Project title:	Improving nitrogen use efficiency, sustainability and fruit quality in high-density apple orchards
Project number:	TF214
Project leader:	Dr Eleftheria Stavridou, NIAB EMR
Report:	Final report, June 2018
Previous report:	Annual report, April 2016
Key staff:	Mike Davies, Veronica Martinez, Carlos Angulo
Location of project:	NIAB EMR
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Date project commenced:	1 April 2014
Date project completed (or expected completion date):	June 2016

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.

Eleftheria Stavridou

Research Leader

NIAB EMR

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Report authorised by:

[Name]

[Position]

[Organisation]

Signature .... Date ....

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GROWER SUMMARY

Headline

- In the final year of this project, application of different levels of nitrogen to Gala and Braeburn did not affect tree Class I yield.

Background and expected deliverables

The adoption of high-density planting systems for apple trees in the UK will increase the use of irrigation 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. These are often replaced by fertigation in high density irrigated orchards. However, to meet governmental demands for greater environmental protection and to 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 to more closely synchronise the nutrient application with plant demand.

Nitrogen is often applied in excess of what is required to support optimum productivity and eventually 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, 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 effectiveness 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 the irrigation emitter (Neilsen et al., 1997, Neilsen et al., 2000). 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 nitrogen (N).

There is a paucity of information on the effects of fertigation on the yield, quality and storability of 'Gala' and 'Braeburn'. 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 NIAB EMR (Else, 2013) has delivered water and fertiliser savings of over 50% by scheduled irrigation without reducing productivity or fruit quality. Else (2016) indicated 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 strategies relative to traditional methods and optimise them to ensure yield consistency and quality.

Summary of the project and main conclusions

In the final year of the project, two experiments were carried out on a seven-year-old orchard at NIAB EMR (‘Gala’/M.9 and ‘Braeburn’/M.9) with a distance of 3.5 m between rows and 1 m between trees within rows. Five N rates (0, 10, 20, 30 and 40 N g in total amounts per tree) were supplied by fertigation taking into consideration the initial soil N content. Irrigation was applied to the trees once the average soil matric potential within the rooting zone had reached -200 kPa but fertiliser was injected for a short period at the end of each irrigation event.

Soil samples were taken after harvest and analysed for nutrient concentration and soil acidification. Foliar and fruit nutrient content was determined during the growing season.

Total and marketable yields were determined. Fruit quality was evaluated at harvest, three and six months after storage. Quality factors evaluated included firmness, percentage and intensity of colour, elemental and sugar (°BRIX) concentrations and disorders.

The Class I yields were not significantly affected by fertilisation treatment on either cultivar (Figure 1A). However, a non-significant tendency for lower yield under the N0 treatment (without N fertiliser) was observed for both cultivars. ‘Gala’ Class I yield was on average 23 kg per tree, while ‘Braeburn’ was 18 kg per tree, equating to harvest total of 66 and 51 tonnes per ha, respectively. The lack of yield response to the applied N may be the result of many factors, but especially due to the release of N, from the decomposition of native soil organic matter and senescent leaves. The average number of fruit per tree (Figure 1B) were unaffected by the treatments in either cultivar.

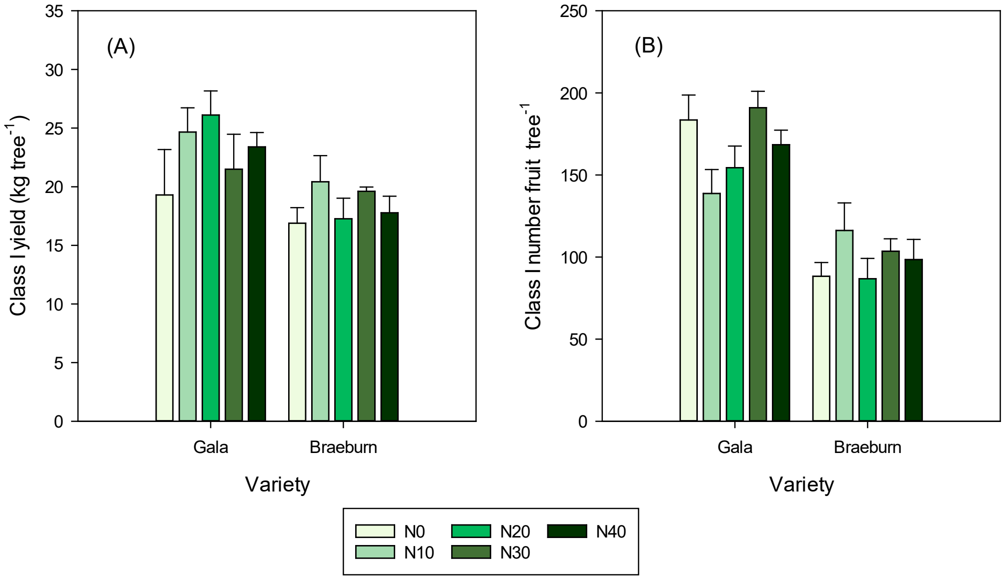

Figure 1. The effects of the fertiliser treatments on Class I yield (A) and the average number of fruit (B) per tree for 'Braeburn' and 'Gala'. Vertical bars are standard errors. There were no statistically significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Soluble solids content and fruit firmness measured at harvest as well as at 3 and 6 months post-harvest were not significantly affected by fertilisation treatments in either variety (Table 1). 'Braeburn' firmness was 87, 82 and 76 N at harvest, 3 and 6 months post-harvest, respectively. While, 'Gala' firmness averaged 72, 71 and 70 N at harvest, 3 and 6 months post-harvest, respectively (Table 1). In both varieties, firmness was reduced at the end of the storage period. No differences on soluble solids content were observed during storage. 'Braeburn' and 'Gala' soluble solid content were on average 11.2 °Brix and 10.5 °Brix, respectively (Table 1). When N application is not excessive, N should not have any detrimental effect on fruit quality and storability. Similarly to Drake et al. (2002) no effect of N levels on fruit firmness and soluble solids, and titratable acidity was found. Raese & Drake (1997) observed that lower rates of N fertiliser promoted greater fruit firmness and soluble solids concentration in 'Fuji' than the higher rates of 113 or 170 kg per ha.

