Improving nitrogen uptake by fertigation in European 'Conference'

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Abstract

The standard nitrogen (N) application in Belgian 'Conference' pear orchards is to scatter calcium nitrate granules on the herbicide strip under the trees. However, this N fertilization does not guarantee a sufficient N content in the fruits (minimum 50 mg 100 g^{-1} fresh weight) to allow prolonged storage and good shelf life. In 2018, a fertilization trial started in which the standard N application was compared with N fertigation in an attempt to improve the nitrogen uptake by the tree and to increase the N content in the fruits. Apart from the untreated control (no N fertilization) and the standard N soil application (40 kg N ha^{-1} in spring followed by 20 kg N ha^{-1} in summer), three different fertigation treatments were tested: the standard dose (40 kg N ha^{-1} in spring and 20 kg N ha^{-1} in summer), a reduced N application (-25%; 30 kg N ha^{-1} in spring and 15 kg N ha^{-1} in summer) and a split application throughout the season (6×10 kg N ha^{-1}). In each of the three years of study, the mean N content of the fruit in the standard N soil treatment was comparable to that of the different N fertigation treatments. However, in two out of three years there was more variability in the N content of the fruits of this standard treatment compared to that of the N fertigation treatments demonstrating a more homogeneous fruit quality using fertigation. The ^{15}N isotope was used in the fertilizer to determine the N use efficiency (FNUE) for summer applications in pear fruit. Only a small fraction (<5%) of current summer application reaches the fruit in the year of application, while 5-12% is detected in the fruit of the following year. Differences between standard soil N application versus N fertigation on N levels of the leaves, the fruits and the soil are discussed.

Keywords: nitrogen, pears, fruit quality, 'Conference', fertigation, ^{15}N

INTRODUCTION

As an outdoor perennial crop, the uptake of nutrients by pear trees is strongly influenced by weather and soil conditions. Soil humidity, soil temperature, soil structure, soil type, pH, will affect the availability and the uptake of different mineral elements by the trees. Hence, even if the amount of fertilizer remains identical every year, there will be differences in the mineral content of leaves and fruits across years. In this study we focus on N uptake by 'Conference' pear trees. The N levels in leaves and fruit can be strongly influenced by weather conditions as soil humidity and soil temperature influence the mineralization of N and hence its availability in the soil. Duarte et al. (2010) found that fruit trees are highly inefficient in N uptake whereby recovery rates of ca. 20% of the applied fertilizer are commonly observed. Pome fruits do not require a lot of N (50-60 kg N ha^{-1} for pears) to retain good fruit production and quality, but N application timing and rate needs to be synchronized with pear tree requirements as many aspects of N uptake and transport are poorly understood (Sánchez, 2015).

In recent years, flowering of fruit trees in Belgium has been accompanied by long periods of drought. As a result, nutrient uptake was hindered during a crucial period of the season (e.g., in 2020 drought stress was already present during bloom and the weeks after

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bloom). These long periods of drought have led to many new installations of irrigation systems in pear orchards and create the possibility of fertigation technologies which might be leveraged to increase N uptake. Yin et al. (2009) indicated that split fertigation could increase N and P (phosphorus) uptake in 'Anjou' pears which in turn increased the marketable fruit share quite significantly.

The general fertilization advice given to farmers of 'Conference' pear trees is to apply inorganic fertilizer N before flowering since this practice favours shoot growth and N allocation into pear fruit with a second lower N fertilizer application in summer. The latter application is meant to fulfill the early N demand of the new developing organs at the start of the next growing season (Sánchez, 2015). However, little information is available on summer N partitioning in mature 'Conference' pear trees. The use of ^{15}N labelled fertilizers in the summer application should give more information about the efficiency of this nutrient application. The ^{15}N method is frequently used to determine N use efficiency (FNUE) of annual crops, but to a lesser extent in the fruit sector (San-Martino et al., 2010).

