Project title:	Improving nitrogen use efficiency, sustainability and fruit quality in high-density apple orchards
Project number:	TF214
Project leader:	Dr Eleftheria Stavridou, East Malling Research
Report:	Annual report, March 2015
Previous report:	Not applicable
Key staff:	Mike Davies, Veronica Martinez, Carlos Angulo
Location of project:	East Malling Research
Industry Representative:	Nigel Kitney, Hutchinsons Ltd Old Grove Farm, Lower Eggleton, Ledbury, Hereford HR8 2UL
Date project commenced:	1 April 2014
Date project completed (or expected completion date):	31 March 2017

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with 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 interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

Dr Eleftheria Stavridou

Research Leader

East Malling Research

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Report authorised by:

Dr Mark Else

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CONTENTS

GROWER SUMMARY

Headline

- In this nutrition project, there were no significant yield and quality differences between fertiliser treatments, in spite of large differences in the quantity of nutrients (i.e. nitrogen and potassium) applied.

Background and expected deliverables

The adoption of high density planting systems for apple trees in the UK will increase the use of irrigation in order to maintain or increase yields against a backdrop of increasing summer temperatures and decreasing water supplies. Broadcast or foliar fertilizer applications have been traditionally used to improve or sustain the nutrition of deciduous fruit tree orchards in the UK. Broadcast and foliar fertilisers are often replaced by fertigation in high density irrigated orchards. However to meet governmental demands for greater environmental protection and comply with legislation, new production methods that improve water and nutrient use efficiency and utilise ‘best practice’ are needed. Application of nutrients with fertigation is the most efficient method of nutrient delivery as it offers increased flexibility in managing orchard nutrition programmes because of the potential for more closely synchronizing nutrient application with plant demand.

Nitrogen is often applied in excess of that required to support optimum productivity and eventually it accumulates in the soil and becomes vulnerable to leaching. The major apple growing regions are in areas designated as Nitrate Vulnerable Zones (NVZ’s) and growers must reduce their inputs to comply with legislation (The Nitrates Directive Action Programme). As part of the Rural Payments Agency audit, growers in NVZ’s have to justify N applications, relationship between yield and N applications, and prove that industry good practices are followed. Fruit trees recover only about 20% of the applied N fertiliser (Neilsen et al., 2001). The effective rate of N fertigation in apple orchards is also influenced by the amount of irrigation, as excess water can leach N below the root zone. Apple trees grown on dwarfing rootstocks have low rooting densities and under daily irrigation, the roots congregate close to the surface and irrigation emitter (Neilsen et al., 1997). Thus, N supply should be targeted to remain in the root zone and allow root interception; effective irrigation scheduling, particularly in coarse-texture soils, will help reduce the deep percolation of N.

There is a paucity of information on the effects of fertigation on the yield, quality and storability of ‘Gala’ and ‘Braeburn’ (HDC, Apple Best Practice Guide). Daily irrigation decreases leaf N concentration in 'Gala' apple, which implies greater N leaching compared to the intermediate or low irrigation frequencies (Neilsen et al., 1995). Research conducted in the Concept Pear Orchard at EMR (TF 198), in which the Project Leader was involved, has delivered water and fertiliser savings of over 50% by scheduled irrigation without reducing productivity or fruit quality. Preliminary data (TF210) indicate that scheduled irrigation can be used to improve water use efficiency in apple production. There is a need, however, to assess the effectiveness of any new fertilisation strategy relative to traditional methods and optimise them to ensure yield consistency and quality.

Summary of the project and main conclusions

A pilot experiment was carried out on a five-year old orchard at EMR ('Gala'/M.9 and 'Braeburn'/M.9) with a distance of 3.5 m between rows and 1 m between trees within rows. Two fertiliser treatments were applied in order to assess the risk of N leaching (1) broadcast fertiliser (BF) and (2) commercial fertigation/irrigation (FR).