Table 1. Average values of firmness (N) and soluble solid content (ºBrix) for cvs. 'Braeburn' and 'Gala' fruit under different fertilisation treatments at harvest, after 3 and 6 months in storage. Results are mean values of 20 fruits from four plots. There were no statistically significant differences between the treatments.

Cultivar	Treatment	Harvest		3 months after storage		6 months after storage	
		Firmness	Brix	Firmness	Brix	Firmness	Brix
Braeburn	N0	90.3	11.0	82.6	11.1	77.4	11.8
	N10	84.5	11.2	81.4	11.2	75.4	11.0
	N20	86.2	10.9	81.4	10.9	75.8	11.6
	N30	85.9	11.2	81.5	11.3	76.4	11.4
	N40	88.3	11.4	82.0	11.1	76.2	11.2
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Gala	N0	71.4	10.4	72.7	11.3	69.7	9.6
	N10	71.9	10.2	72.2	10.8	71.8	9.1
	N20	71.8	10.6	70.8	11.2	68.6	11.0
	N30	71.8	10.2	71.0	10.7	70.1	10.6
	N40	71.9	10.5	70.8	11.0	70.1	10.3
Significance		*ns*	*ns*	*Ns*	*ns*	*ns*	*ns*

Where ns means there is no significant difference between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

The different rates of N on the fertigation have been tested only on one growing season out of the three years of the project; therefore, caution should be taken when interpreting the results. Repeating the experiments for several years should eliminate possible effects of the external environments. Tree N uptake is a result of the association of many factors, such as N release from the decomposition of native soil organic matter and senescent leaves, soil type, tree N reserves, root growth, irrigation management, temperature etc. In order to fully understand tree N requirements and the effect of N fertigation on tree growth and yield as well as fruit quality, long-term studies are needed.

Overall project conclusions from the whole three-year project

Soil solution analysis is a valuable environmental tool that can be used to monitor the changes in soil water chemistry, such as salinity and nitrate, in and just below the root-zone of irrigated crops. The measurements can be used to assist fertilisation and irrigation management decisions. A soil solution sampler comprises a porous ceramic cup connected to a pipe and is easy to construct. Buried beneath the soil surface at the sampling depth of interest, samples are obtained firstly by applying a negative pressure to the soil solution sampler. The sampler is then sealed and left for a few hours and over time the soil solution moves into the sampler. The sample is then collected. A full description of the construction and use of the sampler can be found in the first annual report of the project (Stavridou, 2015). The disadvantage of the sampler is the difficulty of extracting soil solution following prolonged spells of dry conditions, so sampling should be carried out after rainfall or irrigation events.

In the second year of the project, four fertiliser treatments were tested (broadcast fertiliser, commercial fertigation, fertigation scheduled to meet irrigation demand and targeted fertigation). The results indicated that the extent of nitrate leaching differs between apple cultivars. Nitrate concentrations in the soil solution at 50 cm depth were similar or higher to the concentrations in the fertigation solution. At the end of the growing season, soil N content in the 0-50 cm horizon ranged from 73 to 98 kg N per ha, which was prompted to leaching over winter. Leaching of other mobile nutrients such as phosphorus may occur over winter. There were no significant yield and quality differences between fertiliser treatments, in spite of large differences in the volume of nutrients (i.e. nitrogen and potassium) applied.

Taking into consideration that the different N inputs in Year 2 did not affect yield and fruit quality, discussions with the industry representatives led the final years work into investigating optimum levels of N fertigation. N was applied at 4 different rates (0, 10, 20, 30 and 40 g N tree^{-1}), to help to retain N within the root zone and minimise N leaching. The different rates of fertiliser application did not affect tree yield or fruit quality at harvest, after storage in control atmosphere and shelf-life. Sometimes, even when the nutrient availability is lower than the lowest threshold, trees do not respond to fertilisation because of adequate nutrient reserves built up in perennial organs in previous years (Carranca et al. 2018). The lack of yield response to applied N may be the result of many factors, but especially due to the release of N, from the decomposition of native soil organic matter and senescent leaves.

Caution should be taken when interpreting the results, as all the experiments were carried out for only one experimental year. 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. Tree N uptake is a result of the association of many factors, such as N release from the decomposition of native soil organic matter and senescent leaves, soil type, tree N reserves, root growth, irrigation management, temperature etc. Repeating the experiments for several years would eliminate possible effect of the external environments. In order to fully understand tree N requirements and the effect of N fertigation on tree growth and yield as well as fruit quality, long-term studies are needed.

Financial benefits

Although there were no significant differences found between the N rates, there was a tendency for lower yield when trees were grown without N fertiliser. Lack of N fertilisation could decrease yield by 20-25% and potentially grower's annual income by up to £5,000 per hectare in a fully cropping orchard. Growers should carefully consider N fertiliser application, as excessive N may reduce fruit quality and increases production costs.