After many years of practical research in the Research Station for Fruit we concluded that N uptake in pear fruit was highly variable and poorly understood. More particularly, we still question i) why the applied N fertilizer does not end up in the fruit, when soil and/or leaf levels are sufficiently high, and ii) what is the best timing to apply N fertilizer? To gather more insights in the N uptake of pear trees, ^{15}N isotopes were used.

MATERIALS AND METHODS

In 2018 the trial with N fertigation was started on 'Conference' pear trees which were in the 10^{th} growing year. The research orchard is located at the Research Station for Fruit on a loamy sand soil with 1.34% org. C. (50°46'19.85"N, 5°9'36.49"E). The rootstock utilized was quince C and the tree planting distance is 3.4×1.25 m (2117 trees ha^{-1}). The trial is conducted in 4 replicates or plots of 5 trees each. All measurements are done on the experimental unit composed of 3 trees in the middle (net trees) of each plot. From 2018 until 2021 the fertilizer schemes were kept constant. All N was applied in the form of calcium nitrate [$Ca(NO_3)_2$]. The N fertilization or nutrition treatments that are compared in this trial are shown in Table 1.

Table 1. Nitrogen (N) nutrition schemes applied in each year of the trial (2018, 2019 and 2020).

Number	N treatment (spring + summer; in kg ha^{-1})	Total N[a] (kg ha^{-1})	Type of N application	Timing of N application
0	Non-N fertilized control	-	-	-
1	40 + 20[b]	60	Scattered	March + June
2	40 + 20[b]	60	Fertigation	March + June
3	30 + 15[b]	45	Fertigation	March + June
4	6×10[b]	60	Fertigation	Spread between March and end of August

[a]All N is applied as calcium nitrate [$Ca(NO_3)_2$].
[b]In 2019 the summer application was labelled with ^{15}N.

The standard N application is based on an annual contribution of 60 kg N ha^{-1}. This dose rate is divided into 2 fractions where 40 kg N ha^{-1} is given shortly before flowering (2 to 4 weeks before flowering in case of calcium nitrate) and 20 kg N ha^{-1} is given in the 2^{nd} half of June, when shoot growth has stopped. In practice, these 2 fractions are strewed on herbicide strip under the trees. In this research the comparison is made with the same N dose applied by fertigation with liquid $CaNO_3$ (Calsal 8.7% N). For one treatment the total N rate was reduced by 25% to a spring application of 30 kg N ha^{-1} shortly before flowering and 15 kg N ha^{-1} at the end of June. Fertigation allows to spread fertilization throughout the season. In the last treatment, the total dose 60 kg N ha^{-1} was spread over 6 fertigation applications each of 10 kg N ha^{-1} between flowering and harvest. All 5 treatments had the same amount of water by irrigation.

In the 2019 season, the summer fraction of each treatment was labelled with ^{15}N as described by Colpaert et al. (2021). For these labelled fractions, a ^{15}N-NO_3-enrichment of

5.45% was used and the fertilizer was administered as a granulate in treatment 1, while it was applied in solution (8.7% N) in treatments 2, 3 and 4. Use of ^{15}N labelled fertilizer allows to trace N throughout the tree and to calculate the fraction of N derived from N fertilizer (Ndff). Addition of ^{15}N labelled fertilizer in the summer was done to obtain insight into the contribution of this fraction of the N fertilization to the N content of the fruits in the year of application (2019) and in the following year (2020).

The N fraction derived from the applied N fertilizer (Ndff, nitrogen derived from fertilizer) for pears (Equation 1) was determined for each treatment at harvest in 2019 (August 26, 2019) and 2020 (August 26, 2020) as described (Colpaert et al., 2021). The fertilizer N use efficiency (FNUE, Equation 2) was determined as follows:

$$\text{Ndff} = \left(\frac{^{15}\text{N excess in pear tree sample}}{^{15}\text{N excess in fertilizer N}}\right) \quad (1)$$

$$\text{FNUE} = \left(\frac{\text{N yield (kg N per tree)} \times \text{Ndff}}{\text{Labelled fertilizer N applied (kg N per tree)}}\right) \quad (2)$$

whereby "^{15}N excess" = measured ^{15}N abundance minus the natural ^{15}N abundance (0.003663), and N yield = total mass of N (kg N) in all harvested pears (dry mass basis) per tree.

