Project title:	Developing Nutrient Management Recommendations for Rhubarb
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Project leader:	Angela Huckle, ADAS Boxworth
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Date project commenced:	1 April 2019
Date project completed (or expected completion date):	31 March 2023

DISCLAIMER

1 Contents

1. Grower Summary

1.1 Headline

- Rhubarb crowns are likely to contribute significant amounts of nitrogen for early season growth, particularly before the roots and leaf canopy have developed.
- Whilst this may reduce the impact of pre-emergence applications, it will be necessary to ensure sufficient nitrogen is present when developing crowns exhaust internal reserves and become increasingly reliant on new nitrogen from the soil – particularly in conditions where nitrogen uptake is likely to have been limited in the previous season.
- Whilst no clear nitrogen response has been demonstrated in the trials to date, minor trends indicate that optimum nitrogen applications are likely to approach 180 – 240 kg N/ha.

1.2 Background

The perennial nature of rhubarb creates a complex cropping system where optimisation of nutrient provision can be difficult. 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 Recommendations for rhubarb are significantly out of date and may not reflect current practice, such as the use of multiple selective pulls, or include references to practices that are no longer suitable (e.g. manure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. The recent increases in fertiliser costs are likely to provide further impetus for growers to optimise N applications to ensure that crop requirements are met to produce target yields whilst minimising the economic and environmental costs of application. In order to fully address this area, and to provide evidence to update RB209, project SF 172 was undertaken to explore the nutrient requirements of rhubarb over multiple seasons. The impact of covid-19 prevented a full season of treatments and harvests in 2020, and so research activities in the 2021 season are the first full year of this project. However, key messages from the 2020 season were incorporated in the trial design for 2021 (particularly reducing focus on pre-emergence applications) in order to maximise the relevance of the evidence produced to both commercial practice and the biological needs of the crop.

The work will address the following objectives:

1. To update information on nutrition and feeding for rhubarb
2. To determine whether additional N 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)

1.3 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 (Category A – Trial 1) or before emergence (Category B- Trial 2). In addition, the application of N in the late season was tested (Category C – Trial 3). A summary of application rates and timings are given in **Figure 1** and a summary of treatments given in Table 1 and Table 2 below, with background site information given in Table 3.

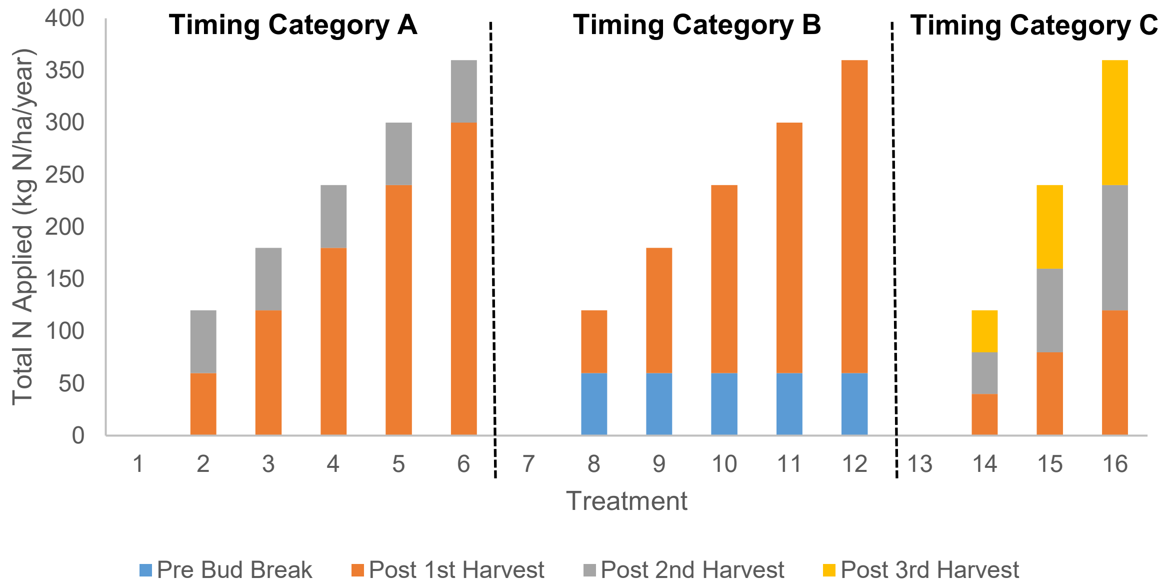

Figure 1. Summary of nitrogen treatments in the 2021 season.

Treatments were applied to replicated 3.8 x 7m plots at Hammonds Ltd. (site 1) and E. Oldroyds & Sons (site 2) as required in spring 2021, with three successive harvests at each site from March to September 2021. In addition to gross and marketable yield, samples were taken for biomass analysis to estimate total N offtake in the above ground parts of the plant.

Table 1. Summary of treatments and timings for timing categories A and B.

	Treatment Number	Application timing (kg N/ha) Treatment 1 (Pre-emergence)	Treatment 2 (Post 1st Harvest)	Treatment 3 (Post 2nd Harvest)	Total applied (kg N/ha)
Timing A	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
Timing B	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 timing category C.

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

Table 3. Average SMN results for trial sites.

	Site	Soil Available N (kg N/ha) 0-30cm	30-60cm	60-90cm	Total (0-90cm)
Trial 1 & 2	1	20.2	14.2	13.7	48.1
	2	10.6	16.4	3.8	30.8
Trial 3	1	19.6	16.8	13.9	50.3
	2	9.6	9.7	7.2	26.5

1.4 2021 Season Results

Whilst good crop development was seen at both sites, there was not a significant response to N application at either site, nor a significant response to timings of application (Figure 1, Figure 2). However, these data suggest that significant productivity can be seen even at 0 kg N/ha, especially for the initial harvests, which would indicate the sufficient N was available in the soil and in the crown reserves to fulfil N requirements for growth. However, there is a minor, non-significant trend which indicated that peak N response was being seen around 180 – 240 kg N/ha – this was due to a drop off in early harvests at lower N concentrations, whilst applications above this threshold either did not lead to a proportionate increase in yield or led to a minor reduction in marketability due to increased stick length above the required specification and (potentially) greening.

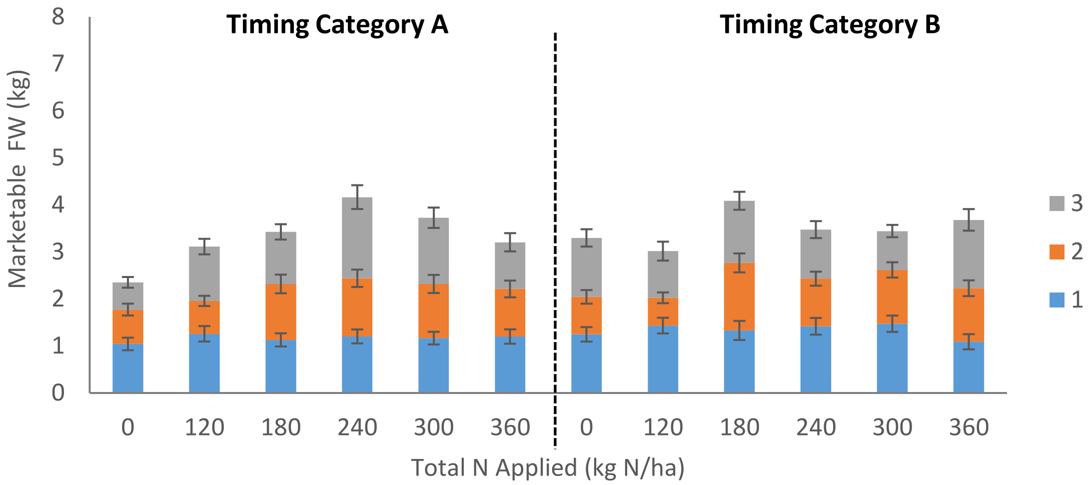

Figure 1. Marketable Fresh Weight per crown by harvest (Site 1)

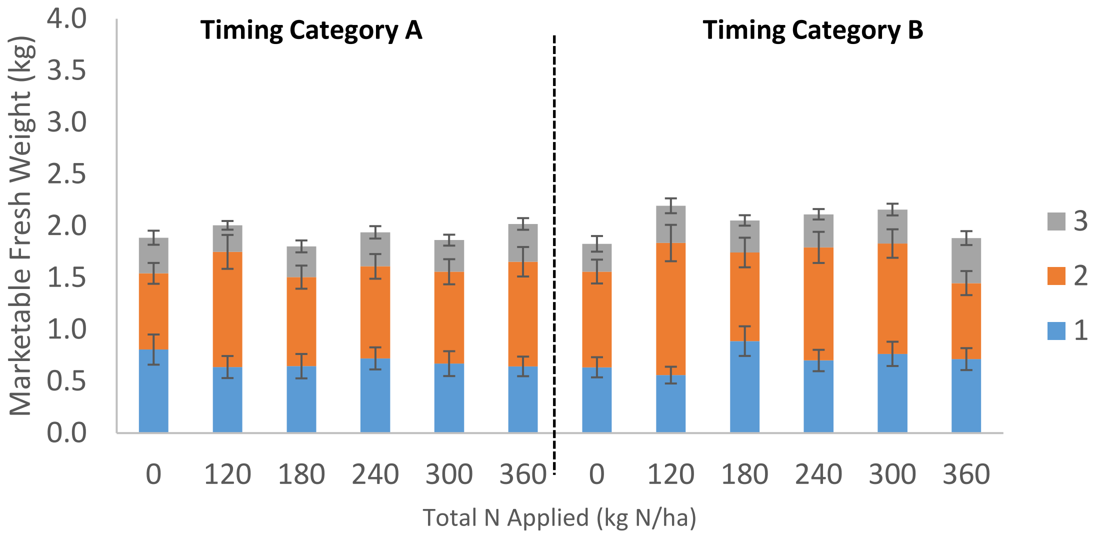

Figure 2. Marketable Fresh Weight per crown by harvest (Site 2)

1.5 Crop N Offtake

Similar to the yield outputs, crop N offtake did not show any significant response to N treatment (Figure 3, Figure 4), although a minor increase in offtake was seen at site 1 which appeared to plateau around the 240 kg N/ha mark, corresponding with the observations made from the yield data. Due to the high variability in the data it is difficult to draw any firm conclusions from these trials, although apparent trends are present which are to be tested in the final year of this project.

