Project title:	Developing Nutrient Management Recommendations for Rhubarb
Project number:	SF172
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Report:	Annual report, 31 March 2021
Previous report:	None
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Date project commenced:	1 April 2019

Date project completed 31 March 2023

(or expected completion date):

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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.

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1. Grower Summary

1.1 Headline

- Pre-emergence nitrogen applications to mature rhubarb applications are unlikely to have significant benefits, most likely as a result of draw-down of nutrient and energy reserves in the crown.
- Time applications of nutrients to match likely periods of significant crop need – recovery from harvests, or late season applications to promote crown storage in advance of the following season.
- Trials are underway to examine the impact of a range of nitrogen application scenarios over the 2021 and 2022 seasons.

1.2 Background

Rhubarb is a complex cropping system, with energy and nutrients carried over between seasons to impact yield year-to-year. The early season growth of rhubarb, it has previously been seen as necessary to apply fertilisers, particularly nitrogen (N), in the early spring. Current grower practice (as demonstrated in the grower survey reported in the 2020 annual report of SF 172) showed considerable variation in both volume and timing of N applications, with growers targeting pre-emergence and post-harvest applications, using application rates between 100-250 kg N/ha/year against current RB209 recommendations of 70-300 kg N/ha/year for established crops. Recommendations for rhubarb are significantly out of date and may not reflect current practice, such as the use of multiple selective pulls, or include references to practices that are no longer suitable (e.g. manure use). Other cultural approaches including the use of wool waste ("shoddy") and the discarding of leaves onto the soil surface as a secondary source of nutrients add further layers of complexity to understanding the nutrient requirements of rhubarb. SF 172 is a multi-year project looking to further examine optimum nutrient management approaches for commercial rhubarb in the UK. The work will address the following objectives:

1. To update information on nutrition and feeding for rhubarb
2. To determine whether additional feeding of green rhubarb increases yield, quality and season length when pulled multiple times during a season
3. Knowledge exchange to include provision of speakers for AHDB or third parties events throughout the project duration
4. To update relevant sections of the Nutrient Management Guide (RB209)

It is likely that N is likely to have the biggest impact on yield responses, so trials in the 2020 season focused on timing and rates of application. Whilst significantly impacted by the Covid-

19 epidemic, early results from the trial indicated that pre-emergence applications did not have a significant impact on yield (at least for the first harvest). This is most likely to be due to the accumulation of nutrients and energy in the crown that is drawn down for early season growth rather than assimilating fresh inorganic N from the soil. As a result of these findings, trial activities were refocused to look at the impact of increased late spring applications, with the significant portion of N applications targeted at the first and second postharvest periods. This reflects the likely increased demand for N during the recovery phase after harvest after the crown reserves are likely to have been exhausted. In addition, trial activities have been expanded to examine the impact of a late-season application of N to test whether it is possible to enhance crown reserves of N and whether they would feed forward into yield outputs.

1.3 Summary of 2021 Trials

Trials in the 2021 season were focused on three scenarios. Varied rates of N application were tested with the majority of applications targeted at the post-harvest period after the first harvest, with smaller applications made either after the second harvest (trial 1) or before emergence (trial 2). In addition, the application of N in the late season was tested (trial 3). A summary of application rates and timings are given in **Figure 1.**