In this trial, the following parameters were monitored: production (kg $tree^{-1}$), average fruit weight (g), firmness, sugar content and back ground colour of the fruits, shoot growth (cm), and N-NO_3^-content in the soil. To determine the N-content in the fruits (mg N 100 g^{-1} fresh fruit weight) a mixed sample of 40 fruits was processed by crushing the fruits in a mixer and drying the obtained pulp for 72 h at 70°C. Dried samples were send to Yara Analytical Services in Pocklington (England) for mineral analysis. Fruit quality was assessed at harvest and after 4 months of storage under ultra-low oxygen (ULO) conditions. Extra attention was given to the background colour where the loss of green background is an important component of fruit quality. Shelf life of the pears was conducted during 8 days at 18°C. After 4 and 8 days shelf life, the background colour was determined by colour sorting on a commercial Aweta sorter. Fruit firmness was measured at harvest and immediately after ULO-storage using a penetrometer (kg 0.8 cm^{-2}). All statistical analyses were performed using the Unistat Statistical Package, version 10.1 (Unistat Ltd., London, England). The original or transformed data were analysed with the General Linear Model procedure with Anova as an output. Treatment means are standard separated by Duncan's multiple range test at a 5% level confidence level ($p<0.05$).

RESULTS AND DISCUSSION

To avoid interference of carry-over effects of the 2017 season, only the results of 2019 and 2020 are discussed.

Tree vigor

In 2019, average shoot length was not much affected by the different N nutrition schemes. Only the non-N fertilized control (0 kg N ha^{-1}) showed shorter shoots (also in 2020), but this was not statistically different from the shoot length of the fertilized objects. The fractionated N treatment of 6×10 kg N ha^{-1} displayed a tendency of slightly shorter shoots than the other fertilized treatments in 2019, but this was not confirmed in 2020. Shoot growth continued for a prolonged period in 2020 as a result of the relatively late applications of the last two fractions in this fractionated N scheme (6 and 1 week(s) before harvest). The 3 other N nutrition schemes (1, 2 and 3) were very comparable in shoot growth (data not shown).

Fruit set and production

In both 2019 and 2020 there was no significant influence of the N fertilization of the previous year (2018 and 2019, respectively) on the number of flower buds per tree nor on the fruit set expressed in number of fruits per 100 flower buds (Table 2). Although the non-N fertilized control had sufficient flower buds to achieve a good production in 2019, it reached a lower yield tree^{-1} than all the N fertilized treatments and it was even significantly lower than the yield in N nutrition schemes 1 (standard spreading of granulates) and 4 (fractionated fertigation). In 2020 there was no difference in yield between the non-N fertilized control and the N fertilized treatments. Over a 3 years period, the lack of N fertilization in the control caused a non-significant decrease in total production of 5 to 9 kg tree^{-1} compared to the different N fertilization schedules, which is due to a significantly negative impact on the mean fruit weight of 10 to 20 g in both years compared to the N fertilized treatments. The amount of fruits tree^{-1} was not affected.

Table 2. Fruit set (fruits/100 flower buds), production (kg tree^{-1}) and mean fruit weight.