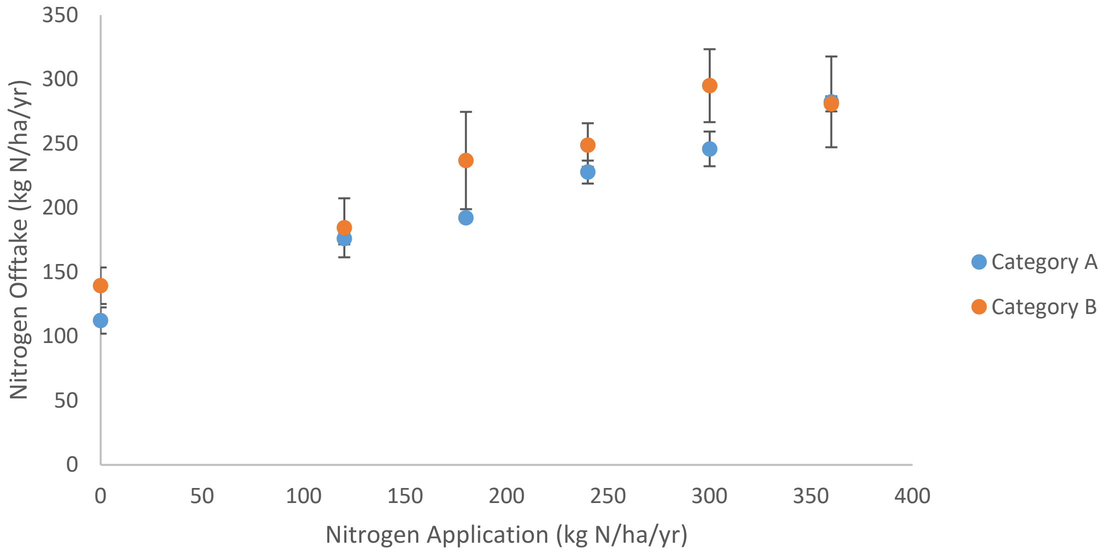

Figure 3. Total crop N offtake at Site 1.

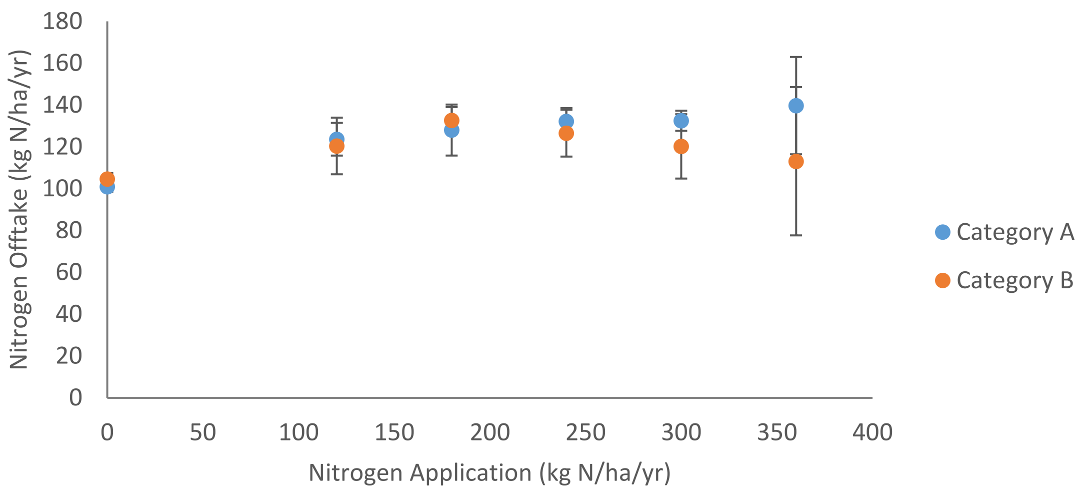

Figure 4. Total crop N offtake - site 2.

1.6 Updating RB209 Guidance for Rhubarb

A key theme emerging from the 2021 trials is the continued support for a significant crown contribution to early season N requirements of the developing plants. It is likely that nitrogen will be taken up in the summer months, stored in the crown (along with starches) and the utilised in the early spring for growth. The uptake and conversion of inorganic nitrogen is an energy-intensive process, so it would be most efficient for the crowns to utilise existing sources before taking up additional N from the soil. Crowns which have sufficient reserves are likely to see strong productivity in the spring, whilst those with less optimum reserves (either as a result of poor growth or through limited N in the previous season) may see reduced growth or heightened need for N in the following spring.

This aspect creates two additional complexities. Firstly, it means that the identification of optimum N requirements based on a single season of results is difficult given that the impact of the crown reserves cannot be separated from the new uptake from the soil. Therefore, it will be necessary to further appraise the impact of varied N treatment on the same crop at the start of the 2022 season to track inter-seasonal effects. Secondly, it means that determining optimum timings of N application (including evaluating the benefit of pre-emergence and post-harvest splits) is further complicated due the presence of internal reserves. However, given that a wide range of factors are liable to impact the timing of crown depletion, it may be advisable for growers to ensure that a minimal amount of N is applied earlier in the season to ensure this does not become limiting for subsequent growth.

1.7 Key Findings & Recommendations

- The rhubarb crown will contribute a significant amount of nutrients and resources to the first crop of the season using reserves built up in the previous summer. Act to maintain productivity and weed control to ensure strong full season growth boosts these reserves.
- While the crown will provide for early N requirements, small pre-emergence applications may be beneficial by ensuring that all N requirements are met when the crowns transition from internal to external N sources for later growth.
- Whilst further replication and testing is required to fully valid total N requirements, these results so far indicate the optimum N applications around 180 – 240 kg N/ha may maximise yields whilst preventing excessive applications.

2 Science Section

2.1 Introduction

The commercial rhubarb product is the immature petioles cut from developing leaves in the early to late spring which are produced from overwintered crowns breaking dormancy. Whilst this is a relatively niche crop occupying around 550 ha of land producing 12k tonnes annually, it is a high value crop with a farm gate value in excess of £17m (Defra, 2018). However, it is a complex cropping system for which optimum nutrient requirements are poorly understood with many of the resources available to growers of considerable age and may not be reflective of current practice or demand of modern cultivars. A survey carried out in year 1 of this project 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.

The volume and quantity of product harvested is dependent on a range of integrated factors including crown age, condition and available resources (sugars and nutrients) which will have been impacted by growing conditions in the previous season(s). Whilst evidence is scarce linking measurable crown condition and ultimate yield, it is likely that factors such as suboptimum nutrition, high weed cover or heavy harvesting may lead to reductions of yield in the following spring. Best practice for rhubarb production is further complicated by production in a range of areas, climates and soil types, the use of atypical nitrogen (N) sources (e.g. wool waste) and production approaches such as lifting crowns for forcing in temperature-controlled sheds for high-value early harvests.

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.

The first year of this project examined total N applications of 175, 275 or 375 kg N/Ha spilt between pre-emergence, post first harvest and post second harvest applications in spring 2020 (**Figure 5**). Due to the onset of the covid-19 epidemic only the first applications were made, although it was still possible to draw valid conclusions from the limit data accumulated.

No significant differences were seen in pre-emergence applications of 53 – 375 kg N/ha in terms of yield outputs, nor was there any impact on N offtake between treatments (Figure 6).

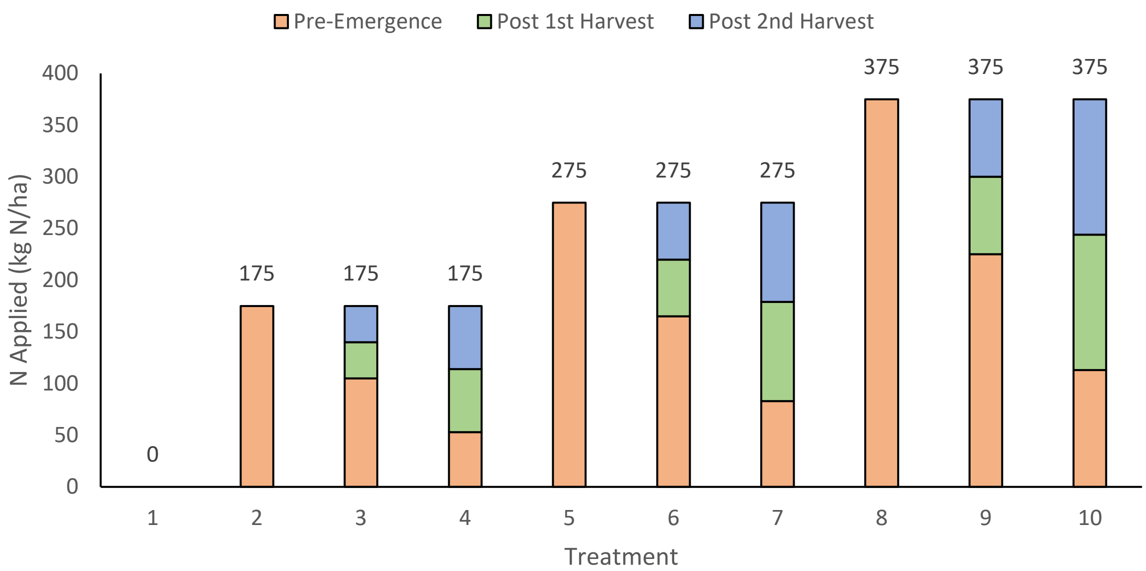

Figure 5. Summary of nitrogen application rates used in the 2020 trials. Total N applications (kg N/ha) are given with each treatment.

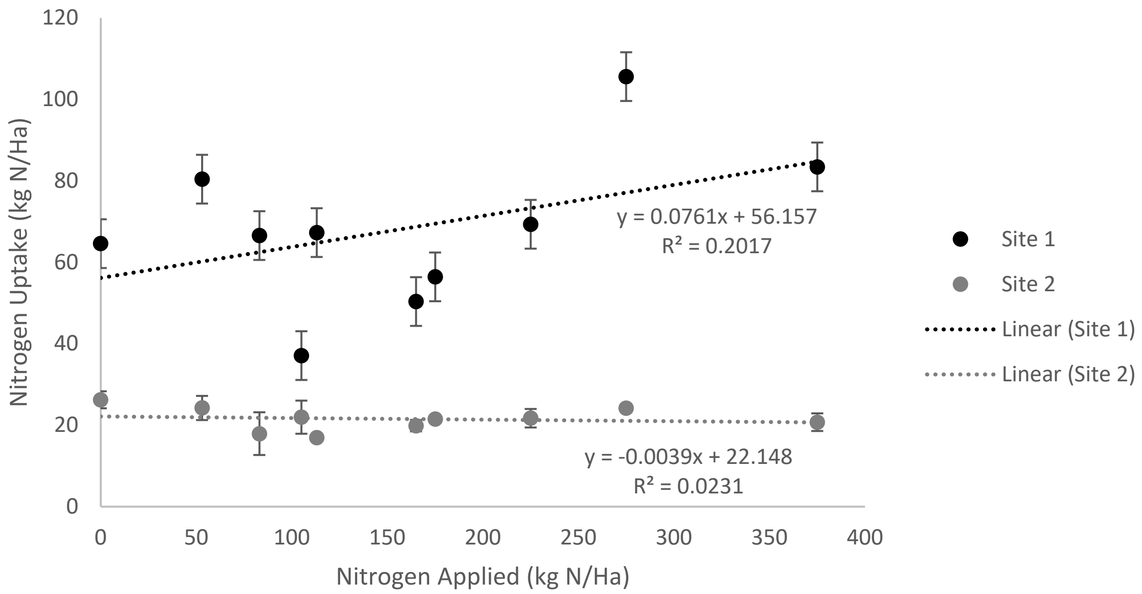

Figure 6. Nitrogen uptake per Ha based on combined leaf and stick samples from trials in the 2020 season.