Action points for growers

- There is need to match N application with tree demand, as excessive N fertilisation could cause high nitrate leaching.
- Frequent monitoring using soil suction lysimeters is a useful tool for determining soil solution nitrate concentration in the root zone in response to nutrient and irrigation management. Soil suction lysimeters are easy to install and only disturb a small area of soil. They can be placed at any depth and they are inexpensive if built yourself (Deery et al., 2006, Falivene, 2008).

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), can reduce firmness and fruit exhibit less red colouration (Neilsen et al., 2009). Incidences of several disorders of apples, including cork spot and bitter pit before harvest and a higher incidence of bitter pit, internal breakdown and scald after storage are linked to excess N (Weinbaum et al., 1992). Trees subject to excess N application can be more susceptible to disease attack such as fire blight (Van der Zwet and Keil, 1979).

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 an 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, Neilsen et al., 2000). 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 (Else, 2013) has delivered water and fertiliser savings of over 50% by scheduled irrigation, without reducing productivity or fruit quality. Else (2016) indicated 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 strategies 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. This project aimed to 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 seven-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 was used for the experiments. 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) decided by NIAB EMR’s farm manager Mr Graham Gaspell. 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 in the experiment at NIAB 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 five fertiliser treatments per experiment. Five N rates (0, 10, 20, 30 and 40 g N in total amounts per tree) were supplied by fertigation taking into consideration the initial soil N content. Irrigation was applied to the trees once the average soil matric potential within the rooting zone had reached -200 kPa. The fertiliser was injected for a short period towards the end of each irrigation event.

Two 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 (Figure 3).

Figure 3. Plot layout for the trial during the growing season 2016.

Plant and soil sampling

At the beginning of the experiment, four soil samples per plot were taken for all treatments at 0–25 and 25–50 cm soil layers using a 4 cm diameter soil auger, then a mixed soil sample collected sent for nutrient analysis. Leaves samples were collected from four points of the half height canopy of the tested trees, which located in north, south, east and west of the test trees end of July. A composite sub-sample of 30 healthy and mature leaves from the mid-portion of extension shoots of the current year's growth were collected from each plot. At commercial harvest, soil sampling was repeated.

Nutrient analysis

Samples were analysed for macro- and micro-nutrient content. Mineral analysis was performed by a commercial analytical laboratory. Leaf samples were analysed for N, P, K, S, Ca, Mg, Mn, Fe, Zn, Cu, B, and Mo. Fruit samples were analysed for N, P, K, Ca, Mg and Zn. The plant tissues were air dried, then dried in an oven at 80 °C and powdered. The ash was made in a furnace at 500 °C. For the nutrients, except N, the ash was digested with concentrated hydrochloric acid and analysed by inductively coupled plasma analyser (ICP). Soil P was extracted by sodium hydrogen carbonate and determined with the solution spectrophotometry method after complexing with ammonium molybdate. Soil K and Mg were extracted with ammonium nitrate and analysed by ICP. The determination of total leaf organic N and total soil N (ammonium and nitrate) was carried out by the DUMAS combustion method. Soil pH was determined on water extract with a pH electrode meter.

Fruit yield and quality

'Braeburn' was harvested at 21/10/2016 and 'Gala' at 07/10/2016. The number and weight of harvested fruit were measured at commercial harvest for each cultivar for each treatment and replicate. Apples were picked from the three central trees and pooled within each plot. The total number and fresh weight of fruit from each three tree plot were determined. Class I (60-65, 65-70 and 70+ mm) and Class II (<60 mm) fruit were graded into different size categories according to fruit diameter. Harvest date was determined by starch degradation charts developed for each cultivar. Quality factors evaluated were firmness, percentage and intensity of colour, sugar 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]) was 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. Oven-drying at 65 °C was carried out on a subsample in a forced-air oven for 24 h and then dry matter content was calculated.

Storage quality

Two sub-sets of 40 fruit were retained for evaluating the effects of fertilisation treatments on storage quality and shelf life. Assessments were carried out 3 and 6 months after harvest. Due to a limitation on storage availability both 'Braeburn' and 'Gala' had to be stored under the same temperature regimes. Fruits after harvest were cooled to store temperature (1.5 - 2.0 °C) within 24 hours and remained in the air for 2 weeks before cabinets were sealed. After sealing, oxygen was allowed to drop by 1% per day until it reached 2% oxygen and this was held for ten days before the controlled atmosphere (CA) was achieved through fruit respiration. Braeburn was stored at <1 CO_2 and 1.5 O_2 and Gala were modified from the standard commercial at 5% CO_2 and 1% O_2. One control atmosphere chamber was used for each of the treatments and replicates. Samples were taken for quality analysis immediately ex-store and after seven days of shelf-life (18 °C). The same methods of quality analysis were used as described above for harvest. Internal disorders were determined visually.

Return bloom assessment

Due to the early spring frost at 26-27 April 2017, return bloom could not be evaluated. The anatomical effects caused by spring frosts in reproductive organs usually result in internal and external morphological abnormalities that affect the normal development of the fruit or even cause abscission. Thus, de-acclimated apple flower buds killed by spring frosts show a general browning as an immediate external symptom. Subsequently, buds desiccate and drop and therefore it was not possible to evaluate the effect of the fertigation treatments on return bloom (Rodrigo, 2000).

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 (ANOVA) tests were carried out and least significant difference (LSD) values for $p<0.5$ were calculated.