Nr.	N Treatment	# Flower buds tree^{-1}		Fruits[a]/ 100 flower buds		kg tree^{-1}		Mean fruit weight (g)	
		2019	2020	2019	2020	2019	2020	2019	2020
0	Control	67 a	122 a	226 a	152 a	18.9 b	22.0 a	167 b	176 b
1	40 kg ha^{-1} N + 20 kg ha^{-1} N scattered	84 a	111 a	202 a	167 a	23.4 a	24.1 a	174 a	180 a
2	40 kg ha^{-1} N + 20 kg ha^{-1} N fertigation	74 a	94 a	212 a	171 a	21.5 ab	21.5 a	181 a	197 a
3	30 kg ha^{-1} N + 15 kg ha^{-1} fertigation	67 a	109 a	237 a	153 a	21.1 ab	24.0 a	176 a	193 a
4	6×10 kg ha^{-1} N fertigation	84 a	107 a	205 a	147 a	23.7 a	23.0 a	178 a	201 a

Entries with different letters within each year are significantly different.
[a]The sum of hand thinned fruits and harvested fruits per tree.

The reduction of 25% in N dose rate by fertigation had no impact on the production nor fruit size after 3 years (treatment 3 vs. 2 in Table 2). Similarly, the fractionated fertilization of 6×10 kg N ha^{-1} via fertigation had no immediate effect on the flower bud formation. The fruit set tree^{-1} was slightly lower in 2020, which resulted in larger pears, albeit that the difference to the other N fertigation treatments 2 and 3 was statistically not significant.

The comparison between the scattered 40+20 kg N ha^{-1} treatment 1 and its fertigated counterpart treatment 2, did not reveal statistical differences in flower buds nor production in either year. In 2020, however, there was a trend to slightly less flower buds using fertigation, but the fruit set (number of fruits per 100 flower buds) was nearly identical (171 vs. 167 for fertigation vs. scattering), which demonstrates that the flower buds had the same potential for fruit set.

Mineral N content in the fruits

At harvest the N level in the fruits was also measured. In 2019, three treatments (control, 40+20 kg ha^{-1} N scattered and 40+20 kg ha^{-1} N fertigation) had a N content below the minimum threshold value of 50 mg N 100 g^{-1} fresh fruit weight (Figure 1). Hence, even with the standard N scheme the N-content of the fruits was too low, despite the high nitrate (NO-3) content available in the soil (see below, soil N content). The highest N content was measured in pears of treatment with 6×10 kg N ha^{-1} fertigation throughout the season. Again in 2020, the average N content of pears in the control was at the lower threshold value. All the N fertilization schemes (treatments 1-4) resulted in a N content in the fruits of minimum 60 mg N 100 g^{-1} fresh weight. The reduced N treatment of 30+15 kg N ha^{-1} (-25% in total N; treatment 3) reached a N content between that of the control and the other fertilization treatments where a total of 60 kg N ha^{-1} was applied. With the common advice of 40+20 kg N ha^{-1} granular application, in 2020 there was more variation between the repetitions compared to the fertigated treatment. However, the variation was less compared to 2019. In 2020 the scattered treatment had the highest N content in pears (nearly 70 mg 100 g^{-1} fresh fruit weight). For all treatments with fertigation the N content was similar. Across both years, the fractionated N fertigation (6×10 kg N) yielded the most consistent and high N content in the pears (60 and 65 mg 100 g^{-1} fresh fruit weight in 2019 and 2020, respectively).