These data would suggest that increases in pre-emergence applications of N do not directly contribute to increased yields or N offtake in that year. If pre-emergence applications are not having a significant impact on yields, it would imply that nitrogen utilised in early growth is already present in the crown rather than being sourced from the soil prior to emergence. This would correspond with the concept that the crown utilises pre-existing resources in the early spring, particularly when the roots and canopy are undeveloped limiting the acquisition of new resources from the soil. However, early applications may ensure that sufficient nitrogen is available for later growth to ensure strong yield returns, whilst many, small applications of nitrogen may promote wider offtake whilst reducing the risk of nutrient runoff. Furthermore, the availability of N in the early season may be of benefit for younger crowns or those which are weakened through insufficient uptake in the previous season. Therefore, trial direction was adjusted to examine crop N responses refocused on the postharvest periods although with small pre-emergence applications were included to test for any impact on later harvests not examined in the 2020 trials.

In addition, 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.

2.2 Project Objectives

This project has the following core objectives:

1. To update information on nutrition and feeding for rhubarb
2. To determine whether additional N 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)

3 Methods and Materials – 2021 Season

3.1 2021 Trial Design

Three separate trials were designed to test primary timing categories (Figure 7). Total N application rates of 0, 120, 180, 240, 300 and 360 kg N/ha/year were tested either with the majority of application following the first harvest followed by a small application (60 kg N/ha) following the second harvest (Category A – Trial 1) or with a small pre-emergence application followed by a majority post first harvest (Category B – Trial 2). A third trial tested equal applications following the first, second and third harvests (Category C – Trial 3).

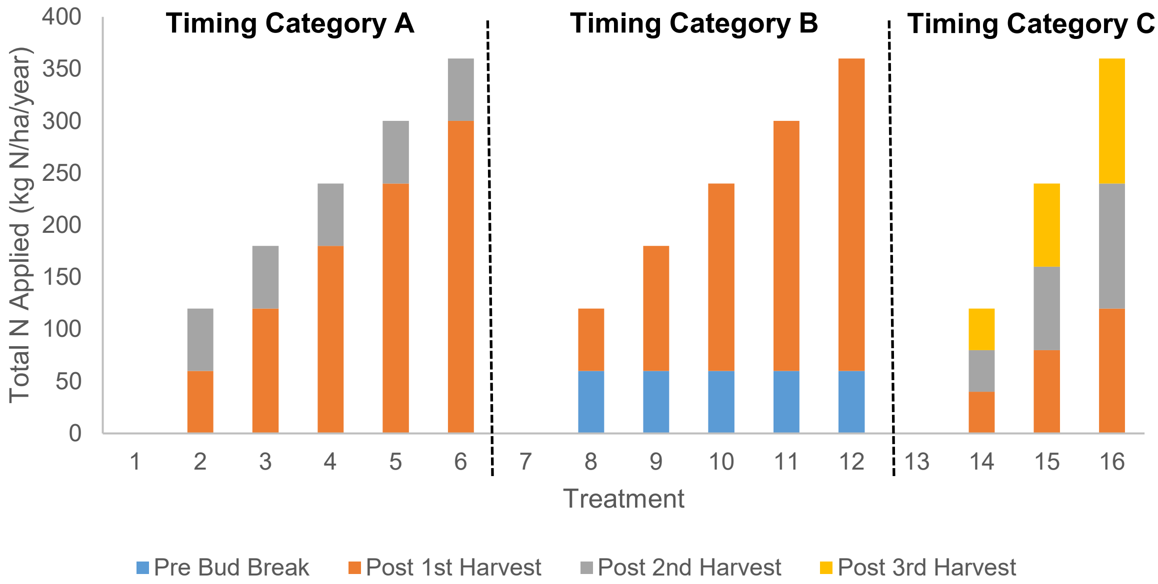

Figure 7. Trial approach for the 2021 season.

A breakdown of applications are given in **Table 4 below** and **Figure 7** above. Mature plantations of the cultivar Timperley Early that had not been subject to a late harvest were used for trial activities. Treatments were made to a randomised block design, with three replicate plots per treatment (**Figure 8**). Each plot was a 7 x 3.8 m area covering four bed rows, with harvests taken from a 5 x 1.9 m area – covering the central two beds.

In addition to the core trials, a small trial exploring the impact of a late harvest was carried out at Hammonds separate to the main trial. An area of cv. Timperley Early was set aside with a section pulled in early September prior to autumnal nitrogen application. This trial was to test whether late harvests had an impact on productivity in following spring, particularly through impacts on crown reserves, or whether later harvests could be taken without compromising yield.

Table 4. Summary of treatments and timings for timing categories A and B.

	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)	
Timing A	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
Timing B	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 5. Summary of treatments and timings for timing category C.

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

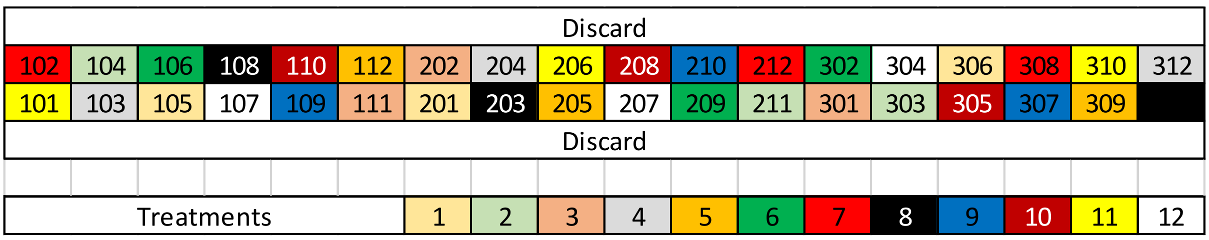

Figure 8. Randomised plot layout.

3.2 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. Images of both trial sites are given in Figure 9 below.

Table 3. Average SMN results for trial sites.

		Soil Available N (kg N/ha)			
	Site	0-30cm	30-60cm	60-90cm	Total (0-90cm)
Trial 1 & 2	1	20.2	14.2	13.7	48.1
	2	10.6	16.4	3.8	30.8
Trial 3	1	19.6	16.8	13.9	50.3
	2	9.6	9.7	7.2	26.5

The plots were marked out in March 2021 with initial assessments of active crown number and weed cover. 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. Applications were made at site 1 (Hammonds) 5/3/21 (pre-emergence), 21/4/21 (post first harvest) and 5/5/21 (post second harvest). At site 2 (Oldroyds) applications were made on the 8/3/21 (pre-emergence), 3/6/21 (post first harvest) and 9/8/21 (post second harvest).

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.

Figure 9. Trial sites mid-way between first and second harvest – Hammonds, 5/7/21 (left) and Oldroyds, 11/6/21 (right)

3.3 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 at each harvest, 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
- Number of Marketable 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 were also rejected if they were longer than 50cm or wider than 3.5 cm. Petioles that did not meet the criteria were considered unmarketable.

For trials 1 and 2 three harvests were completed at both sites as planned. However, in the interest of time constraints and budget only two harvests were taken for trial 3 at Hammonds, and one harvest of trial 3 at Oldroyds. Harvests at site 1 (Hammonds) were taken on the 13th April, 8th June and 6th August 2021. Harvests at site 2 (Oldroyds) were taken on the 6th May, 13th July and 27th September 2021.

3.4 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:

3.4.1 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.

3.4.2 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 at least 48 hours at 80 ^{0}C, or until there was no further weight loss from the sample. Dried samples were sent for foliar mineral analysis.

3.4.3 N Offtake Calculations

Dry matter samples of leaf and petiole were submitted to NRM for total N (% dry matter) on a per plant basis to allow estimation of total crop N offtake per ha.

3.4.4 Statistical Analysis

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

4 Results

4.1 Summary

Crop performance was good at both sites, and applications were made as planned. The results are discussed below for trial 1 and 2 (timing category A and B) for each site, followed by the additional trials – timing category C, and the unpulled/pulled trial.

4.2 Yield Responses

4.2.1 Site 1 – T Hammonds

The crop at site one showed a good level of consistency between plots, with strong growth in the crowns and an even first harvest in terms of stick and yield (Figure 10, Figure 13). On average there were 14.8 ± 0.33 active crowns per plot and target crown density in the field was 14.2 crowns/ha. Harvest figures are summarised in **Table 6**

Trial 1 – Majority N application after 1st harvest, small N application after 2nd harvest

There was no significant difference in gross stick number between treatments, varying between 42.1 sticks/crown(0 kg N/ha) and 65.2 sticks/crown (180 kg N/ha). Likewise, there was no significant difference in marketable stick number which varied between 24.5 sticks/crown (0 kg N/ha) and 38.4 sticks/crown (240 kg N/ha). The only difference approaching significance difference within Trial 1 at site 1 was for total gross stick number (p = 0.06). When viewed across treatments a minor trend is evident in both marketable and gross stick number, which showed a peak around 180 – 240 kg N/ha (Figure 10 & Figure 11).This was largely due to reductions in sticks harvest at the later harvests, especially the third harvest on the 6th August.

For yield, gross fresh weight varied between 3.3 kg/crown (0 kg N/ha) and 6.5 kg/crown (360 kg N/ha) (Figure 13). Marketable weight was greatest at 240 kg N/ha (4.2 kg/crown) and least at 0 kg N/ha (2.4 kg/crown) (Figure 14).

There was a small, but not significant, relationship between treatment and harvest. Marketable stick number was relatively equal between harvests at the first pull, although reductions in stick number at low N rates (especially 0 kg N/ha) at the second, and most notably, the third pull were demonstrated. It is also notable that marketable stick number declined at 360 kg N/ha (Figure 12) although this was largely due to sticks being outside of specification for length rather than a specific reduction in number. Fresh weight (both gross and marketable) was more consistent between treatments (Figure 15), although a similar reduction in the second and third harvests was seen at 0 kg N/ha compared with the other treatments.

Overall, there was no significant interaction between N treatment and yield output, although minor trends demonstrate peak N response around 240 kg N/ha.

Trial 2 – Small N pre-emergence application, majority N application after 1st harvest

Stick numbers were similarly comparable between treatments in trial 2. Gross number varied between 54.2 sticks/crown (0 kg N/ha) to 68 sticks/plot (240 kg N/ha). Marketable stick number was least at the 120 kg N/ha treatment (31.7 sticks/crown) and greatest at 240 kg N/ha (37.9 sticks/crown). Gross fresh weight yield was highest at 120 and 300 kg N/ha (6.7kg/crown) whilst marketable yield was greatest at 180 kg N/ha (4.1 kg/crown).

Similar patterns in stick number (both gross and marketable) were seen in trial 2 as trial 1, with a minor increase in stick number at 180 and 240 kg N/ha compared with the higher or lower doses (Figure 10, Figure 11). Gross and Marketable fresh weight yields showed more variation between treatments, with greatest yields seen at 120 and 300 kg N/ha for both gross and marketable yield (Figure 13, Figure 14). Similarly, when examined on a per crown basis, these is less of a clear response to N application changes compared with trial 1 (Figure 15) These data would suggest the lack of any significant trend, and that observed differences are reflective of natural variation between plots rather than as a direct response to N applications.