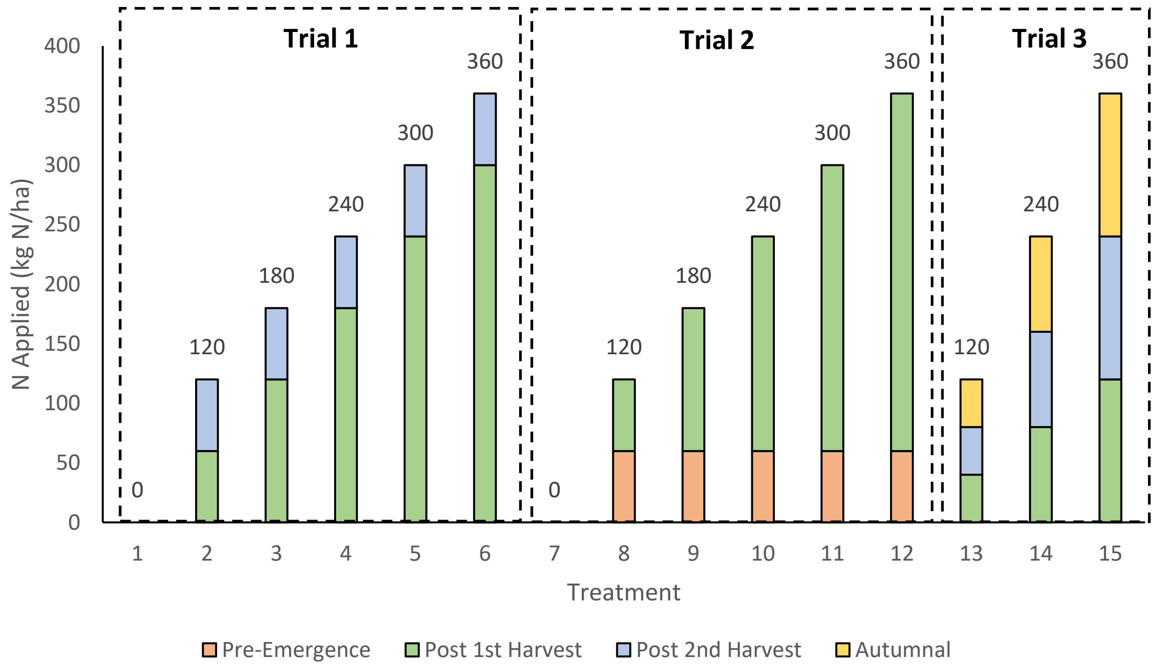

Figure 1. Summary of nitrogen treatments in the 2021 season.

Trials were established at two commercial sites – T Hammonds and Son, Redhill, and E Oldroyd and Sons, Rothwell. Results are undergoing analysis at the time of writing, but this report summarises the methodology implemented in the 2021 season.

Science Section

1.4 Introduction

This is the second annual report of a four year project looking to update nutrient recommendations for UK grown rhubarb. Rhubarb production in the UK is a small but significant sector which currently occupies over 550 ha of land, producing in excess of 12,000 tonnes annually with a farm gate value of £17m (Defra, 2018). The niche nature of the crop has limited the development of evidence for nutrient management best practice, and the complex nature of the crop biology further precludes identification of optimum nutrient applications. The volume and quality of the harvested product – elongated petioles formed in the early spring – is determined by a number of factors including the condition of the crown which is impacted by growing conditions over previous seasons including the availability of nutrients. This is further complicated by a range of production styles (including production for field harvest or lifted crowns for forcing), different growing regions giving climate/soil differences, and the use of atypical nitrogen (N) sources (e.g. wool waste) by growers. The grower survey demonstrated that growers use a variety of sources to judge nutrient applications including crop condition and history alongside intended marketing requirements, although there is a desire for additional forms of evidence such as crown nutritional status to inform nutrient management practices.

N is likely to have the largest impact on yield performance, with current recommendations for 175 kg N/ha (Index 0) to 0 (Index >3) given in RB209 although the grower survey conducted in 2019 for this project demonstrated that there is significant variation across grower holdings in terms of nitrogen application. N is typically applied at multiple points across the cropping cycle, with early applications before bud break followed by additional applications after first and second harvests typical of practice. There is concern that current recommendations are not optimal (e.g. greater applications may improve yield) or that other aspects (e.g. timing of N applications) could be developed to improve overall crop responses. For example, last year’s results suggest that postharvest applications and late season applications may help the crop recover to promote strong development of buds for the subsequent season, leading to overall yield uplift.

1.5 Project Objectives

This project has the following core objectives:

1. To update information on nutrition and feeding for rhubarb
2. To determine whether additional feeding of green rhubarb increases yield, quality and season length when pulled multiple times during a season

3. Knowledge exchange to include provision of speakers for AHDB or third parties events throughout the project duration
4. To update relevant sections of the Nutrient Management Guide (RB209)

1.6 2020 Trial Activities & Outputs

Experimental trials in the 2020 season focused on determining the N requirements of an established rhubarb crop, looking at variable N applications including both volume and timing of application, and examined:

- complete application before emergence,
- applications split equally between pre-emergence and postharvest periods,
- larger applications before emergence followed by smaller postharvest applications of total applications of 175, 275 or 375 kg N/ha (**Figure 2Error! Reference source not found.**).

Whilst the timing of this work was negatively impacted by the covid-19 outbreak so that only the pre-emergence applications were made, it was still possible to demonstrate a number of interesting responses in the crop to varied N applications.