Results

Soil nutrient concentrations

There were not any significant differences between the experimental plots. Soil N concentration was taken into consideration when we applied N. The chemical characteristics of the soil after the growing season are shown in Table 2 and Table 3.

Table 2. Average extractable pH and nutrient concentration at 0-25 and 25-50 cm soil depths in 'Braeburn' plots immediately below the emitter on autumn 2016 as influenced by the fertilisation treatments.

Depth	**Treatment**	**pH**	**N**	**P**	**K**	**Mg**
			mg kg^{-1}			
0-25 cm						
	N0	6.8	5.6	33.5	367.3	88.3
	N10	7.2	5.6	32.8	355.0	77.3
	N20	7.2	5.3	33.8	371.5	76.3
	N30	7.1	8.1	33.3	348.3	83.8
	N40	7.4	6.8	30.0	311.0	68.5
Significance		*ns*	*ns*	*ns*	*ns*	*ns*
25-50 cm						
	N0	7.1	4.5	20.0	190.0	52.8
	N10	7.4	3.1	21.8	198.0	51.5
	N20	7.5	2.6	20.8	210.0	52.5
	N30	7.3	3.0	20.8	180.8	55.5
	N40	7.3	3.3	22.5	236.5	52.8
Significance		*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means there are no significantly difference between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

In autumn, soil N content on 'Braeburn' plots varied between 5.3 to 8.1 mg N kg^{-1} on the topsoil and 2.6 to 4.5 mg N kg^{-1} on the layer 25-50 cm (Table 2). Phosphorus and potassium were higher on the topsoil compared to the lower soil levels. On average the pH level was 7.2, which is considered the optimal range for growing apple trees.

Soil N content on 'Gala' plots after harvest varied between 4.6 to 7.8 mg N kg^{-1} on the topsoil and 2.6 to 4.5 mg N kg^{-1} on the layer 25-50 cm (Table 3). The topsoil had higher phosphorus, potassium and magnesium levels with average values of 30, 293, 84 mg kg^{-1}, respectively. The deeper soil layers contained 18 mg P kg^{-1}, 155 mg K kg^{-1}, 58 mg Mg kg^{-1}. On average the pH level was 7.2, which is considered the optimal range for growing apple trees.

Table 3. Average extractable pH and nutrient concentration at 0-25 and 25-50 cm soil depths in 'Gala' plots immediately below the emitter on autumn 2016 as influenced by the fertilisation treatments.

Depth	**Treatment**	**pH**	**N**	**P**	**K**	**Mg**
			mg kg^{-1}			
0-25 cm						
	N0	6.8	4.6	30.8	286.5	84.0
	N10	7.0	4.9	29.3	290.0	83.8
	N20	6.9	4.7	31.5	282.0	81.8
	N30	7.0	4.7	30.5	311.5	85.0
	N40	6.9	7.8	30.3	294.0	83.0
Significance		*ns*	*ns*	*ns*	*ns*	*ns*
25-50 cm						
	N0	7.4	2.5	16.8	144.5	61.8
	N10	7.4	2.9	18.5	164.0	60.3
	N20	7.3	3.6	18.8	152.8	58.5
	N30	7.6	2.7	17.8	161.3	59.0
	N40	7.4	3.2	17.3	153.8	52.0
Significance		*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means there is no significant difference between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Leaf and fruit nutrient concentrations

Leaf macronutrient concentrations at the end of July were unaffected by the fertilisation treatments in both cultivars (Table 4). All nutrient concentrations were within the recommended levels except zinc which was slightly lower than the normal range (20-50 ppm; Agriculture Victoria, 2017). In 'Braeburn', the N content ranged between 2.9 and 3.2%, with the average being 3.1% (Table 4). Potassium, calcium and magnesium levels can influence post-harvest life. In our experiments, the fertigation treatments did not influence any of those macronutrients and they had average values of 2.1, 1.3 and 0.2%, respectively. Copper concentrations on 'Braeburn' leaves were lower when 20 g N per tree was applied. None of the other micronutrients were influenced by the fertigation regimes.

Similarly to 'Braeburn', there were no significant differences in leaf N content in 'Gala' with an average value of 2.8% (Table 4). Potassium content was lower on the fertigation regime without N addition but it wasn't significantly different. None of the micronutrients were affected by the fertigation regime.

Table 4. Effect of the fertilisation treatment on cvs. 'Braeburn' and 'Gala' leaf macro- and micro-nutrient concentration at the end of July.

Cultivar	Treat.	N	P	K	S	Ca	Mg	Mn	Zn	Cu	B	Mo	Fe
		%						mg kg^{-1}					
Braeburn	N0	2.9	0.1	2.1	0.1	1.2	0.2	112.1	12.2	12.2	20.3	0.2	115.4
	N10	3.0	0.2	2.0	0.2	1.3	0.1	111.1	10.9	11.8	34.2	0.2	113.2
	N20	3.2	0.2	2.2	0.1	1.2	0.1	118.6	11.8	10.1	35.6	0.1	114.8
	N30	3.0	0.2	2.2	0.3	1.3	0.2	117.4	12.7	11.7	28.2	0.1	115.7
	N40	3.3	0.2	2.1	0.3	1.3	0.2	116.4	12.4	12.8	29.0	0.2	116.5
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*	*ns*	*ns*	*ns*
Gala	N0	2.6	0.1	1.7	0.1	1.2	0.2	92.5	10.6	9.7	20.2	0.1	103.9
	N10	2.7	0.2	2.1	0.2	1.3	0.1	93.6	12.5	10.9	22.5	0.2	111.5
	N20	2.9	0.3	2.2	0.2	1.3	0.2	93.8	12.2	11.5	25.9	0.1	106.3
	N30	2.8	0.2	2.0	0.3	1.4	0.2	94.8	11.7	12.8	29.6	0.3	110.8
	N40	3.0	0.2	2.0	0.4	1.5	0.3	94.7	11.9	12.4	27.4	0.2	110.9
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Where * means significantly different at p= 0.001 and ns means no significantly different. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