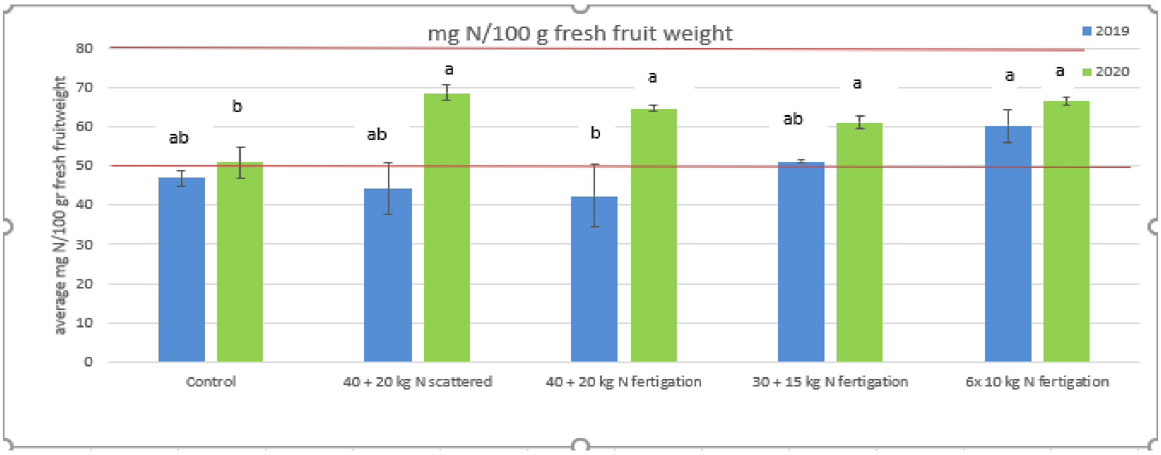

Figure 1. Mineral N content in 'Conference' pears at harvest in 2019 and 2020. Each entry is the average of 4 replicates. Bars indicate the standard deviation (SDEV).

Effect of the summer N application on the mineral N content of the pears

In 2019 the summer fraction of each N fertilization treatment was labelled with ^{15}N. In the fractionated N fertigation treatment 4 (6×10 kg N ha^{-1}) the 5th and 6th fraction were ^{15}N labelled (and applied 6 and 1 week(s) before harvest). At harvest in both years, 2019 and 2020, the N fraction derived from the applied N fertilizer (or Ndff, nitrogen derived from fertilizer) was calculated based on the measured ^{15}N levels in the pears. Subsequently, the Ndff was used to determine how efficient the N derived from fertilizer applied in the summer is used by 'Conference' trees for pear production in the same year (2019) and the following year (2020) by calculating FNUE (Figure 2). The FNUE (%) corresponds to the N fraction of the applied labelled fertilizer in 2019 that is incorporated into the pears in the same year and the following year.

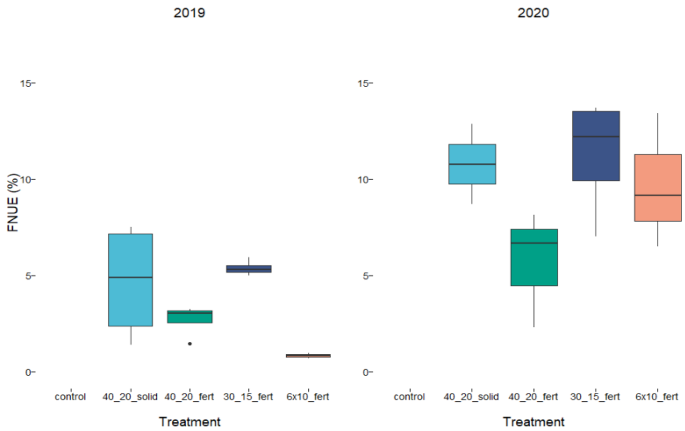

Figure 2. Fertilizer N use efficiency (FNUE) of the ^{15}N labelled fraction of the $Ca(NO_3)_2$ fertilizer applied in the summer of 2019 to 11-year-old 'Conference' pear trees in the fruits at harvest in 2019 and 2020. The different colours denote the four respective fertilization treatments: 40_20_solid 40_20_fert, 30_15_fert and 6×10_fert correspond to treatments 1, 2, 3 and 4, respectively. In each case the summer fraction (20 kg N ha^{-1}) was ^{15}N labelled and for the 6×10 kg N ha^{-1} treatment the 5th and 6th fractions were ^{15}N labelled and applied 6 and 1 week(s) prior to harvest, respectively.