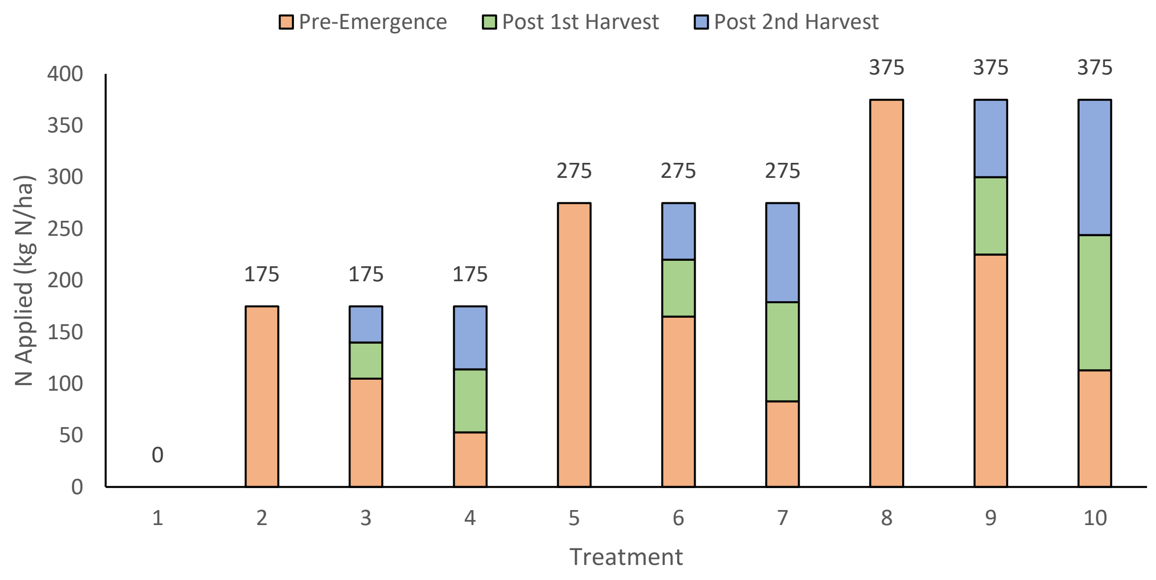

Figure 2. **Summary of nitrogen application rates used in the 2020 trials. Total N applications (kg N/ha) are given with each treatment.**

No significant differences were seen in N accumulation in above ground biomass with Pre-emergence applications of 53-375 kg N/ha (**Figure 3**), indicating that pre-emergence N applications did not have any significant impact on N offtake or yield, at least for the first harvest. This is most likely due to initial growth of petioles in the spring being dependant on accumulated sugars and nutrients already present in the crown as opposed to the uptake of new nutrients – this would also correspond to the regrowth of petioles outpacing the regrowth of roots in the early season, with the resulting restrictions on nutrient access making the crown reliant on internal stores as an alternative. These data indicated that large early season applications may be ineffectual, although this may also mean that crowns with insufficient stores from the previous season (e.g. due to young age, under application or excessive harvest) may show small yields or a greater reliance on preharvest applications due to insufficient internal reserves. A full discussion of the 2020 trials are given in the SF 172 2020 annual report. Supplementary to the 2020 trials, a limited trial was carried out at T Hammonds & Sons to explore the impact of late season N application – a single application of 0, 75 and 150 kg N/ha were made to three replicate plots of a pulled and unpulled crop to test the impact of late season application. On the basis of this trial, autumnal applications will be included in the 2021 season trials. Yield results for this trial were collected into April 2021 with the main rhubarb harvests.