Table 6. Summary yield figures for Trial 1 and Trial 2 in total across the 2021 season – Site 1.

		Site 1			
	N Application (kg N/ha)	Gross Fresh Weight (kg/crown)	Marketable Fresh Weight (kg/crown)	Gross Number (sticks/crown)	Marketable Number (sticks/crown)
Trial 1	0	3.3 ± 0.6	2.4 ± 0.4	42.1 ± 5.6	24.5 ± 3.7
	120	4.7 ± 0.7	3.1 ± 0.4	58.4 ± 11.6	32.3 ± 4.4
	180	5.3 ± 0.7	3.4 ± 0.5	65.2 ± 8.7	35.5 ± 5
	240	5.9 ± 0.7	4.2 ± 0.6	61.3 ± 8.1	38.4 ± 5.1
	300	5.8 ± 0.7	3.7 ± 0.5	63.6 ± 7.7	35.8 ± 5
	360	6.5 ± 0.7	3.2 ± 0.5	62.1 ± 8.1	30.4 ± 4.4
Trial 2	0	4.2 ± 0.6	3.3 ± 0.5	54.2 ± 7.4	34.9 ± 5.3
	120	6.7 ± 0.7	3 ± 0.5	59.6 ± 8	31.7 ± 4.6
	180	5.5 ± 0.8	4.1 ± 0.6	63.5 ± 8.1	36.5 ± 5
	240	5.8 ± 0.8	3.5 ± 0.5	68 ± 8.5	37.9 ± 5.4
	300	6.7 ± 0.8	3.4 ± 0.5	67 ± 8.1	30.8 ± 4
	360	5.9 ± 0.8	3.7 ± 0.6	66.5 ± 8.6	34.7 ± 4.9

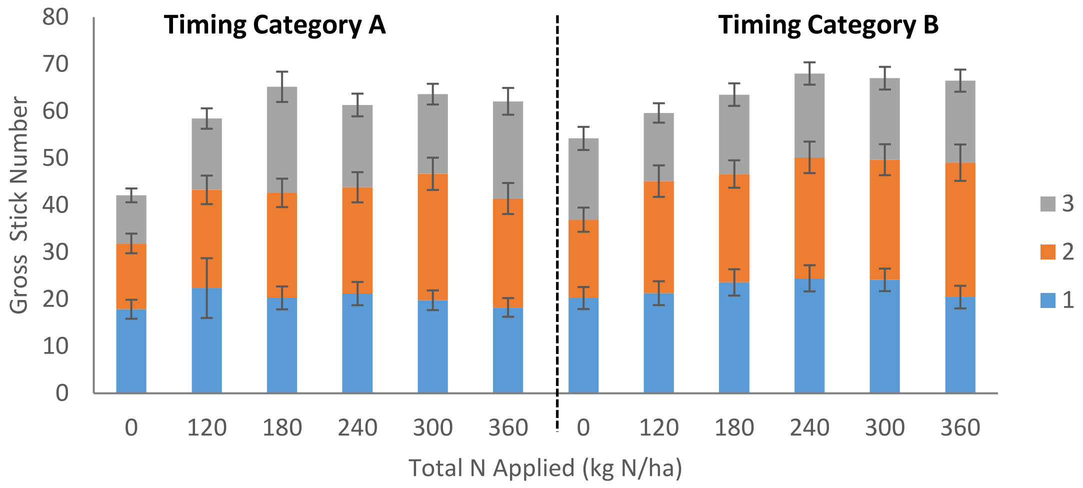

Figure 10. Gross stick number per crown by harvest (Site 1)

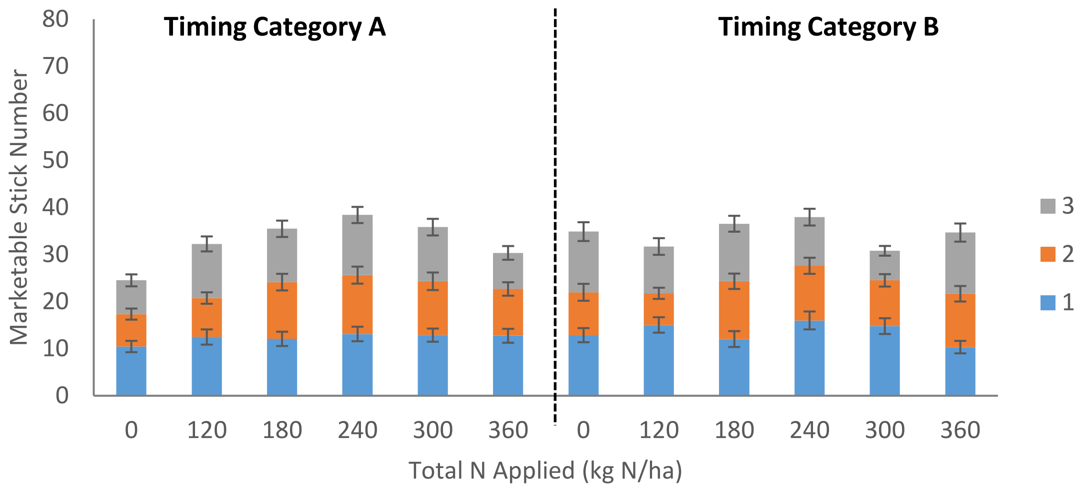

Figure 11. Marketable stick number per crown by harvest (Site 1)

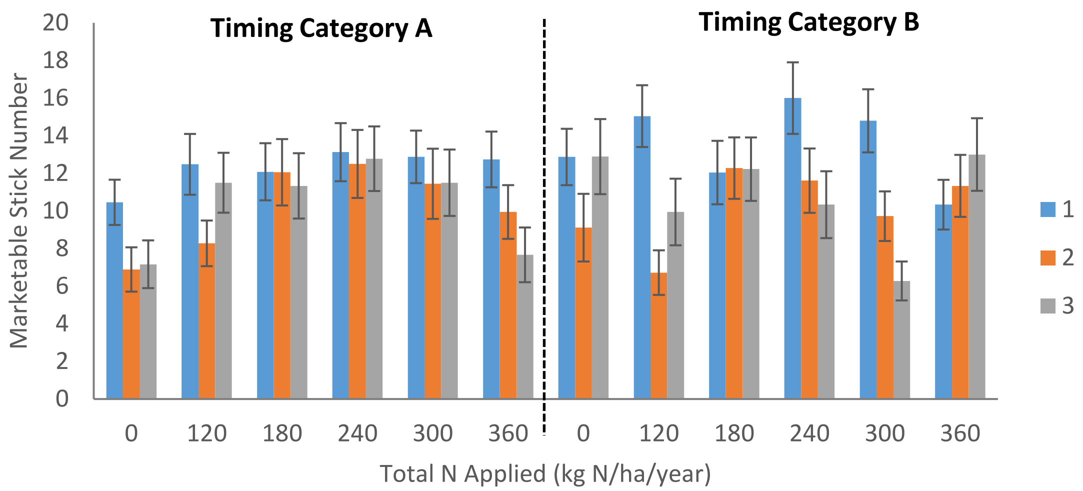

Figure 12. Marketable yield – sticks per crown by harvest (Site 1).

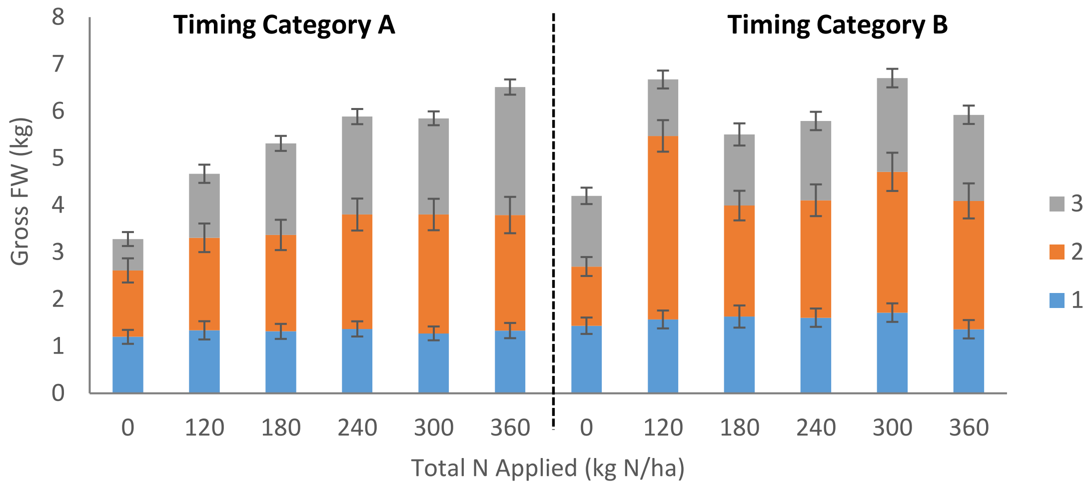

Figure 13. Gross yields per crown by harvest (Site 1)

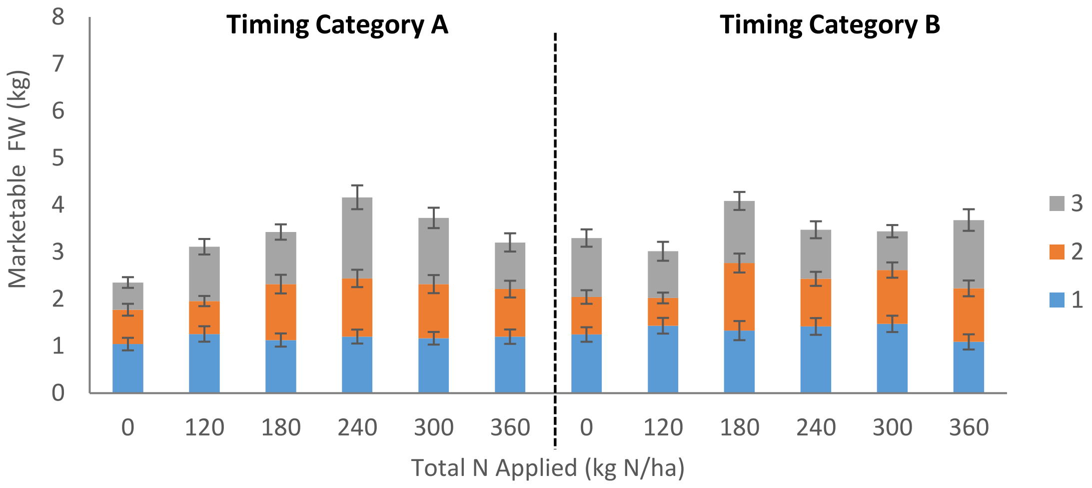

Figure 14. Marketable yields per crown by harvest (Site 1)