In pear fruit of 2019 only a small part (1-5%) of the summer N dose rate (20 kg N ha^{-1}) was detected in the fruit (Figure 2). No significant differences were noted between the fertilization treatments. This means that i) very little of summer N fertilizer application reaches the fruit before harvest, and ii) the large majority of N uptake of the summer fraction is used to build up the N reserve in the trees (in roots, shoots, branches and trunk) for the following year (and probably a small fraction remained in leaves and fell on the ground at leaf fall in the autumn). A large variation in NFUE of the pears occurred in 2019 in the standard scattered fertilization scheme (treatment 1) compared to the fertigation treatments 2, 3 and 4. This variation might be attributed to the fact that only a relatively narrow zone or band of the herbicide strip is wetted by the drip irrigation and outside this wetted area the scattered granulated fertilizer (over the complete black strip) does not penetrate sufficiently into the soil especially under more dry conditions. The weeks in August 2019 prior to the harvest were drier than the long-term average (53.6 vs. 73.1 mm, respectively). In contrast, using fertigation the total N dose rate penetrates well into the soil and becomes rapidly available to the roots. In the pears of 2020 up to 7 to 12% of the N content originated from the summer fertilization of 2019. In conclusion, there is a larger impact of summer N nutrition on pears of the following year than on those of the current year of summer fertilization. In other words, summer N derived from the fertilizer is more efficiently used in the pears in the following year than in the year of application. Again, significant differences between fertilization schemes were lacking. The variation in NFUE in the standard scattered fertilization scheme (treatment 1), however, was strongly reduced in 2020, whereas in the N fertigated treatments 2-4 the variation strongly increased compared to 2019. Whether the long period of drought from March until August in 2020 played a role remains unclear.

Fruit quality

In 2019, there were no differences in fruit firmness at harvest among treatments. In February 2020, after 4 months of ULO storage, the fruits of treatment 4 (6×10 kg N ha^{-1}) were slightly softer than the fruits of the other treatments. The firmest pears were measured in the control, but these pears were slightly smaller, which might explain their increased firmness. What concerns the important quality parameter of green background colour, the pears of the control showed the worst quality after storage. The fraction of pears with a yellow background colour already amounted up to 20%. At that time there were no differences between the N fertilization schemes (data not shown), despite the large differences in N content (Figure 1).

For the pears of the 2020 harvest, no differences were measured in firmness at harvest nor after ULO storage which lasted until February 2021. After storage, the pears of the control treatment displayed the worst quality, similar to the pears of the 2019 season. In 2 of the 4 replicates, only 20% of the pears had a green background colour resulting on average in 42% green pears (Figure 3). For the N fertilized treatments, on average ±60% of the fertigated pears (treatments 2-4) still had a green background colour after storage. In the scattered treatment, the fraction of green pears reached even 75% (Figure 3). As expected after 4 days of room temperature display, 44% of these pears of the N scattered treatment remained green, while in the fertigated treatments and in the control treatment this fraction of good quality pears dropped to ±20%. The difference between the control and fertigated treatments mainly lied in the proportion of yellow pears, which reached up to 34 and ±17%, respectively. So, with fertigation a larger group of pears had a green-yellow colour.