Figure 1. Parts used to build a lysimeter; PVC conduit tube (15mm I.D.), rubber bung, 24mm round end ceramic cup, polycarbonate clamp and tube

Soil solution sampling was undertaken using soil suction lysimeters buried at two different depths within the rooting zone beneath the emitter and 0.25 m from the emitter and then analysed for nitrate nitrogen. The lysimeter tubes are simple and inexpensive and can be used in a variety of ways. The lysimeter consisted of a porous ceramic cup, a PVC body tube, a rubber bung and rubber tube as shown in Figure 1. The PVC tubes were cut to 30 cm and 60 cm sections and the ceramic-cup was inserted into one end of the tube and glued into it. For the upper end of the lysimeter, a removable, yet airtight cap is required. For this, large rubber stoppers (No. 19) were used. Tubing from the reservoir to the soil surface was used to apply partial vacuum (suction) in the lysimeter using a vacuum pump (with a suction range of 0–100 kPa). Once a vacuum was drawn, the tubes could be sealed off by folding and clamping the rubber tubes using tube clamps. Water in the soil is drawn into the collector through the porous ceramic cup in response to the negative pressure (vacuum) inside the lysimeter.

Nitrate concentration in soil solution was measured weekly with a portable ion-selective nitrate meter. Soil samples were taken after harvest and analysed for nutrient concentration and soil acidification. Foliar nutrient concentration was monitored during the growing season.

Total and marketable yields from treatment were determined. Fruit quality was evaluated at harvest. Quality factors evaluated were firmness, percentage and intensity of colour, elemental and sugar (%, BRIX) concentrations and disorders.

Main findings so far

- Samples were unable to be taken when soil water content fell too low. Therefore, during these periods, nitrogen leaching risk was reduced.
- Nitrate concentrations in the soil solution at 50 cm depth were similar or higher to the concentrations in the fertigation solution.
- The results indicate that the extent of nitrate leaching differs between apple varieties.
- At the end of the growing season, soil N content in the 0-50 cm horizon ranged from from 37 to 82 kg N ha^{-1}.
- Leaching of other mobile nutrients such as P may occur over winter.
- There were no significant yield and quality differences between fertiliser treatments, in spite of large differences in the quantity of nutrients (i.e. nitrogen and potassium) applied.
- Nutrient analysis of harvested fruit showed that K+Mg/Ca and N/Ca ratios were within the recommended range for Gala, but N/Ca ratio for Braeburn was high which may affect storage potential.
- Environmental (i.e. leaching beyond the root zone) and economic (i.e. money spent on fertiliser) considerations highlighted the need to further understand the fate of applied nutrients.

Financial benefits

No financial benefits have been identified from this project to date.

Action points for growers

- There are no action points for growers at present as the project is at an early stage.

SCIENCE SECTION

Introduction

The adoption of high density planting systems for apple trees in the UK will increase the use of irrigation in order to maintain or increase yields against a backdrop of increasing summer temperatures and decreasing water supplies. Broadcast or foliar fertiliser applications have been traditionally used to improve or sustain the nutrition of deciduous fruit tree orchards in the UK. Broadcast and foliar fertilisers are often replaced by fertigation in high density irrigated orchards. However to meet governmental demands for greater environmental protection and comply with legislation, new production methods that improve water and nutrient use efficiency and utilise 'best practice' are needed. Application of nutrients via fertigation is the most efficient method of nutrient delivery as it offers increased flexibility in managing orchard nutrition programmes because of the potential for more closely synchronising nutrient application with plant demand.

Nitrogen (N) is one of the nutrients that is most often associated with changes of the physicochemical properties of fruits. In general, apples tend to be larger with high N fertiliser rates and annual yields may increase but cumulative yields are not always improved (Neilsen et al., 2009). However, excess N increases the vegetative growth, which accentuates shading within the tree and negatively affects flower bud development, fruit set, fruit quality, and shoot survival (Weinbaum et al, 1992). High N inputs decrease juice soluble solids concentrations (Dris et al., 1999), firmness can be reduced and fruit exhibit less red coloration (Neilsen et al., 2009). Incidences of several disorders of apples, including cork spot and bitter pit before harvest and higher incidence of bitter pit, internal breakdown and scald after storage are linked to excess N (Weinbaum et al., 1992).