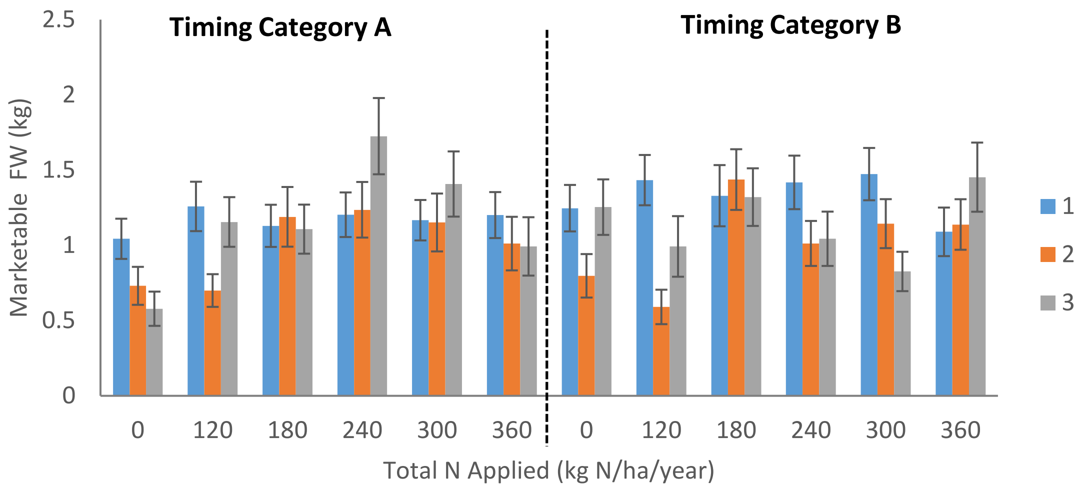

Figure 15. Marketable yields per crown by harvest (Site 1)

4.2.2 Site 2 – Oldroyds

Trial 1

The average number of crowns per plot was 14.8 ± 0.5, and the target field density was 13.6k crowns per ha. Crop condition was generally good, although the older crop showed slightly less uniformity compared with the crop trialled at site 1. Summary harvest results are presented in Table 7. The final harvest was taken later in the season (27th September) and the crop was starting to senesce, although later harvests are generally lower yielding compared with harvests in the earlier season.

Trial 1 – Majority application after 1st harvest, small application after 2nd harvest

Overall yield responses were relatively consistent between treatments according to all yield outputs. There was a slight reduction in gross stick number at 120 kg N/ha (33.1 sticks/crown compared with 39.9 - 43.1.1 sticks/crown across other treatments - Figure 16), although marketable stick number was consistent across all treatments (Figure 17). Marketable stick number was also relatively consistent between harvests (Figure 18), although there was a minor but non-significant reduction in stick number (especially for the second harvest) at 0 kg N/ha compared with the other treatments.

Trial 2 – Small N pre-emergence application, majority N application after 1st harvest

Yield responses in the second trial shows a more pronounced response to N application, although no significant differences were evident between treatments. Gross stick number was greatest at 180 kg N/ha (49.8 sticks/crown) (Figure 16), and marketable stick number was increased with greater N application which was greatest at 240 and 300 kg N/ha (32.7 and 30 sticks/crown respectively (Figure 17).

Gross fresh weight was greatest at 180 kg N/ha (3.2 kg/crown), and 300 kg N/ha (3.1 kg/crown) although there were no significant differences between treatments (Figure 19). Marketable fresh weight yields were much more consistent between treatments, although there were minor reductions at 0 and 360 kg N/ha compared with the other treatments (Figure 20). The reduction at 360 kg N/ha was largely due to an increase in oversized sticks rather than a reduction in total stick mass. When broken down by harvest, the second harvest was generally greater that the first or third harvest (Figure 21), although this is likely to be the long time gap between the first and second harvest (6th May – 13th July) compared with the third harvest (27th September).

Whilst the crop was relatively variable, and there were no significant differences between treatments, there are some minor trends that are evident when compared across treatments. When considering the relative proportions of the first and second harvests there appears to be a small increase in yield outputs around 180 – 240 kg N/ha at Timing Category B, particularly through harvested stick number. However, the lack of significance and high background variability makes it difficult to define any clear response to N application.

Table 7. Summary yield figures for Trial 1 and Trial 2 in total across the 2021 season – Site 2.

		Site 2			
	N Application (kg N/ha)	Gross Fresh Weight (kg/crown)	Marketable Fresh Weight (kg/crown)	Gross Number (sticks/crown)	Marketable Number (sticks/crown)
Trial 1	0	2.7 ± 0.5	1.9 ± 0.3	43.1 ± 5.8	26.9 ± 4
	120	2.5 ± 0.5	2 ± 0.3	33.1 ± 4.8	24.8 ± 3.6
	180	2.5 ± 0.4	1.8 ± 0.3	40.9 ± 5.5	26.6 ± 3.7
	240	2.7 ± 0.4	1.9 ± 0.3	39.9 ± 5.2	27.2 ± 3.7
	300	2.6 ± 0.5	1.9 ± 0.3	41 ± 5.6	26.8 ± 3.8
	360	2.8 ± 0.5	2 ± 0.3	41 ± 5.7	27.3 ± 3.7
Trial 2	0	2.6 ± 0.4	1.8 ± 0.3	39.9 ± 5.4	26.7 ± 3.8
	120	2.8 ± 0.4	2.2 ± 0.3	42.9 ± 5.9	29.4 ± 4
	180	3.2 ± 0.6	2.1 ± 0.3	49.8 ± 6.5	29.8 ± 4.4
	240	2.8 ± 0.5	2.1 ± 0.3	47.4 ± 6.2	32.7 ± 4.4
	300	3.1 ± 0.5	2.2 ± 0.3	47 ± 5.7	30 ± 3.9
	360	2.7 ± 0.5	1.9 ± 0.3	37.2 ± 4.8	24.5 ± 3.4

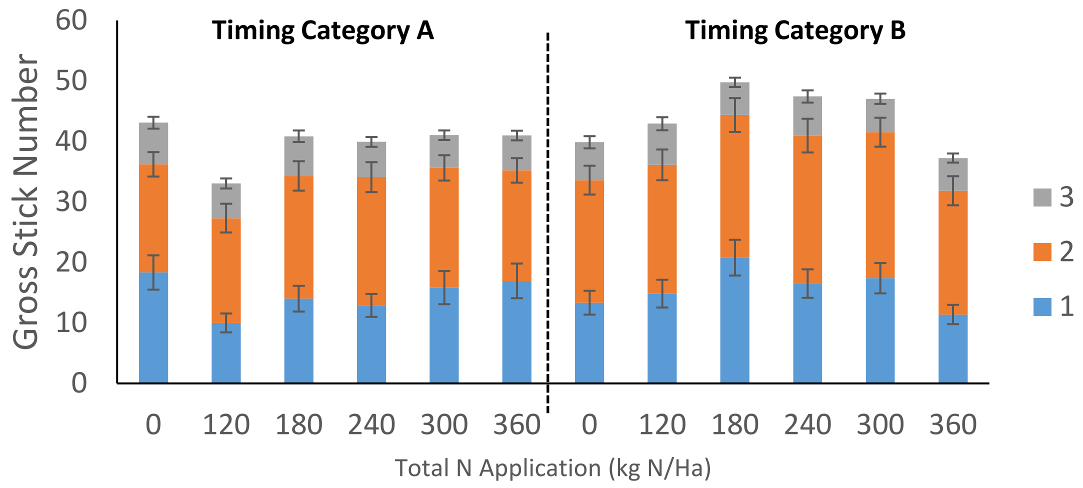

Figure 16. Gross stick number per crown by harvest (Site 2)

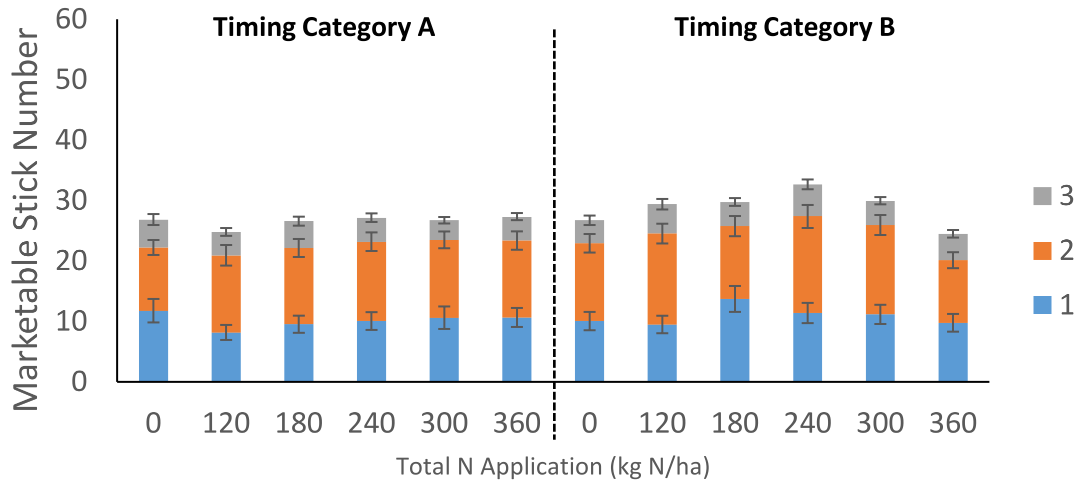

Figure 17. Marketable stick number per crown by harvest (Site 2)

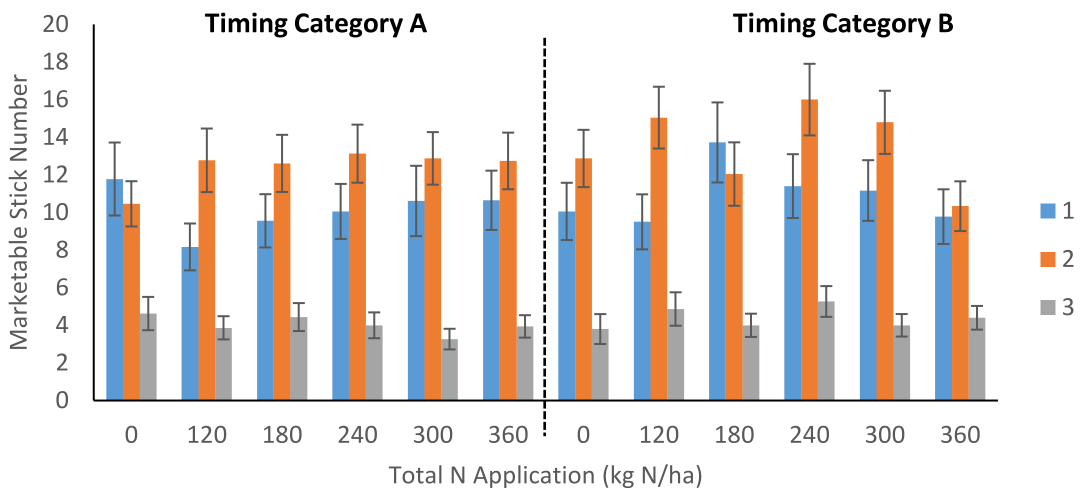

Figure 18. Marketable stick number per crown by harvest at site 2.