Soil N content

During the growing seasons at different time points soil samples collected down to 90 cm depth were taken to know the N-NO_3^- availability in the soil, which is free for uptake by the roots. In 2019, during the whole season the highest amount of free N-NO_3^- was present in the standard N treatment with 40+20 kg N ha^{-1} scattered on the black strip (treatment 1). The treatments 2-4 where N was supplied by fertigation had less N available in the soil. During the winter, a high amount of soil N-NO_3^- can flush into the soil water. This is a problem for the surface and ground water quality. At the last soil sampling on November 22, 2019, the scattered N treatment still displayed the highest N-NO_3^--reserve with 145 kg ha^{-1} in the zone of 0 to 90 cm depth. Whereas in August for this treatment most $N\text{-}NO_3^-$ accumulated in the zone from 0 to 30 cm depth, there was no $N\text{-}NO_3^-$ left in the 0-30 cm depth zone in November, suggesting the migration of $N\text{-}NO_3^-$ into the zones 30-60 and 60-90 cm in which 64 and 66 kg $N\text{-}NO_3^-$ ha^{-1} was measured, respectively. The treatment with split fertigation during the season had also a relatively high amount of $N\text{-}NO_3^-$ available in November. This was 117 kg $N\text{-}NO_3^-$ ha^{-1} spread over the 3 zones. For treatment 2 and 3 with fertigation earlier in the season, it was limited to 43 and 62 kg $N\text{-}NO_3^-$ ha^{-1}, respectively. In conclusion, in 2019 the standard scattered N nutrition scheme caused the highest $N\text{-}NO_3^-$ throughout the season and in the following autumn, which can be explained by the dry spring in 2019. This might have prevented a good N penetration into the soil throughout the black strip.

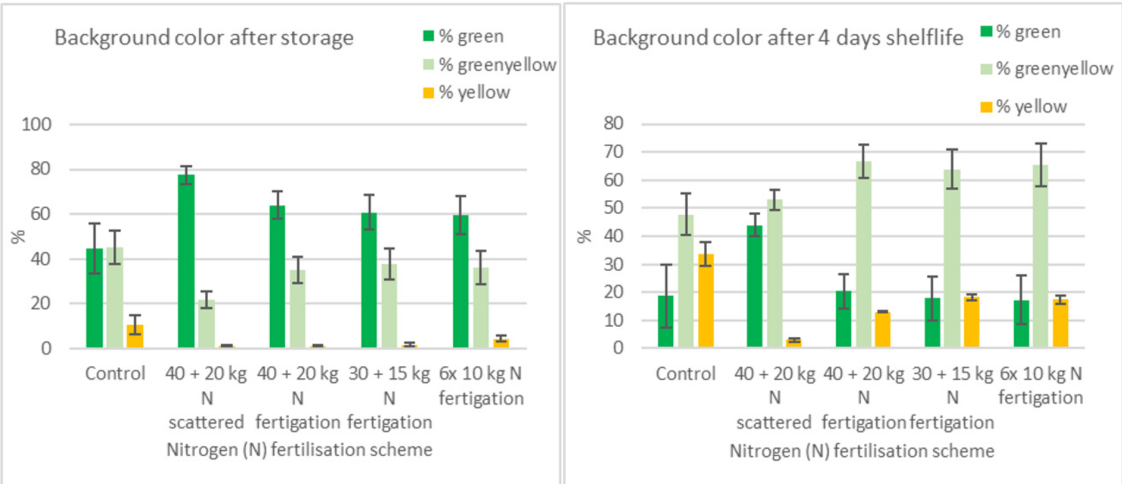

Figure 3. Background color of pears harvested in August 2020 and stored in ULO until February 2021 after opening the storage room (left) and after additional 4 days of shelf-life at 18°C (right). Per replicate 20 kg pears were scored for background color on a commercial Aweta sorter. Percentages are the average of four replicates (±SDEV).