At the commercial harvest (07/10/2016 and 21/10/2016 for 'Gala' and 'Braeburn', respectively), fruit nutrient concentration was not affected by the fertilisation treatments in either cultivar (Table 5). Fruit N concentrations ranged from 0.19% to 0.21% and 0.17% to

0.20% in ‘Braeburn’ and ‘Gala’, respectively. Fruit K concentrations varied from 0.64% to 0.92% in ‘Braeburn and in ‘Gala’ from 0.65% to 0.72%. ‘Braeburn’ fruit concentrations of Mg and Ca ranged from 0.030% to 0.036% and 0.020% to 0.032%, respectively. In ‘Gala’, fruit Mg and Ca average concentrations were 0.03%. The ratio of (K + Mg)/Ca ranged from 30 to 34 in ‘Braeburn’ and 23 to 31 in ‘Gala’.

Table 5. Effect of the fertilisation treatment on cvs. ‘Braeburn’ and ‘Gala’ fruit macro- and micro-nutrient concentration at commercial harvest (07/10/2016 and 21/10/2016 for ‘Gala’ and ‘Braeburn’, respectively). There were no statistically significant differences between treatments.

Cultivar	Treatment	N	P	K	Ca	Mg	K+Mg/Ca
		% dry matter					
Braeburn	N0	0.20	0.038	0.64	0.022	0.030	30
	N10	0.21	0.038	0.66	0.021	0.031	33
	N20	0.21	0.035	0.92	0.032	0.030	30
	N30	0.20	0.030	0.67	0.021	0.036	33
	N40	0.19	0.030	0.67	0.020	0.031	34
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Gala	N0	0.18	0.039	0.65	0.024	0.021	28
	N10	0.17	0.039	0.72	0.024	0.032	31
	N20	0.18	0.040	0.69	0.023	0.029	31
	N30	0.17	0.030	0.71	0.033	0.034	23
	N40	0.20	0.039	0.67	0.031	0.032	23
Significance		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means no significant differences. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Fruit yields and quality at harvest

The total yield and yield of Class I from each tree of 'Braeburn' and 'Gala' were not significantly affected by the fertilisation treatments (Figure 4). However, a tendency for lower yield under the N0 treatment (without N fertiliser) was observed for both cultivars. 'Gala' Class I yield was on average 23 kg tree^{-1}, while 'Braeburn' was 18 kg tree^{-1} equating to harvest total of 66 and 51 t ha^{-1}, respectively.

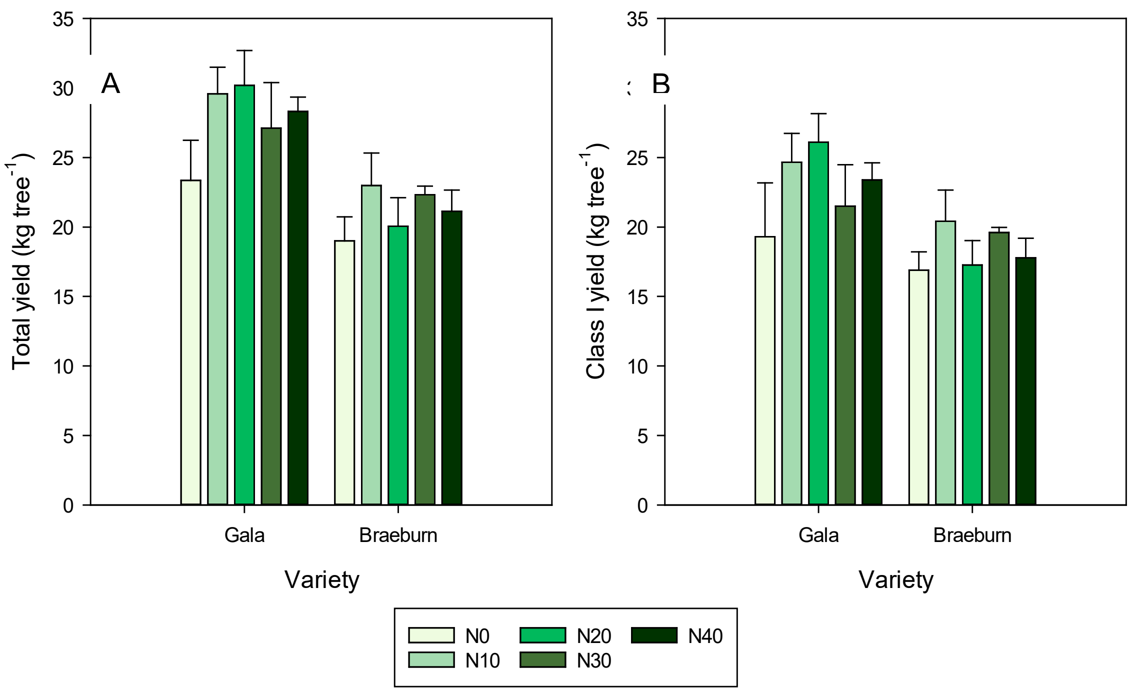

Figure 4. The effects of the fertiliser treatments on total (A) and Class I (B) yield of 'Braeburn' and 'Gala' trees. Vertical bars are standard errors. There were no statistically significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

The treatments also did not affect the average number of fruit per tree and individual fruit fresh weight (Figure 5). 'Braeburn' total fruit number per tree on average was 105 and 93% of them were Class I fruit. 'Gala' had heavier crop load and total fruit number per tree was on average 206, with 86% of them being Class I. Average 'Braeburn' Class I fruit weight was 190 g and for 'Gala' was 130 g.