Nitrogen is often applied in excess of that needed to support optimum productivity and eventually it accumulates in the soil and becomes vulnerable to leaching. The major apple growing regions are in areas designated as Nitrate Vulnerable Zones (NVZ's) and growers must reduce their inputs to comply with legislation (The Nitrates Directive Action Programme). Growers in NVZ's during audit by the Rural Payments Agency have to justify their N applications, the relationship between yield and N applications and prove that industry good practices are followed. Fruit trees recover only about 20% of the applied N fertiliser (Neilsen et al., 2001). The effective rate of N fertigation in apple orchards is also influenced by the amount of irrigation applied, as excess water can leach N below the root zone. Apple trees grown on dwarfing rootstocks have low rooting densities and under daily irrigation the roots congregate close to the surface and irrigation drip emitter (Neilsen et al., 1997). Thus, N supply should be targeted to remain in the root zone and allow root interception; effective irrigation scheduling, particularly in coarse-textured soils, will help reduce the deep percolation of N.

Moreover, soil acidification beneath the drip emitters can be rapid after the application of ammonium nitrate fertilisers (Neilsen et al., 1995). Fertilisers applied through fertigation are concentrated into a restricted zone below the drip emitter so that any chemical interactions between soil and fertiliser have the potential to be more intense. This project will provide information on the short-term effects of fertigation on soil acidification and the effects that rapid soil acidification may have on yield, fruit quality and nutrition of apple trees.

There is a paucity of information on the effects of fertigation on the yield, quality and storability of apple cvs. 'Gala' and 'Braeburn' (HDC, Apple Best Practice Guide). Daily irrigation decreased leaf N concentration in cv. 'Gala', which implies greater N leaching compared to the intermediate or low irrigation frequencies (Neilsen et al., 1995). When water application rates are determined by reference to evaporative demand, effective control of nitrate movement within the soil profile is achieved (Neilsen et al., 1998). Research conducted in the Concept Pear Orchard at EMR (TF 198), in which the Project Leader was involved, has delivered water and fertiliser savings of over 50% by scheduled irrigation, without reducing productivity or fruit quality. Preliminary data (TF 210) indicate that scheduled irrigation can be used to improve water use efficiency in apple production. There is a need, however, to assess the effectiveness of any new fertilisation strategy relative to traditional methods and optimise them to ensure yield consistency and quality.

Quantifying nutrient inputs and outputs from orchards helps to identify potential nutrient excess or shortage and will improve N use efficiency. The proposed project will develop approaches to optimise N inputs, lower N leaching and maximise N use efficiency, fruit yield, and quality and improve the environmental sustainability of intensive apple production. However, further work will be needed to investigate the longer-term effects of fertigation on soil acidification, nutrient leaching and solubility of toxic elements.

Materials and methods

Experimental design

A pilot experiment was carried out on a five-year old mixed apple 'Gala'/M9 and 'Braeburn'/M9 orchard at EMR (Figure 2) with an in-row spacing of 1 m and 3.5 m between rows. Each tree was supported by a 2.4 m spindle stake and each individual row contained a single variety. All trees within the orchard received the same crop husbandry practices (*e.g*. pest and disease spray programmes, weed control). Until the beginning of this project, the frequency and duration of irrigation applied to all trees was the same, irrespective of variety. Irrigation water was supplied by irrigation lines running along the centre of each row at a height above the ground of 50 cm, with 1.6 L h^{-1} pressure compensated drippers positioned 50 cm apart, directly next to each tree and mid-way between adjacent trees within the row.

Figure 2. Two rows of the mixed apple orchard used within the experiment at EMR. The row on the left is 'Gala/M9', the row on the right is 'Braeburn/M9'.