In 2020, the $N\text{-}NO_3^-$ pattern in the soil was different. Samples were taken using a 1.6 cm diameter gauge auger. Each sample consisted of a mixture of at least 6 subsamples, which were distributed randomly throughout the plot with varying distances from the emittor. At the first sampling moment (April 24) the scattered N treatment showed again the highest soil N content. At the 2nd sampling on June 2 when also only the spring dose had been applied, 40 kg N ha^{-1} administered by fertigation (treatment 2) resulted in the largest soil $N\text{-}NO_3^-$ resource. In the zone 0-60 cm this was 192 kg $N\text{-}NO_3^-$ ha^{-1}. Due to the dry season, no soil samples at 60-90 cm depth could be taken. The difference with 30 kg ha^{-1} N by fertigation was 109 kg $N\text{-}NO_3^-$ ha^{-1} at that time in June. At this time point there was no difference between the 30 kg ha^{-1} N treatment and the 3×10 kg ha^{-1} N that were already applied in treatment 4. However, one month later in July the fractionated N treatment had a soil (0 to 60 cm) $N\text{-}NO_3^-$ reserve above 200 kg ha^{-1}. Around harvest, in August, the highest soil $N\text{-}NO_3^-$ reserve was again measured in the 6×10 kg ha^{-1} N fertigation with 216 kg $N\text{-}NO_3^-$ ha^{-1} (treatment 4) and also in the 40+20 kg ha^{-1} N fertigation with 190 $N\text{-}NO_3^-$ ha^{-1} (treatment 2). The treatment with -25% N nutrition had a soil N content of 118 kg $N\text{-}NO_3^-$ ha^{-1}. This was comparable with the standard scattered soil application (125 kg $N\text{-}NO_3^-$ ha^{-1}). For 2020, we conclude that the fractionated N scheme (6×10 kg N ha^{-1}) with fertigation caused larger fluctuations in available $N\text{-}NO_3^-$ in the soil. The fluctuations were clearly greater compared to the scattered 40+20 kg ha^{-1} N scheme. Most likely the extreme dry spring and summer periods in 2020 interfered with the dynamics of the soil $N\text{-}NO_3^-$ content. Especially in combination with drip irrigation variability in observed $N\text{-}NO_3^-$ increases due a different microbiologic activity between the wet zone just below the emittor and the more dry soil further away from the emittors. The treatment of 30+15 kg N ha^{-1} by fertigation always lead to a lower soil N-NO_3^- reserve from the beginning of June compared to the 40+20 kg N ha^{-1} fertigation treatment.

CONCLUSIONS

In both trial years, a 60 kg N dose rate was applied to 'Conference' pear trees as a granular soil application or by fertigation using calcium nitrate. For the fertigation, the standard 40 kg (spring) + 20 kg (summer) application was compared to a 6×10 kg application and a reduced N application by 25%. The control treatment (no N) showed a reduced shoot growth, a lower production tree^{-1} associated with smaller (but firmer) fruits, and more yellow fruits after storage and hence, lack of N fertilization negatively affected pear quality. The reduced N treatment (by fertigation) caused an intermediate effect in shoot growth but did not lower the N content nor firmness or colour of the pear fruit. Surprisingly, compared to the scattered N scheme all fertigation plots suffered from a negative impact on the background colour of the pears, which is an important quality parameter influencing the pricing.

Both trial years exerted a deficit of precipitation in spring, the most important period for nitrogen uptake by the roots. Most of the deficit was corrected by irrigation on all treatments. but a difference in N content of the pears between 2019 and 2020 remained. In 2019, the pear N content was highest in the fractionated 6×10 kg ha^{-1} N treatment but in 2020 the scattered N treatment produced pears with the highest N content. Across both years the fractionated 6×10 kg ha^{-1} N treatment resulted in a consistently high N content in the fruits suggesting it is a more robust N fertilization scheme at least in years with prolonged drought periods. These results also indicate that N is for a large part mobilized from reserve organs, rather than taken up by N amendments of the same season. This preliminary conclusion is supported by our findings that only 1-5% of ^{15}N fertilizer given in early summer was transported into the fruits in the year of application, whereas 7-12% was retrieved in the fruits of the next year. These findings together with the negative impact of no N fertilisation on fruit production and quality, warrants for a low yet regular application of N in pear growing.

Although pome fruits are categorized as low nitrogen demanding crops, the leaching of N-NO_3^- into deeper ground water or surface water (by drainage channels) can be of concern. This is usually the case at the end of season when plant growth ceases and precipitation increases. The 6×10 kg N fertigation resulted in higher and more varying N levels in the soil in autumn which could be due to the latest N gifts. The 25% reduced N gift showed lower N-NO_3^- levels in the soil.

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