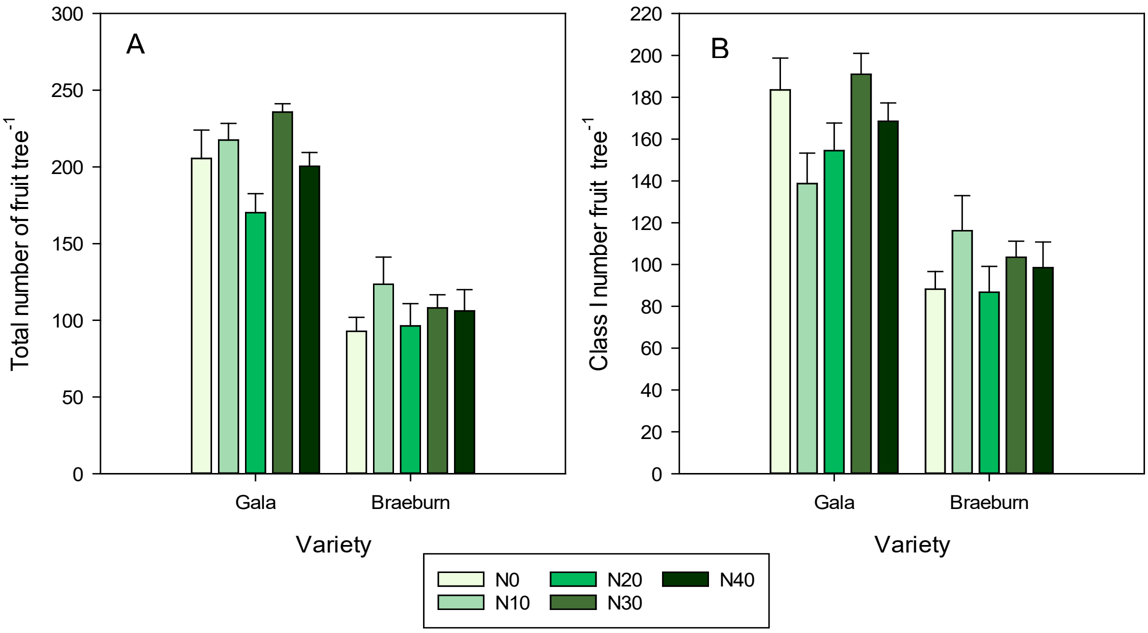

Figure 5. The effects of the fertiliser treatments on total (A) and Class I (B) number of fruit of 'Braeburn' and 'Gala' trees. Vertical bars are standard errors. There were no statistically significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Soluble solids content, fruit firmness, and dry matter measured at harvest were not significantly affected by fertilisation treatments in either variety (Table 6, 7 and 8).

Fruit quality after storage

Fruit firmness was evaluated at harvest as well as three and six months after storage. Nitrogen fertigation levels did affect neither 'Braeburn' nor 'Gala' fruit firmness in any of the assessing dates. Fruit firmness coming out of the store in February ranged from 81.4 to 82.6 N and 70.8 to 72.7 N for 'Braeburn' and 'Gala', respectively (Table 6). Fruit flesh firmness declined up to 14% after six months of storage (Table 6) and ranged from 75.4 to 77.4 N and 68.6 to 71.8 N for 'Braeburn' and 'Gala', respectively. Fruit firmness remained above the commercial threshold of 60 N in all treatments for both cultivars (Table 6).

Table 6. Average values of firmness for cvs. ‘Braeburn’ and ‘Gala’ fruit under different fertilisation treatments at harvest, after 3 and 6 months in storage and shelf life. Results are mean values of 20 fruit from four plots. There were no statistically significant differences between the treatments.

Cultivar	Treatment	Harvest	3 months after storage		6 months after storage	
			After storage	Shelf life	After storage	Shelf life
Braeburn	N0	90.3	82.6	83.1	77.4	77.2
	N10	84.5	81.4	83.3	75.4	76.2
	N20	86.2	81.4	82.7	75.8	76.0
	N30	85.9	81.5	83.5	76.4	76.2
	N40	88.3	82.0	84.0	76.2	77.1
Significance		*ns*	*ns*	*ns*	*ns*	*ns*
Gala	N0	71.4	72.7	67.3	69.7	64.7
	N10	71.9	72.2	69.1	71.8	67.4
	N20	71.8	70.8	66.9	68.6	63.7
	N30	71.8	71.0	69.3	70.1	67.3
	N40	71.9	70.8	68.8	70.1	63.9
Significance		*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means non-significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Post-harvest average values of SSC were not affected by the fertigation regimes in any of the cultivars (Table 7). Post-harvest SSC did not differ with the SSC at harvest. The three months post-harvest Brix values of ‘Braeburn’ ranged from 10.9 to 11.3 °Brix while the 6 months post-harvest was between 11.0 and 11.8 °Brix. ‘Gala’ had similar Brix values three months post-harvest and they were between 10.7 and 11.3 °Brix (Table 7), while six months post-harvest were a bit lower (9.1-11.0 °Brix).

