (residual N to 90 cm plus added N) supplied either as soil incorporated solid fertiliser with overhead irrigation (Solid) or drip fertigation (Fert). Transplanting 2. Bar shows $LSD_{(5\%)}$ N x method.

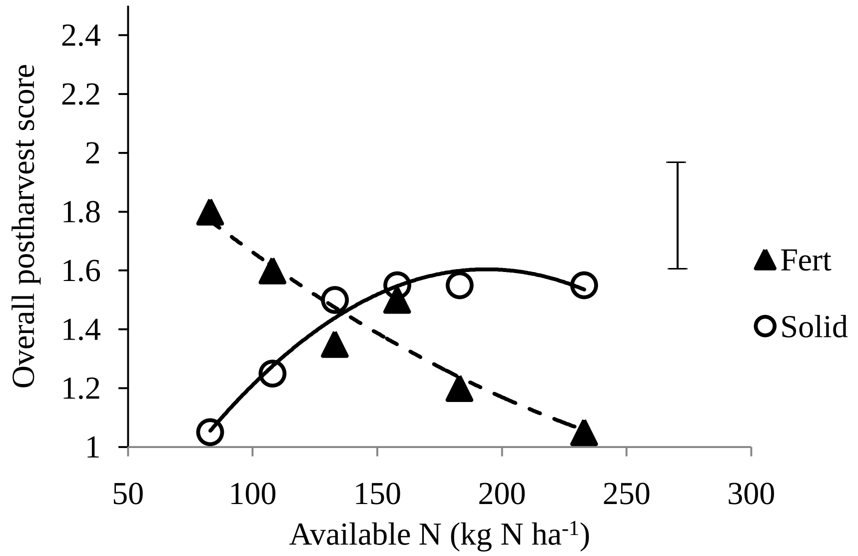

Fig 3. Overall processed leaf score in response to available N (residual N to 90 cm plus added N) supplied either as soil incorporated solid fertilizer with overhead irrigation (Solid) or drip fertigation (Fert). Transplanting 1. Bar shows $LSD_{(5\%)}$ N x method.

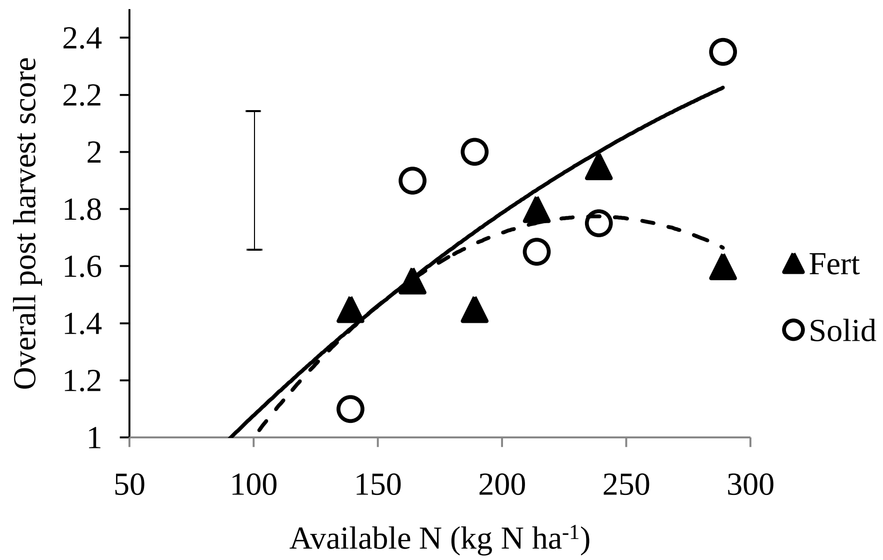

Fig 4. Overall processed leaf score in response to available N (residual N to 90 cm plus added N) supplied either as soil incorporated solid fertilizer with overhead irrigation (Solid) or drip fertigation (Fert). Transplanting 2. Bar shows $LSD_{(5\%)}$ N x method.