Two experiments were set up in the orchard, one for each variety, with two fertiliser treatments per experiment. The two fertiliser treatments were:

1. Broadcast fertiliser (BF), in which granular fertiliser applied and the frequency and duration of irrigation events were decided by Mr Graham Caspell, EMR's farm manager
2. Fertigation regime (FR), in which fertigation events were decided by Mr Graham Caspell, EMR's farm manager

Broadcast fertiliser was applied in spring at the rate 9 g N $tree^{-1}$ as MultiCut ® Sulphur (23-4-13 + 7 SO3) in March, while in the FR was applied 60 g N $tree^{-1}$ as Kristalon Blue LB (19-6-20 + Mg, S, B, Cu, Fe, Mn, Mo and Zn).

Within each experiment, three rows for each variety were selected and the trees within each row were divided into five-tree plots; measurements were made on the central three trees of each plot and those on either side acted as guard trees between the different treatments. Each experiment was conducted in a completely randomised block design with four blocks. Each row contained two experimental blocks.

Soil solution monitoring

Construction

Ceramic suction cups are active lysimeters, which draw water out of the soil through negative air pressure (suction) exerted within the ceramic cup. The ceramic cups used for the construction of the lysimeters were 65 mm long, and had 24 mm outside diameter and 19 mm inside diameter. PVC tubes were cut to 30 and 60 cm sections and the ceramic-cup was inserted into one end of the tube, glued into it using polyurethane epoxy glue, and allowed to dry. For the upper end of the lysimeter a removable, yet airtight, cap was required. For this, large rubber stoppers (No.19) with a hole in the centre were used. A rubber tube was fitted to the bottom of the lysimeter for drawing a partial vacuum (suction) in the lysimeter using a handheld vacuum pump (with a suction range of 0–100 kPa) and extracting the soil solution.

Installation

A lysimeter was installed in each plot by boring using a soil auger, to the depths of interest (25 and 50 cm depth). A hole slightly larger than the lysimeter diameter was made vertically. Prior to lysimeter installation, the hole was filled with slurry (made from the soil removed) to ensure good hydraulic contact between the existing soil and the ceramic cup. The soil around the hole was packed down firmly so that the lysimeter would not move and water would not flow downwards preferentially along the tube. Every care was taken to minimize soil disturbance, and contamination of deeper layers with topsoil. Lysimeters were installed beneath the emitter close to the tree. At the 50 cm soil depth a second lysimeter was installed 25 cm far from the emitter. After the installation all lysimeters were emptied repeatedly before initiating solution collection for nutrient analysis.

Figure 3. Soil water sampling from a suction cup lysimeter at 60 cm soil depth

Sampling

To apply vacuum, the outer 10 mm tube was unclamped and the vacuum of 60 kPa was applied. Then the tubes were sealed off by clamping the rubber tubes using plastic clamps. After approximately 24 h, depending on how dry the soil is, the solution sample was retrieved. The rubber tube was opened and the sample extracted with a 50 mL syringe that was connected to the tube (Figure). The tubes were re-clipped and left at atmospheric pressure until the next sampling so that the sample accurately reflected concentrations in the soil on the day of sampling.

Analysis

Samples were collected weekly and NO3-N was analysed in the laboratory with an ion selective electrode (ISE, Cole-Parmer Instrument Co. Ltd.). Before each set of measurements, the electrode was calibrated using a range of NO_3^- solutions (1, 10, 100 1000 ppm). The temperature of the calibrating solutions differed from the samples by a maximum of ±1 ºC.

Figure 4. Soil water analysis by ion selective electrode.

Fruit yield and quality

The number and weight of harvested fruit were measured each year at commercial harvest for each cultivar for each treatment and replicate. Harvest date was determined by starch degradation charts developed for each cultivar. Quality factors evaluated were firmness, percentage and intensity of colour, sugar (BRIX) concentrations, and disorders. Fruit firmness was measured using an LRX penetrometer, providing values of force at maximum fruit load. Juice was also extracted from the fruit and soluble solids content (SSC [°BRIX]) were measured with a digital refractometer. Percent red skin colour was estimated visually to the nearest 5%. A random sample of 10 apples per plot was selected for nutrient analysis.