Table 7. Average values of SSC (ºBrix) for cvs. 'Braeburn' and 'Gala' fruit under different fertilisation treatments at harvest, after 3 and 6 months in storage and shelf life. Results are mean values of 20 fruit from four plots. There were no statistically significant differences between the treatments.

Cultivar	Treatment	Harvest	3 months after storage		6 months after storage	
			After storage	Shelf life	After storage	Shelf life
Braeburn	N0	11.0	11.1	11.3	11.8	10.5
	N10	11.2	11.2	11.2	11.0	10.9
	N20	10.9	10.9	11.3	11.6	11.1
	N30	11.2	11.3	11.4	11.4	10.7
	N40	11.4	11.1	11.3	11.2	10.8
Significance		*ns*	*ns*	*ns*	*ns*	*ns*
Gala	N0	10.4	11.3	10.8	9.6	10.1
	N10	10.2	10.8	11.1	9.1	10.2
	N20	10.6	11.2	11.1	11.0	10.6
	N30	10.2	10.7	10.5	10.6	9.9
	N40	10.5	11.0	10.6	10.3	10.3
Significance		*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means non-significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

There were no significant differences on dry matter percentage between the nitrogen levels for any of the cultivars (Table 8). 'Braeburn' average dry matter percentage at harvest was 14%, which was reduced to 9% three months after storage and 13% at the final assessment six months post-harvest. 'Gala' dry matter was 13% at harvest and unlikely the 'Braeburn' there were no differences between the post-harvest assessments.

Table 8. Average values of dry matter for cvs. 'Braeburn' and 'Gala' fruit under different fertilisation treatments at harvest, after 3 and 6 months in storage and shelf life. Results are mean values of 20 fruit from four plots. There were no statistically significant differences between the treatments.

Cultivar	Treatment	Harvest	3 months after storage		6 months after storage	
			After storage	Shelf life	After storage	Shelf life
Braeburn	N0	14.5	9.1	9.5	13.3	13.2
	N10	14.0	8.8	8.5	12.1	12.9
	N20	14.0	8.8	9.1	12.5	12.8
	N30	14.2	9.2	9.2	15.1	13.1
	N40	14.4	9.0	8.8	13.9	12.8
Significance		*ns*	*ns*	*ns*	*ns*	*ns*
Gala	N0	13.7	12.5	13.0	12.5	12.4
	N10	13.3	12.8	12.7	12.2	12.2
	N20	13.6	12.9	11.4	12.7	12.3
	N30	12.0	12.6	12.3	12.1	11.5
	N40	14.2	13.4	12.5	12.2	12.3
Significance		*ns*	*ns*	*ns*	*ns*	*ns*

Where ns means non-significant differences between treatments. Treatments included the following grams of nitrogen per tree: N0=0, N10=10, N20=20, N30=30, N40=40.

Fertilisation treatments did not affect internal fruit quality during storage and only random incidences of internal disorders (<1%) were found.

Discussion

Fertigation of 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 is in contrast with previous studies (Neilsen et al., 1995, Neilsen et al., 1994). Fertigation with ammonium nitrate did not cause strong acidification, probably because relatively small, individual doses of the fertiliser were applied and because the water used for irrigation was alkaline; these results agree with the results of Treder (2005) in 'Jonagold' orchards.

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 different N inputs on the nitrogen fertigation treatments throughout the season, there were no effects on tree nutritional status or performance. Leaf N content was above normal levels (1.9-2.4%) (Agriculture Victorian, 2017) for both cultivars (3.1% in Braeburn and 2.8% in Gala) but no nutrient imbalance was observed.

The different rate of fertiliser application did not have an effect on tree yield or fruit quality at harvest, after storage in control atmosphere, and shelf life. Sometimes, even when the nutrient availability is lower than the lowest threshold, trees do not respond to fertilisation because of adequate nutrient reserves built up in perennial organs in previous years (Carranca et al. 2018). The lack of yield response to applied N may be the result of many factors, but especially due to the release of N, from the decomposition of native soil organic matter and senescent leaves. Most of the N loss from mature apple trees occurred in the leaves, which account for 47 kg N ha^{-1} yr^{-1}. Another 24 kg N ha^{-1} yr^{-1} is lost from the trees in the thinned flowers and fruits and tree prunings. Only 21 kg N ha^{-1} yr^{-1} is removed in the harvested fruit. Therefore, 77% of the N lost from the trees each year returns to the soil and becomes available again to the tree over time (Peryea, 1995). This amount of N returned in the soil (ca. 71 kg N ha^{-1}) is much greater than the requirement of these dwarf trees, which, according to Neilsen & Neilsen (2002), varies with tree age from 8.8 to 44 kg ha^{-1} $year^{-1}$. Nitrogen rate did not affect the fruit size, these results agree with those obtained by Wargo et al. (2003), who verified that fruit size is influenced more by crop load than by the amount of N applied to the apple tree. Wrona (2006) also did not get any increment on yield and leaf N status on young 'Jonagored'/M.9 apple trees due to forms and rates of N addition to two different soils.

When N application is not excessive, N should not have any detrimental effect on fruit quality and storability. Similarly to Drake et al. (2002), no effect of N levels on fruit firmness and soluble solids was found. Raese and Drake (1997) observed that lower rates of N fertiliser promoted greater fruit firmness and soluble solids concentration in 'Fuji' than the higher rates of 113 or 170 kg ha^{-1}. Dry matter content was within the ranges that have previously been reported for ‘Braeburn’ and ‘Gala’ (Saei et al. 2011,Mills et al, 1994). Fruit firmness was lower in ‘Gala’, which could be attributed to the high crop load. Saei et al. (2011) found that lower crop load (100 fruit per tree) resulted in firmer fruit at harvest. Fruit with higher dry matter content had higher firmness at harvest and remained relatively firmer during storage than the fruit of lower dry matter (Saei et al, 2011).