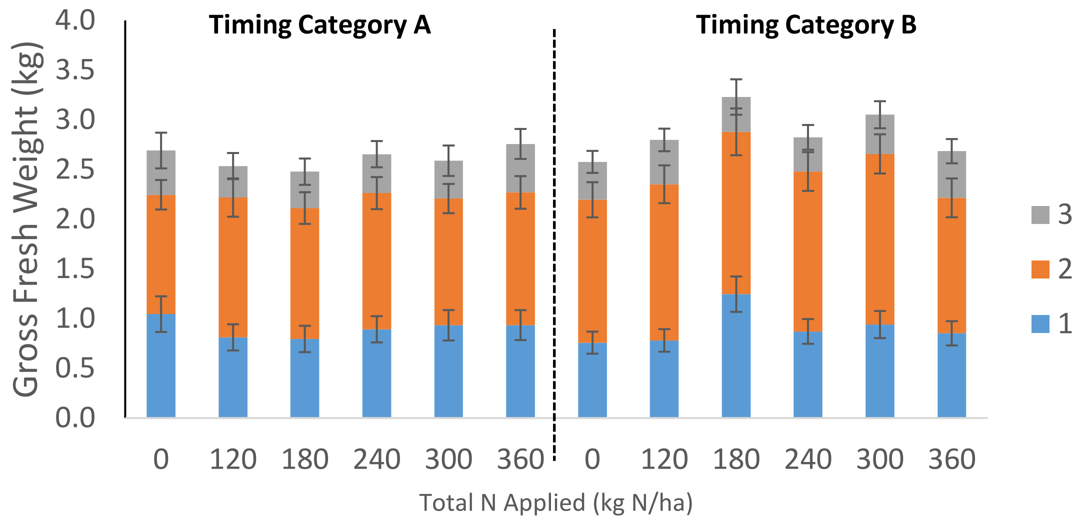

Figure 19. Gross Fresh Weight per crown by harvest (Site 2)

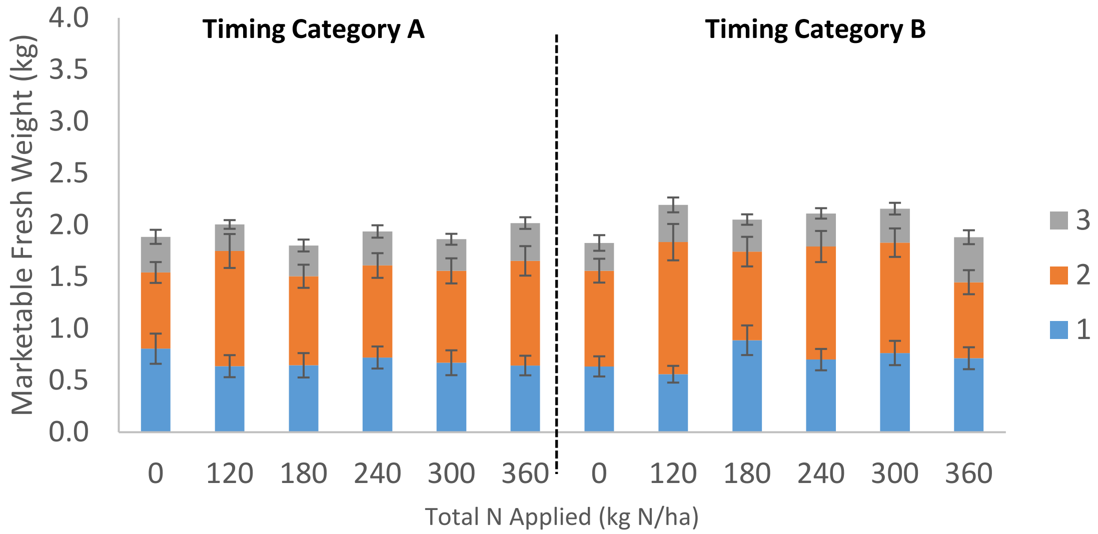

Figure 20. Marketable Fresh Weight per crown by harvest (Site 2)

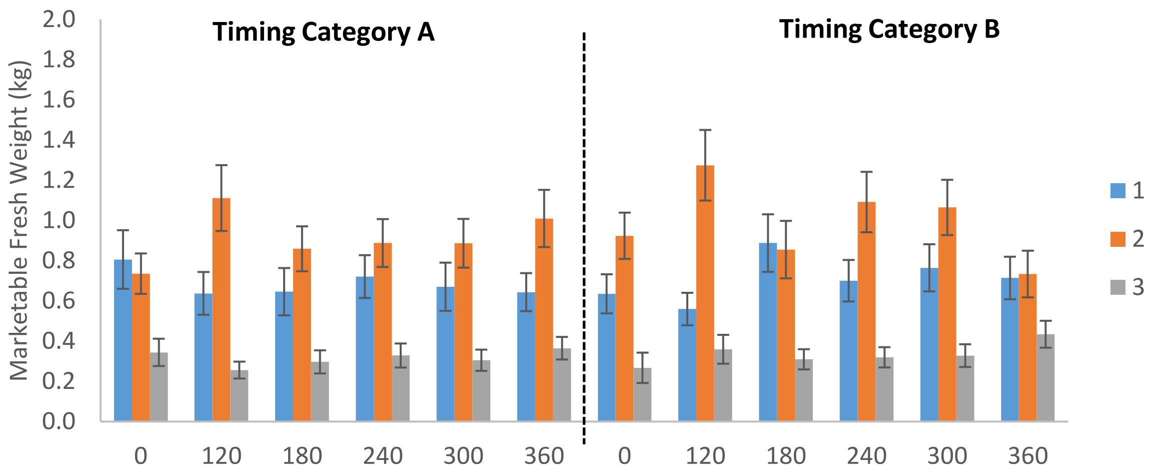

Figure 21. Marketable fresh weight per crown by harvest at site 2.

4.3 Nitrogen Uptake

Dry biomass samples were taken for stick and leaf portions to provide estimates from above ground dry matter content. Samples submitted for laboratory analysis were used to determine N content of dry biomass. When compared against biomass figures total crop offtake was calculated for each N application and timing category according to target field density assuming 85% establishment. There were no significant differences found in tissue N content between treatments at each site, indicating that allocations of N to the stick and petiole did not show variation between treatments, although biomass N figures were assessed on a per plot basis to ensure accurate estimation of crop offtake.

4.3.1 Trial 1 & 2

Site 1 - Hammonds

At site 1 there was a significant increase in N offtake with increased N application at both timing categories (Figure 22). Overall, timing category B showed a greater offtake compared with timing category A, although due to significant variation between plots the only N application at which this difference was significant was at 300 kg N/ha. These data suggest a substantial amount of N is removed from the ground, even at 0 kg N/ha application, which showed offtake of c. 110 kg N/ha although this was significantly lower than the greatest N offtake of 295 kg N/ha which was seen at category B applications of 300 kg N/ha.

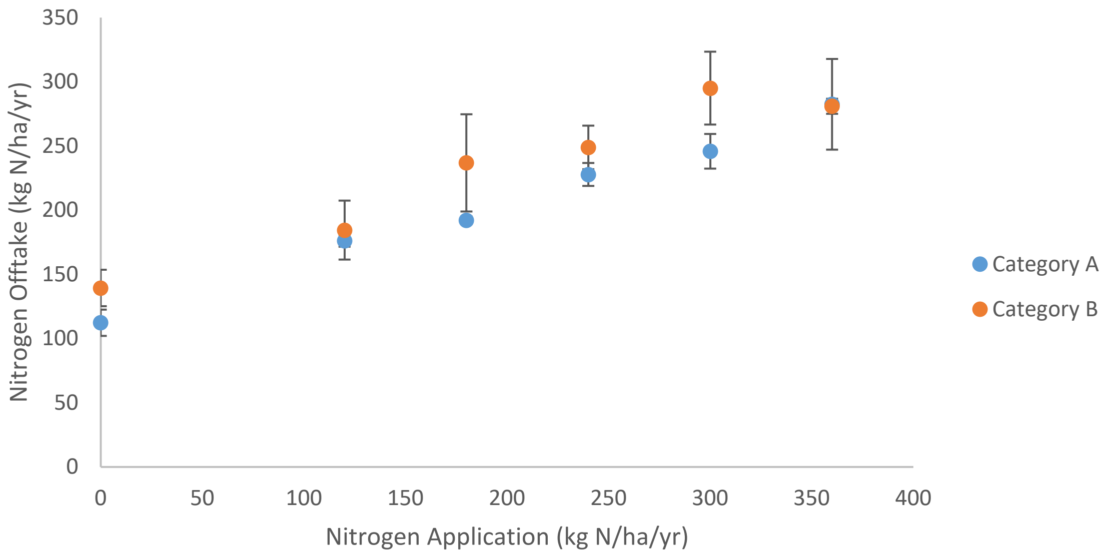

Figure 22. Total crop N offtake at Site 1.

Due to differences in the proportion of biomass removed at each harvest, the N offtake showed significant variation between the subsequent harvests (Figure 23). For the first harvest relatively equal N offtake was seen across treatments in both timing categories, mirroring the equal gross FW between harvests. For the second and third harvests the rate of N offtake showed a clear positive response in both timing categories. The even offtake for the initial growth would suggest that the plants are largely drawing on internal reserves in the crown and are not impacted by soil N availability. For later growth, especially for the third harvest, the plants are more reliant on external N sources and so are showing a greater response to soil N applications. Given the third harvest was taken in early August, this would be at a time when the plants are fully established with both good root and canopy development, unlike the first April harvest whereby early plant development will be limited meaning that the plants are more reliant on crown reserves.

When broken down by stick or leaf partition, the N offtake was consistent between treatments for the first harvest but showed significant variation with the second and third harvests (Figure 23). The relative increase in offtake to the leaf showed greater variation between treatments compared with the stick, especially at higher N applications. This would suggest that the greater N uptake at higher applications is being channelled into the leaves without impacting N content of the stick – this would correlate with the greening up of the leaf as increased leaf protein content. The more consistent offtake in the first harvest (and greater N response at the third harvest) would also correlate with the theory that initial growth is supplied with N from the crown while later growth utilises new N taken up from the soil. If initial growth was impacted by the availability of soil N then more variation would be seen in stick/leaf N offtake for the first harvest – as this is only seen in the third harvest it would imply that it is only later growth that is impacted by soil N availability which the plant is utilising to supplement depleted N stores in the crown.

Overall, these results suggest that a minimum of 80 kg N/ha is taken off, even without supplementary N application, from the soil with a background SMN 29.7 kg N/ha, indicating that sufficient reserves are present in the crown which are exploited at the start of the season.