Plant and soil sampling

A composite sample of 30 leaves from the mid portion of extension shoots of the current year's growth were collected from each plot tree immediately. At the end of the experiment, four soil samples per replicate were taken for both treatments at 0–25 and 25–50 cm soil layers using a 4 cm diameter soil auger. Samples were analysed for macro- and micro-nutrient content.

Statistical analyses

Statistical analyses were carried out using Genstat 13.1 Edition (VSN International Ltd). To determine whether differences between irrigation treatments were statistically significant, analysis of variance (AVOVA) tests were carried out and least significant difference (LSD) values for $p<0.5$ were calculated.

Results

Soil solution nitrate concentrations

The results showed large but inconsistent effects of the fertiliser treatment on soil solution nitrate concentration. Data indicated that soil nitrate solution concentration was higher under the FR treatment at soil depth of 25 cm (Figure 51), but was not statistically significant, possibly due to high spatial variance and insufficient sample size. A small number of lysimeters had problems with holding the vacuum at the time of collection. These samplers were identified and replaced. After August it was not possible to extract any leachate from 50 cm soil depth for the CC treatment in cv. 'Gala' although the cup was holding vacuum, suggesting that the interface between the cup and the soil was 'broken'. A further difficulty was that some samples had anomalously high or low nitrate concentrations without being possible to explain.

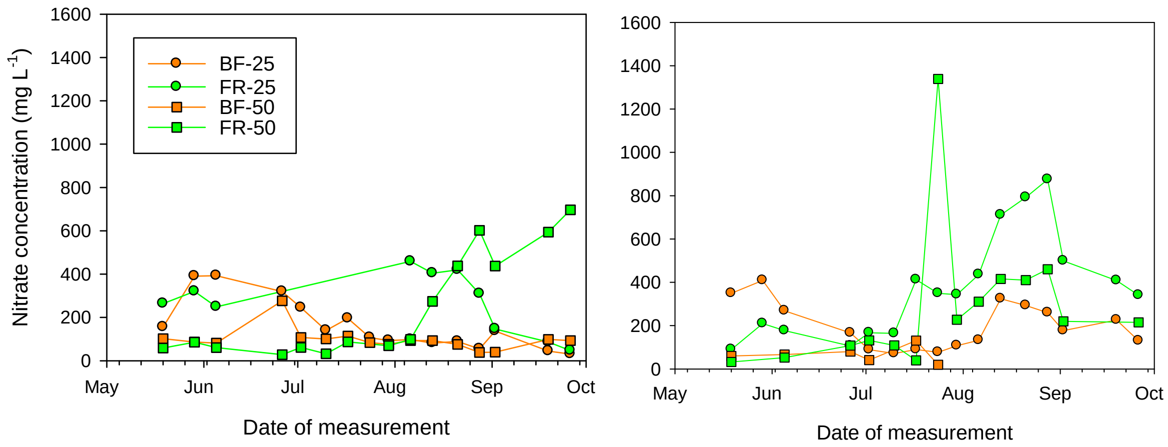

Figure 51. Measured soil solution nitrate concentration in response to the fertilisation treatment in a ‘Braeburn/M9’ and ‘Gala/M9’ orchard.

As shown at Figure 51 soil solution nitrate concentration under the FR treatment, both at 25 and 50 cm soil depths, were similar or higher to the N applied through the fertigation (300 mg nitrate L^{-1}). The distance of the lysimeter from the emitter did not affect soil solution nitrate concentrations at the 50 cm depth (data not shown).