The fruit Ca levels and the K+Mg/Ca values were over the thresholds of 0.028% Ca dry matter and 12.5 K+Mg/Ca, that were suggested by Van der Boon (1980) as the limits to avoid physiological disorders, such as bitter pit. Moreover, the N concentration in the fruits was adequate according to Shear (1979), who suggested that an N concentration of 0.36 % DW was the limit for the avoidance of physiological disorders, such as bitter pit.

The different rates of N on the fertigation have been tested only on one growing season of the three years of the project; therefore, caution should be taken when interpreting the results. Repeating the experiments for several years should eliminate possible effect of the external environments. Tree N uptake is a result of the association of many factors, such as N release from the decomposition of native soil organic matter and senescent leaves, soil type, tree N reserves, root growth and irrigation management temperature. In order to fully understand tree N requirements and the effect of N fertigation on tree growth and yield as well as fruit quality, long-term studies are needed.

Although the N rate did not affect yield in the present study, a non-significant tendency for lower yield was found when no N was applied. When trees were grown without N, 20-25% less Class I fruit has been produced; even though this was not significantly different, it can still affect growers' annual income as it could decrease it by up to £5,000 ha^{-1}. Growers should be aware, that in situations where N release from the soil is lower than in soil conditions mentioned above, a high reduction in yield may occur if N fertilisation is not adequate. This is most likely to occur in soils with low organic matter content, a large percent of stones in the plough layer, in shallow soils, and in soils with water pH under 5.0.

Overall project conclusions

Soil solution analysis is a valuable environmental tool that can be used to monitor the changes in soil water chemistry, such as salinity and nitrate, in and just below the root-zone of irrigated crops. The measurements can be used to assist fertilisation and irrigation management decisions. A soil solution sampler comprises a porous ceramic cup connected to a pipe and is easy to construct. Buried beneath the soil surface at the sampling depth of interest, samples are obtained firstly by applying a negative pressure to the soil solution sampler. The sampler is then sealed and left for a few hours and over time soil solution moves into the sampler. The sample is then collected. A full description of the construction and use of the sampler can be found in the first annual report of the project (Stavridou, 2015). The disadvantage of the sampler is the difficulty to extract soil solution following prolonged dry conditions, so sampling should be carried out after rainfall or irrigation events.

In the second year of the project, four fertiliser treatments - broadcast fertiliser, commercial fertigation, fertigation scheduled to meet irrigation demand and targeted fertigation – were tested. The results indicated that the extent of nitrate leaching differs between apple cultivars. Nitrate concentrations in the soil solution at 50 cm depth were similar or higher to the concentrations in the fertigation solution. At the end of the growing season, soil N content in the 0-50 cm horizon ranged from 73 to 98 kg N ha^{-1}, which was prompted to leaching over winter. Leaching of other mobile nutrients such as phosphorus 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.

Taking into consideration that the different N inputs in year 2 did not affect yield and fruit quality, discussions with the industry representatives identify the need to optimise the N fertigation. Therefore, at the final and third year of the project N was applied at 4 different rates (0, 10, 20, 30 and 40 g N $tree^{-1}$), to help to retain N within the root zone and minimise N leaching. The different rate of fertiliser application did not have an effect on tree yield or fruit quality at harvest, after storage in control atmosphere and shelf life. Sometimes, even when the nutrient availability is lower than the lowest threshold, trees do not respond to fertilization because of adequate nutrient reserves built up in perennial organs in previous years (Carranca et al. 2018). The lack of yield response to applied N may be the result of many factors, but especially due to the release of N, from the decomposition of native soil organic matter and senescent leaves.

Caution should be taken when interpreting the results, as all the experiments were carried out only for one experimental year. 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. Tree N uptake is a result of the association of many factors, such as N release from the decomposition of native soil organic matter and senescent leaves, soil type, tree N reserves, root growth, and irrigation management temperature. Repeating the experiments for several years should eliminate possible effect of the external environments. In order to fully understand tree N requirements and the effect of N fertigation on tree growth and yield as well as fruit quality, long-term studies are needed.

Knowledge and Technology Transfer

- Presented the project aims and results at the West Sussex Fruit Group during their visit at EMR, 29 July 2014
- The project aims and results were presented at French Grower's Group during their visit to EMR, 01 April 2015
- The project aims and results were presented at the Kent Ambassadors Visit to EMR, 23 April 2015
- The project aims and results were presented at Plant Growth, Nutrition & Environment Interaction conference, Vienna , 25 June 2015
- The project aims and results were presented at the West Sussex Fruit Group during their visit to EMR, 29 July 2015
- The project aims and results were presented at the III International Symposium on Horticulture in Europe, 17-20 October 2016

- The project aims and results were presented at the 12th Conference for the fruit production in Slovenia, 17 December 2016
- A summary of the results was published at the AHDB (former HDC) tree fruit growers magazine
- The project aims and results were presented added at the EUFRUIT metaknowledge database, 20 December 2016
- The project aims and results were presented at the EUFRUIT meeting, 3 July 2017

Acknowledgements

We thank Mr Graham Caspell and his team for their helpful advice and support.

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