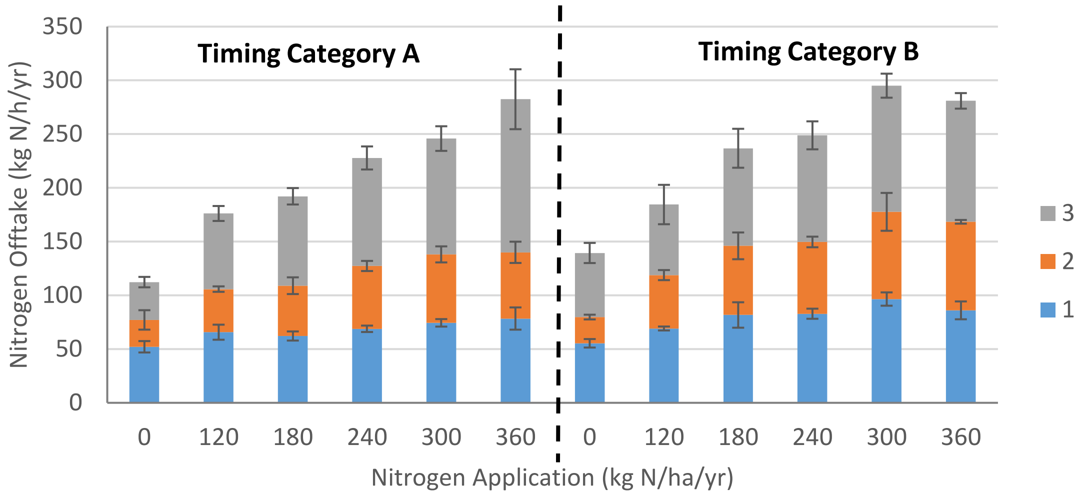

Figure 23. N offtake at site 1 by harvest.

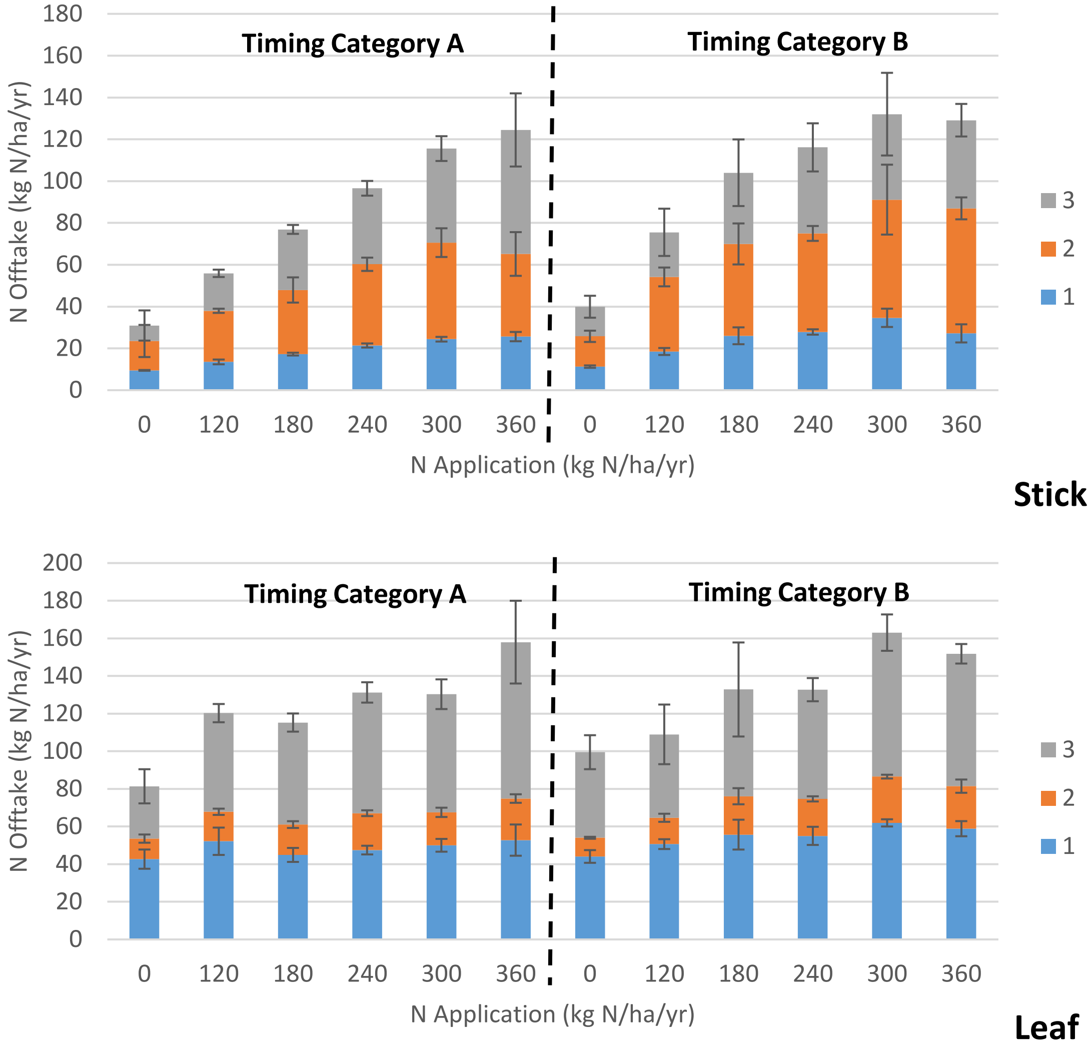

Figure 24. N offtake by leaf and stick partition by harvest at site 1.

Site 2- Oldroyds

N offtake at site 2 showed a more varied response than site 1. Whilst there were no significant differences between timing categories, there was a minor (non-significant) trend which showed increasing N offtake from 0 to 180 kg N/ha (Figure 25). After this rate there was a small apparent decline, although high variation at the higher N rates makes this hard to determine. However, these data suggest that a positive N response is seen up to 180 kg N/ha. A similar trend was identifiable when split between harvests, particularly within timing category B (Figure 26). Both the first and second harvest show a similar response to N application, with an uplift in N offtake which peats at 180 and 240 kg N/ha.

Both trials demonstrate a significant offtake even at 0 kg N/ha, replicating what was seen at site 1. This also suggests that early N is taken from reserves in the crown rather than utilising newly absorbed N, especially timing category B which includes small pre-emergence applications, and for the second harvest which would have seen large applications beforehand.

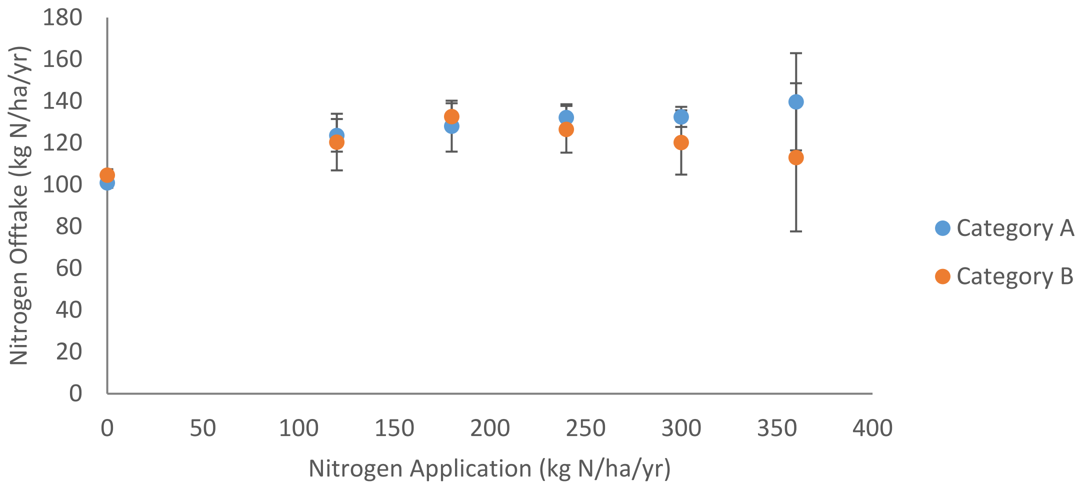

Figure 25. Total crop N offtake - site 2.

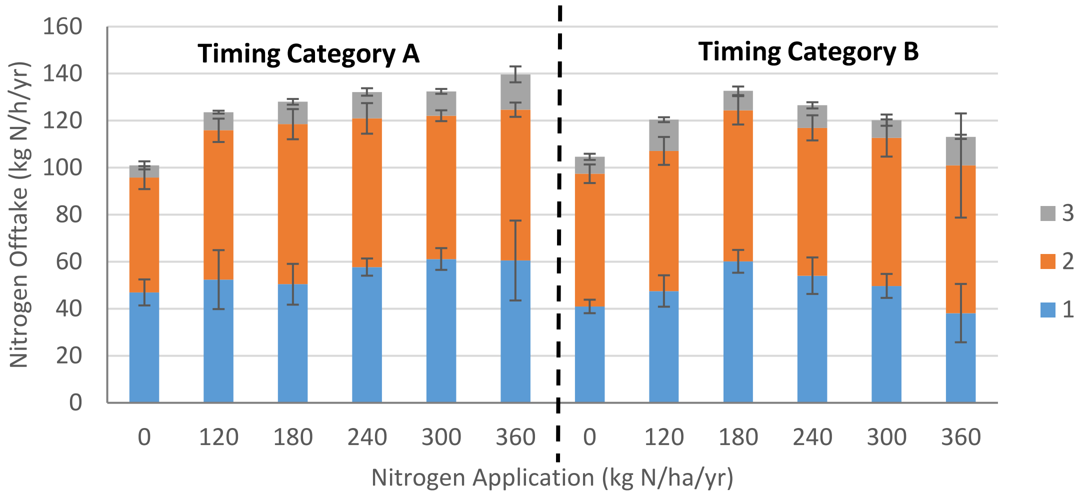

Figure 26. Total crop N offtake broken down by harvest – site 2.

When broken down by above ground partition, there is significantly greater partitioning to the leaf section relative to the stick compared with site 1 (Figure 27). This is most likely as a result of the later harvests at site 2 compared with site 1 – each harvest was roughly a monthly later at each site, meaning that a greater proportion of leaf was developed at site 2 compared with site 1. As canopy expansion and development of light capture and photosynthesis machinery will have been prioritised, there would have been proportionately greater investment in the leaf relative to the stick.