Soil nutrient concentrations

Soil pH and cation exchange capacity (CEC) at 0-25 and 25-50 cm depth beneath drip emitters were unaffected by the fertilisation treatments in either cultivar (Table 1). In general, soil macronutrient concentrations were not affected by the treatments with exception the potassium (K) under cv. ‘Gala’ (Table 1). Potassium at both sampling depths was lower on cv. ‘Gala’ trees grown with BF. There were no significant difference on manganese (Mn), copper (Cu), boron (B), zinc (Zn), molybdenum (Mo) and iron (Fe) concentration between the treatments for either of the cultivars (data not shown). Between 37 and 80 kg N ha^{-1} remained in the soil at 0-50 cm depth after harvest. High concentrations of other nutrients (e.g. 360 kg P ha^{-1}) remained in the soil after harvest as well.

Table 1. Average extractable pH, CEC and nutrient concentration at 0-25 and 25-50 cm soil depths immediately below the emitter after harvest as influenced by the fertilisation treatments

Cultivar	Treatment	pH	CEC	N	P	K	Mg	Ca
			meq 100g^{-1}	mg kg^{-1}				
Depth 0-25 cm								
Braeburn	BF	6.8	12.7	4.5	32.3	270.3	91.5	1944.5
	FR	6.7	12.8	5.1	33.0	273.5	94.3	1957.5
Significance[a]	*ns*	*ns*	*ns*	*Ns*	*ns*	*ns*	*ns*	*ns*
Gala	BF	6.5	12.1	3.6	32.0	235.8	76.3	1755.8
	FR	6.6	12.4	5.7	32.8	256.5	80.0	1813.3
Significance	*ns*	*ns*	*ns*	*Ns*	*ns*	**	*ns*	*ns*
Depth 25-50 cm								
Braeburn	BF	7.1	12.9	7.3	24.3	178.5	71.0	2119.0
	FR	6.8	12.6	5.3	27.5	214.5	75.3	2004.5
Significance	*ns*	*ns*	*ns*	*Ns*	*ns*	*ns*	*ns*	*ns*
Gala	BF	6.9	12.3	2.6	22.8	157.3	61.8	1915.5
	FR	6.8	12.5	7.8	25.5	179.5	63.8	1883.0
Significance	*ns*	*ns*	*ns*	*ns*	*ns*	*	*ns*	*ns*

[a] *, ** and *** means significantly different at p=0.05, 0.01 and 0.001, respectively, or no significantly (ns) different

Leaf and fruit nutrient concentrations

Leaf macronutrient concentrations in the middle of the growing season were unaffected by the fertilisation treatments in both cultivars except calcium (Ca) in 'Braeburn' (Table 2). Lower manganese concentrations found on cv. 'Braeburn' trees grown with fertigation compare to the broadcast fertiliser (Table 2). Leaf magnesium (Mg), Zn, B and Fe concentrations were slightly lower than the recommended levels in both cultivars (Table 2).

At the commercial harvest, fruit nutrient concentration was not affected by the fertilisation treatments for both cultivars (Table 3).

Table 2. Effect of the fertilisation treatment on cvs. ‘Braeburn’ and ‘Gala’ leaf macro- and micro-nutrient concentration.

Cultivar	Treatment	N	P	K	S	Ca	Mg	Mn	Zn	Cu	B	Mo	Fe
		%						mg kg^{-1}					
Braeburn	BF	3.0	0.2	1.9	0.1	1.3	0.2	125.5	13.6	10.1	31.2	0.1	123.5
	FR	3.0	0.2	1.9	0.1	1.2	0.2	86.9	12.8	9.7	29.7	0.1	123.0
Significance[a]		*ns*	*ns*	*ns*	*ns*	*	*ns*	*	*ns*	*ns*	*ns*	*ns*	*ns*
Gala	BF	2.8	0.2	1.7	0.1	1.2	0.2	91.7	10.0	9.2	21.1	0.2	98.5
	FR	2.9	0.2	1.9	0.1	1.3	0.2	92.5	10.1	9.4	23.2	0.2	105.5
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

[a] *, ** and *** means significantly different at p=0.05, 0.01 and 0.001, respectively, or no significantly (ns) different

Table 3. Effect of the fertilisation treatment on cvs. ‘Braeburn’ and ‘Gala’ fruit macro- and micro-nutrient concentration at commercial harvest. There were no statistically significant differences between treatments.