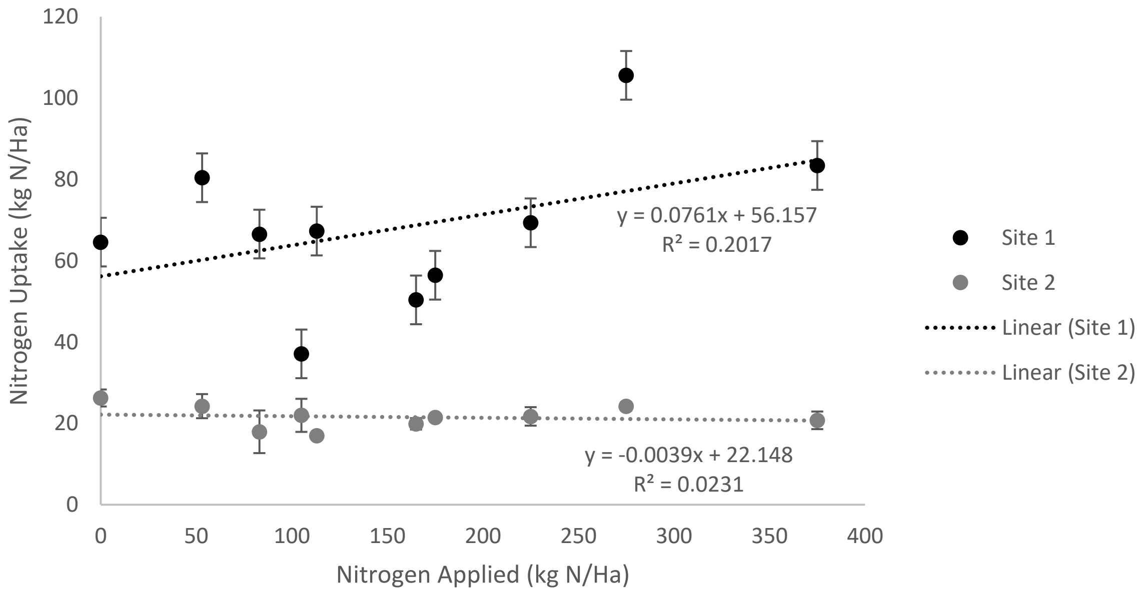

Figure 3. Nitrogen uptake per Ha based on combined leaf and stick samples from trials in the 2020 season.

2 Methods and Materials – 2021 Season

2.1 2021 Trial Design

Following the outputs of the 2020 trials, a number of changes were made to the experimental plan to maximise the potential of the trials to determine optimum N responses for rhubarb. Firstly, trials were adjusted to focus on testing the majority of N applications following the first harvest with applications of 0, 60, 120, 180, 240 or 300 kg N/ha made after the first pull. This approach was tested in two different scenarios – an small application of N (60 kg N/ha) either before emergence in the early spring (**Trial 1**), or after the second harvest to give total applications (**Trial 2**) of 0, 120, 180, 240, 300 or 360 kg N/Ha. This approach was developed in recognition that pre-emergence applications did not appear to have a significant effect in the 2020 trials, although given that data was only available for the first harvest in this season, the small pre-emergence application was tested to accommodate the potential for this to have an effect in subsequent harvests. In addition to the two trials above, a small extension trial was included to test the impact of autumn application to test whether this improved yield responses in the following year. In this scenario total N applications of 120, 240 and 360 kg N/ha were split into three equal applications in the autumn, and following the first and second harvests (**Trial 3**). The first autumnal application will be made in late 2021. A summary of the treatment regime is given in **Figure 4** below.