Cultivar	Treatment	N	P	K	Ca	Mg	Zn	K+Mg/Ca	Mg/Ca
		mg 100 g^{-1}							
Braeburn	CC	67.3	9.1	4.9	5.4	101.5	0.3	19.8	12.5
	FR	69.0	9.4	5.0	5.5	110.4	0.1	21.2	12.7
Significance[a]		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Gala	CC	86.0	9.6	5.7	10.3	110.3	0.0	11.5	8.7
	FR	79.3	9.0	5.2	9.5	99.8	0.0	11.5	8.6
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

[a] *, ** and *** means significantly different at p=0.05, 0.01 and 0.001, respectively, or no significantly (ns) different

Fruit yields and quality at harvest

In cv. 'Braeburn', average individual fruit fresh weight was 159 and 141 g from the BF and FR treatments respectively, while in cv. 'Gala' it was 93 and 103 g respectively. Average individual fruit fresh weight was unaffected by the treatments in either cultivar (data not shown). The total yield and yield of Class I from each tree of 'Braeburn/M9' and 'Gala/M9' were not significantly affected by irrigation treatment (Figure 7).

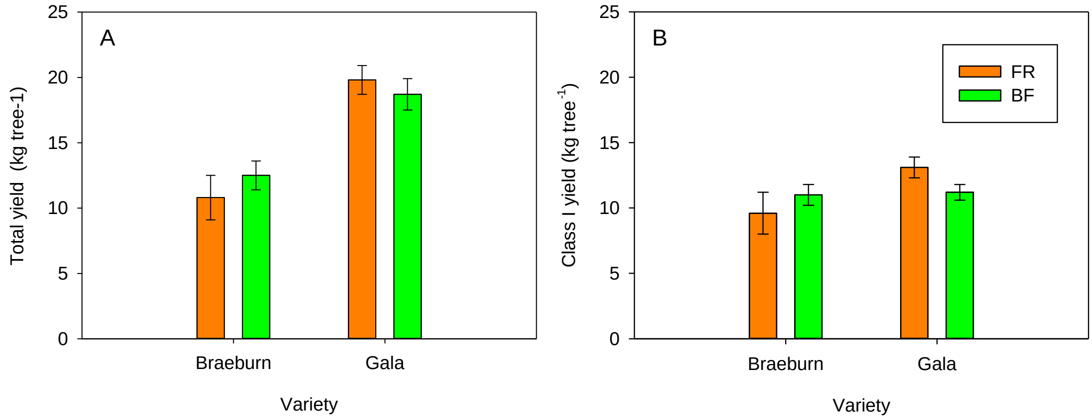

Figure 7. The effects of the fertiliser treatments on Class I (A) and Class II (B) 'Braeburn/M9' and 'Gala/M9' trees. Vertical bars are standard errors. There were no statistically significant differences between treatments.

Soluble solids content, fruit firmness, and skin colour (parameters a, b and L) measured at harvest were not significantly affected by irrigation treatments in either variety (Table 4).

Table 4. Average values of SSC, firmness and colour parameters for cvs. 'Braeburn' and 'Gala' fruit harvested from the BF and FR treatments. Results are mean values of 20 fruit from four plots. There were no statistically significant differences between the treatments.

Cultivar	Treatment	SSC	Firmness	Colour		
		%	(N)	a	b	L
Braeburn	BF	11.4	82.5	15.1	31.4	47.4
	FR	11.8	84.4	18.1	30.5	46.4
Significance[a]		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Gala	BF	11.5	86.8	21.2	28.1	53.3
	FR	11.5	84.9	20.9	28.1	52.0
Significance		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

[a] *, ** and *** means significantly different at *p*=0.05, 0.01 and 0.001, respectively, or nonsignificantly (ns) different

Discussion

Neilsen et al. (2009) found that high N inputs (168 mg N L^{-1} daily) increased midsummer leaf and harvested fruit N concentrations. However in the present study, despite the higher N, P, K inputs on the FR treatment throughout the season, there were no effects on tree nutritional status or performance. Yield and leaf N, P and K concentrations were similar to both treatments. Such results imply that the amount of nutrient applied by the FR treatment could be reduced and that fertigation should be scheduled more efficiently, as nutrient losses have occurred.