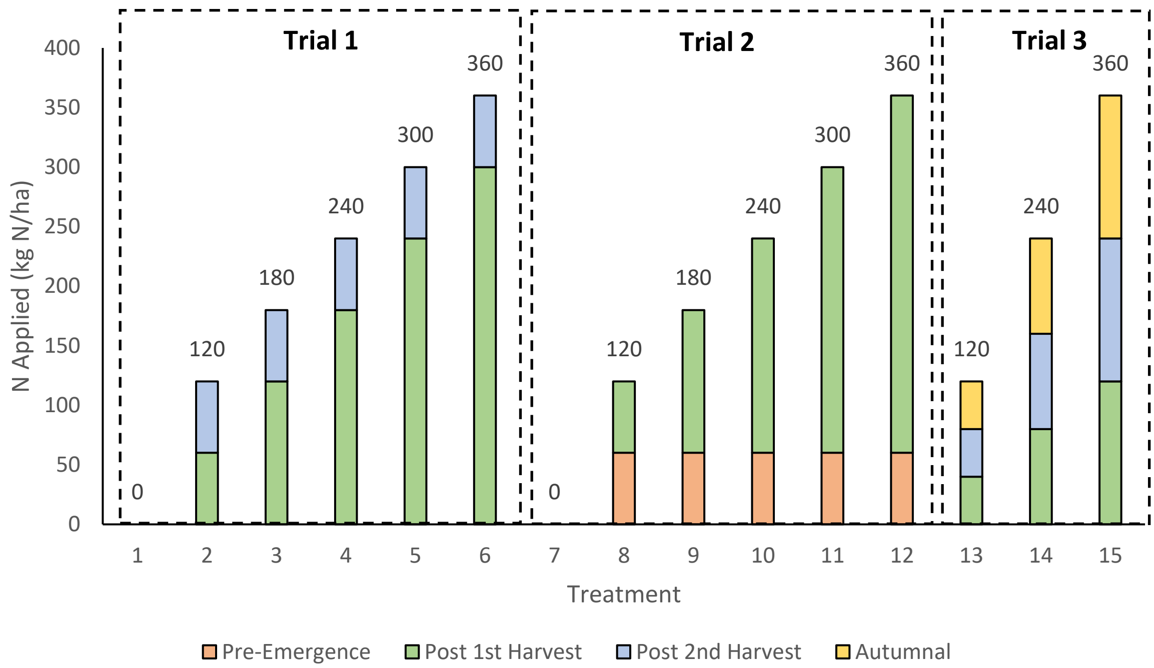

Figure 4. Summary of nitrogen treatments in the 2021 season.

Two commercial sites were selected for trial use. Site 1 in the 2020 trials (Barfoots Ltd.) showed high levels of variation in crown number and condition, and this was reflected in significant variation in yield outputs (see **Figure 3**). Climate differences between Barfoots Ltd. in Southampton and site 2 (T Hammond and Sons, Redhill) also impacted the ability to draw comparisons between treatments at each site. To address these issues, site 1 was relocated Hopefield Garm, Rothwell, with trials 1 and 2 due to be replicated at each site for assessment in crops to be harvested in the spring of 2021 and 2022. The Trial 3 autumn applications were made to one separate trial site at T Hammond only, covering an unpulled crop and a crop pulled in the late season prior to N applications. Mature plantations of the cultivar Timperley Early that had not been subject to a late harvest were used for trial activities. Rates applied at each stage from trials 1, 2 and 3 are given in **Table 1** and Error! Reference source not found. **2** below.

Table 1. Summary of treatments and timings for trials 1 and 2.

	Treatment Number	Application timing (kg N/ha)			Total applied (kg N/ha)
		Treatment 1 (Pre-emergence)	Treatment 2 (Post 1st Harvest)	Treatment 3 (Post 2nd Harvest)	
Trial 1	1	0	0	0	0
	2	0	60	60	120
	3	0	120	60	180
	4	0	180	60	240
	5	0	240	60	300
	6	0	300	60	360
Trial 2	7	0	0	0	0
	8	60	60	0	120
	9	60	120	0	180
	10	60	180	0	240
	11	60	240	0	300
	12	60	300	0	360

Table 2. Summary of treatments and timings for trial 3.

Treatment Number	Application timing (kg N/ha)			Total applied (kg N/ha)
	Treatment 2 (Post 1st Harvest)	Treatment 3 (Post 2nd Harvest)	Treatment 4 (Autumn)	
13	0	0	0	0
14	40	40	40	120
15	80	80	80	240
16	120	120	120	360

2.2 Site Selection and Trial Development

The trial used a crop of Timperly Early at both trial sites – the grower hosts ensured that both sites did not receive any N fertiliser, digestate or organic manure from autumn 2020 (with the exception of planned supplementary N applications for Trial 3 at site 2). Soil analyses obtained for both sites are detailed in the table below. Lime, phosphate and potash were applied as appropriate to ensure nutrients were not limiting. SNS indices at both sites were Index 0 (Table 3) at the start of the 2021 season before first fertiliser applications.

	Site	Soil Available N (kg N/ha)		
		0-30cm	30-60cm	60-90cm
Trial 1 & 2	1	20.2	14.2	13.7
	2	10.6	16.4	3.8
Trial 3	1	19.6	16.8	13.9
	2	9.6	9.7	7.2

Table 3. Average SMN results for trial sites.

The plots were marked out in March 2021 and measured 7 m x 3.8 m and consisted of four beds, with three replicate plots per treatment at each site. Plots were selected on the basis of even crown number and comparable soil conditions with the wider planted area. Four rows on either side of the trial area and 15 m either end will act as a guard to eliminate the edge effect. N was applied to the buffer areas to match the application rates of the non-trial areas of the field. The crops were managed according to standard commercial practice, including pesticide and nutrient applications (excluding of N tested in the trials above).

For trial 3, N was applied to plots laid out in the pulled and unpulled fields at site 2 in the first week of September 2020. Matching trials 1 and 2, individual plots of 7m lengths of 4 beds (3.3m) were used in a randomised block design, buffered by four rows between plots.

N applications for trials 1 and 2 were made as required, with the first application made during the first week of March 2021 (pre-emergence applications) followed by the first post-harvest application during the second week of April, and the second post-harvest application during the first week of June. Post-harvest applications were made before the regrowth of the subsequent crop. The autumn application for trial 3 is planned for August or September 2021 depending on crop condition and harvesting history.

Initial assessment of crown number and average buds per crown (determined by counting the number of buds in 12 crowns per plot) were also made at the start of the trials at each site. Crown samples were also collected for nutrient content analysis. The yield and postharvest assessments will be taken during the 2021 season.

To ensure that potassium (K) was not limiting, the host grower at each site applied 175 kg K_2O/ha. Soil sampling indicated that sufficient soil pH, P_2O_5 and magnesium was present at the start of the trial.

2.3 Harvest Assessments

Yield data for individual plots were harvested from the same six crowns each time in the central bed. Harvesting was done using commercial practice from a single harvest (see notes below relating to covid-19), with the leaves removed from the petioles. All the sticks were harvested per crown keeping each crown separate. The harvested leaves were bulked together to record the fresh weight per plot.

For each plot the following assessments were made:

- Number of petioles - Total
- Total Fresh Weight of Harvestable petioles
- Total Fresh Weight of Marketable/Unmarketable petioles

Marketable yield was measured as the number of petioles within marketable specification and then weighed to give weight of all marketable petioles. Sticks were considered marketable if the cut length exceeded 25cm, with a minimum diameter of 1cm, were free of significant bending/twisting and pest/disease damage. Petioles that did not meet the criteria were considered unmarketable.

2.4 Postharvest Assessments

Following each harvest, material was subject to a range of assessments to quantify quality. For measurements that are routinely appraised as part of commercial supply (e.g. length, dimensions) assessments were based on commercial specifications.

Five sticks were selected at random from each plot and subject to the following measurements:

2.4.1 Dimensions

Total length of the stick, additionally petiole width and depth was measured 5 cm from the snapped end.

2.4.2 Colour

Petiole colour is a key criterion for the marketability of rhubarb. Red pigmentation in the petiole fades as chlorophyll concentration increases, particularly near the top of the stick in green pull rhubarb. Measurement of colour based on visual assessment (e.g. categorical assessments) can be subjective. To avoid this, sticks were subject to assessment by colourimeter to determine stick colour against the L*, a* and b* axes (white-black, green-red and blue-yellow respectively). These parameters were used to calculate the colour index value using the equation 2000 x a*/L* x (a*2 + b*2)0.5. This approach was described previously by López

Camelo *et al*. (2004) to numerically quantify the green-to-red shift in tomato ripening, and given that a similar transition is seen in rhubarb, this approach was considered justified. A more positive colour index indicates a stronger red, while a smaller (or negative value) indicates increasing depth of green. L* a* b* values were taken using a Konica Minolta CR-400 Chroma Meter. Measurements were taken at three equidistant points along each petiole, with the first 5 cm from the snapped end to represent the top, middle and bottom measurement from the inside face of the petiole.

2.4.3 Biomass

Petiole biomass was recorded from the remaining crowns taking a 25% subsample, together with the leaves that were removed from the petioles at harvest time. Fresh and dry weight were recorded from these samples. Samples were dried for 48 hours at 80 ^{0}C. Dried samples were sent for foliar mineral analysis.

2.4.4 Statistical Analysis

Trial results were tested for significance by analysis of variance (ANOVA) using Genstat (VSN International, 2019).

3 Results & Discussion

All required applications and harvests have been made at the time of writing. Analysis is currently underway and will be completed for an industry panel meeting in the autumn of 2021.

4 Conclusions

At the time of writing no additional conclusions to those given in the SF 172 2020 annual report.

5 Acknowledgements

Thanks are due to Neil Cairns, Lindsay Oldroyd, Phillip Lilley and Robert Tomlinson, and for Richard Weightman and Clive Rahn for their support of this project.

6 References

7 Appendices