At most sampling times, soil solution could not be extracted from all the replicates and moreover the spatial variability was high. Due to this, there were no statistically significant differences in nitrate concentration in the soil solution, but the results indicated a higher average soil solution nitrate concentration during the growing season for the FR treatment. Solution concentrations approximated the concentration of the fertigation solution, even at the 50 cm depth, which exceed the drinking water standard. Neilsen et al. (2000) found that drip-irrigated 'Gala/M9' had most of their root intersections within 25cm depth. The presence of high nitrate concentrations in the soil solution below the root zone suggests that a substantial portion of added N is liable to leaching. Moreover, up to 80 kg N ha^{-1} remained in the 0-50 cm soil layer at the end of the season, which can be lost over winter. It was not possible to determine the quantity of leached nitrate, as we have no measure of water flow and therefore no means to determining nitrate flux. Leaching over winter can occur for other mobile nutrients as well i.e. 360 kg P ha^{-1} remained in the 0-50 cm soil layer after harvest

In order to decrease the variability and boost the statistical power it is necessary to ensure that an adequate number of soil solution samples are collected. Therefore, it has been decided to increase the number of lysimeters per replicate for the 2015 growing season. In order to be able to cope with the workload, samples will be collected only on lysimeters placed under the emitters. The results so far indicated that the distance of the lysimeter from the emitter did not affect nitrate concentrations in the soil solution, when the emitters are positioned only 50 cm apart. Moreover, taking into consideration that often only small amounts of water were extracted it has been decided to schedule sampling depending on the soil matric potential at different depths and after rainfall events.

Fertigating amoniacal forms of N and P on restricted soil volume can affect the base status of soils, because the transformation of ammonium to nitrate is an acidifying process and it can cause soil acidification. However, our results did not show any effect of the fertigation treatment on soil pH at 0-25 and 25-50 cm soil layers, suggesting that in the short-term fertigation does not affect the soil chemical properties, which it is in contrast with previous studies (Neilsen et al., 1995). Long-term changes in the soil chemical properties will continue to be monitored during the project.

Cultivars differed in their responses to the treatments and leaf Ca and Mn concentrations. The fertigation treatment decreased leaf Ca and Mn concentrations only in cv. 'Braeburn'. Therefore, nutrient management should be adapted to meet the demands of individual cultivars.

Conclusions

- Samples were unable to be taken when the soil water content fell too low. Therefore, during these periods nitrogen leaching risk was reduced.
- More lysimeters per replicate are needed in order to reduce variability and increase the statistical power.
- Nitrate concentrations in the soil solution at 50 cm depth were similar or higher to the concentrations in the fertigation solution.
- The results indicate that the extent of nitrate leaching differs between apple cultivars.
- At the end of the growing season, soil N content in the 0-50 cm horizon ranged from 37 to 80 kg N ha^{-1}.
- Leaching of other mobile nutrients such as P may occur over winter.
- There were no significant yield and quality differences between fertiliser treatments, in spite of large differences in the amount of nutrients (i.e. nitrogen and potassium) applied.
- Nutrient analysis of harvested fruit showed that K+Mg/Ca and N/Ca ratios were within the recommended range for cv. 'Gala', but N/Ca ratio for cv. 'Braeburn' was high, which may affect storage potential.
- Environmental (i.e. leaching beyond the root zone) and economic (i.e. money spent on fertiliser) considerations highlighted the need to further understand the fate of applied nutrients.

Knowledge and Technology Transfer

- The project aims and results were presented at the West Sussex Fruit Group during their visit to EMR, 29 July 2014

Acknowledgements

We thank Mr Roger Payne for excellent technical assistance, and Mr Graham Caspell and his team for their helpful advice and support.

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