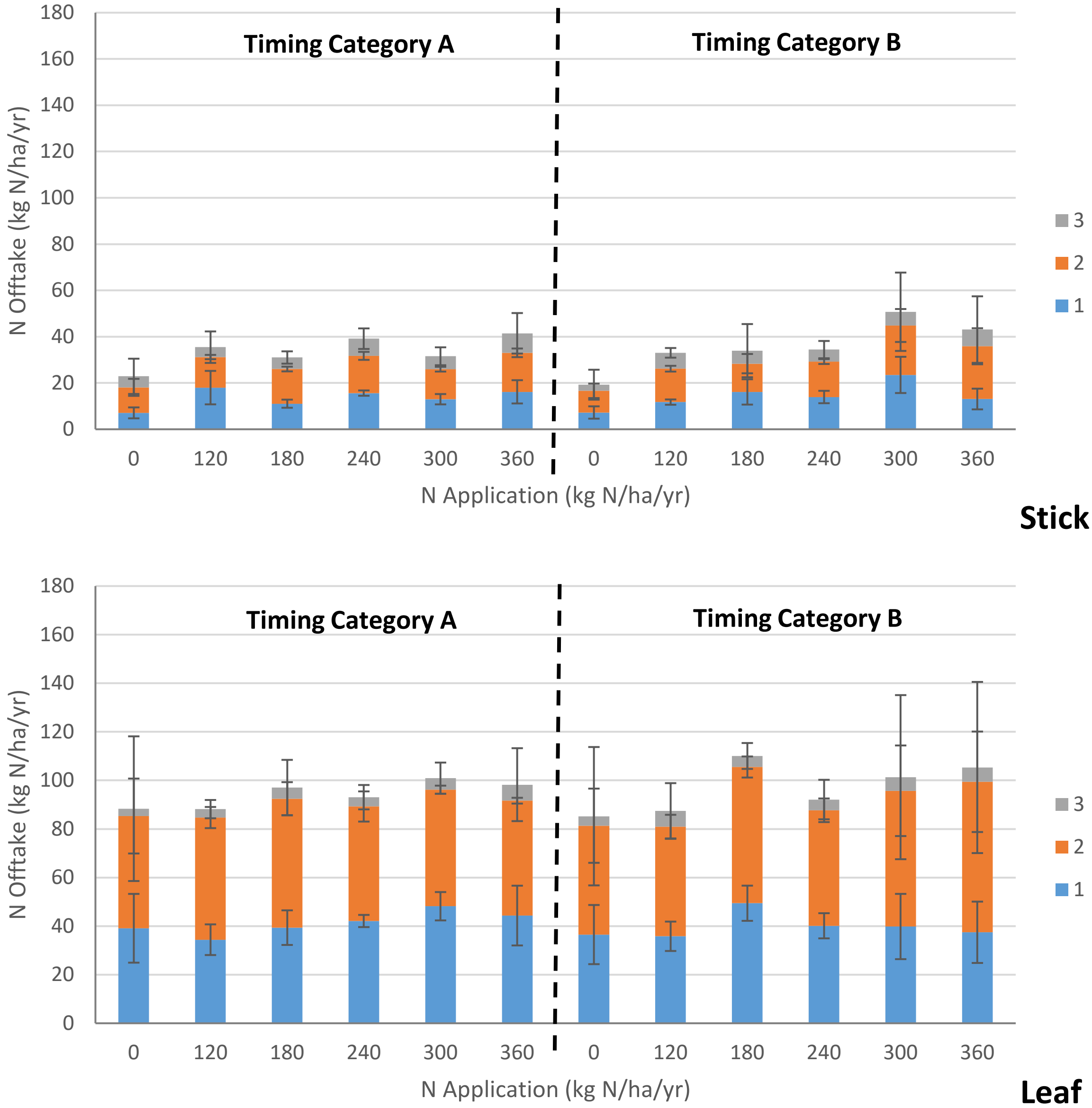

Figure 27. Crop N offtake broken down by over ground partition and harvest – site 2.

4.3.2 Timing Category C – (Site 1 – Hammonds Only)

Timing Category C was a limited trial testing 120, 240 and 360 kg N/ha split into three equal applications following the first, second and third harvests with no pre-emergence applications. This was carried out only at site 1, and results are available only from the later two harvests in June and August (which correspond to the main commercial harvest windows). Similar to the category 1 and 2 trials, background variation was high and there was no significant response to N response through either stick weight or number (Figure 28). Similarly, there is was no significant difference in stick quality between treatments (discussed below and presented in Figure 29 for comparison). As only limited harvest data is available N offtake cannot be estimated in a way that is comparable with the main trial data, although the muted yield response would indicate that it is unlikely that this treatment approach has had any significant impact on N offtake.

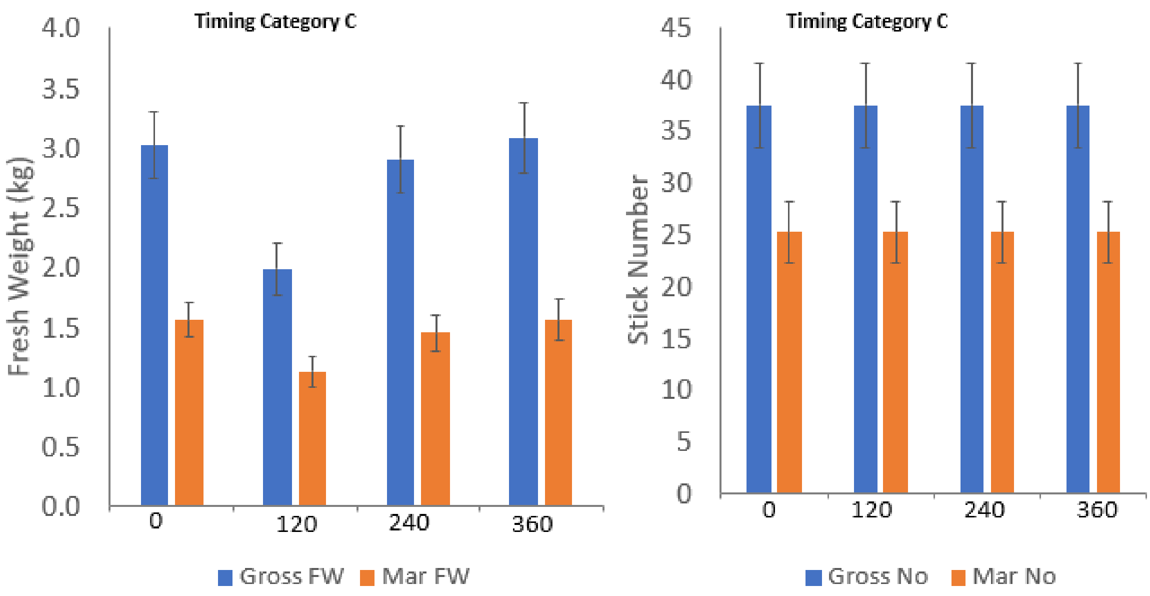

Figure 28. Yields from trial 3 (site 1) as expressed through gross/marketable yield and gross/marketable stick number

4.4 Yield Quality Measures

Stick quality was assessed through stick colour assessment of colour using a chromameter, with average colour values developed for each stick (Figure 29 and Figure 30). Average stick colour was highly variable between sites and treatments and shows no clear trend. Stick colour, whilst a key quality requirement for customers, is difficult to express on average as it is an integrated value along stick length. Furthermore, longer more mature sticks are more liable to green up giving a reduced colour value despite retaining strong red pigmentation at the base. Whilst there is no clear trend between N response and colour is demonstrated this is most likely as a result of difficulties assessing this aspect rather than the presence or absence of a specific colour response to N availability.

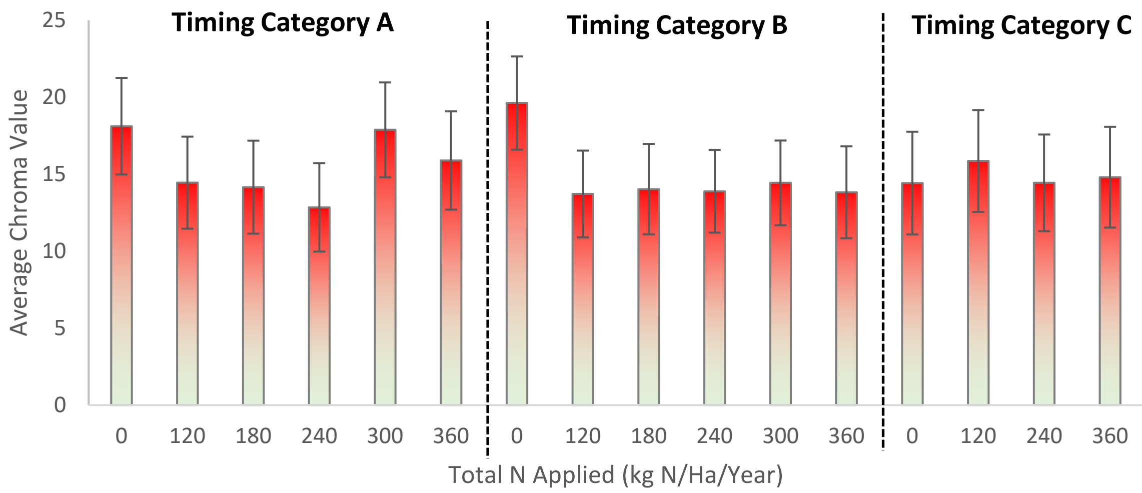

Figure 29. Average stick colour taken at site 1. A more positive chroma value indicates a stronger red colour of the stick.

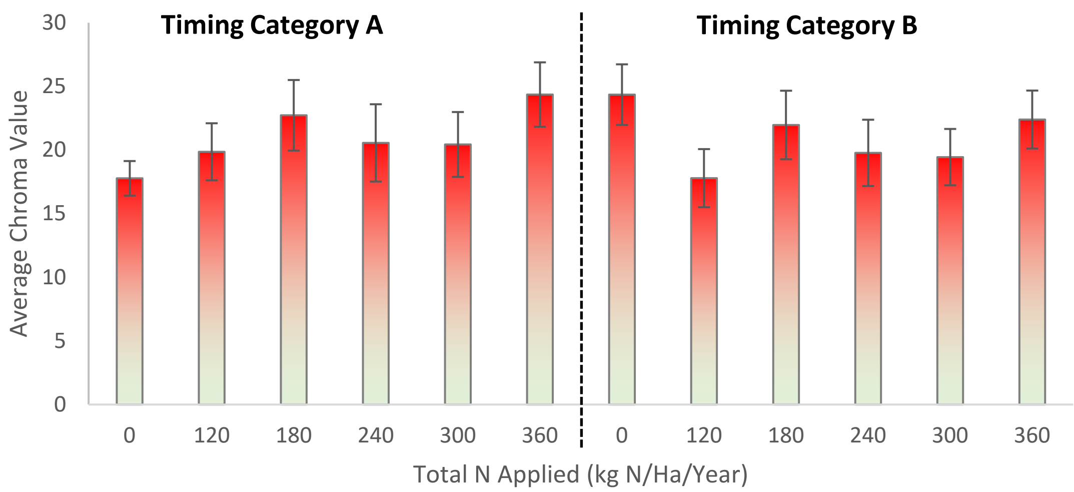

Figure 30. Average stick colour taken from the second harvest at site 2. A more positive chroma value indicates a stronger red colour of the stick.

4.5 Late Pulled vs. Unpulled Trial

The late pulled trial area showed a significant reduction in yield in terms of both gross and marketable FW, although this did not translate through to a reduction in gross or marketable number (Figure 31). A similar number of sticks indicates that bud inception was not altered, although a reduction in weight indicates that less reserves were available from the crown in the following spring as a result of the late pull. This also supports the concept that early spring growth is heavily reliant on the reserves of the crowns, and that weakness in conditions in the late autumn (including a harvest) would translate through to reduced yield performance in the following spring.

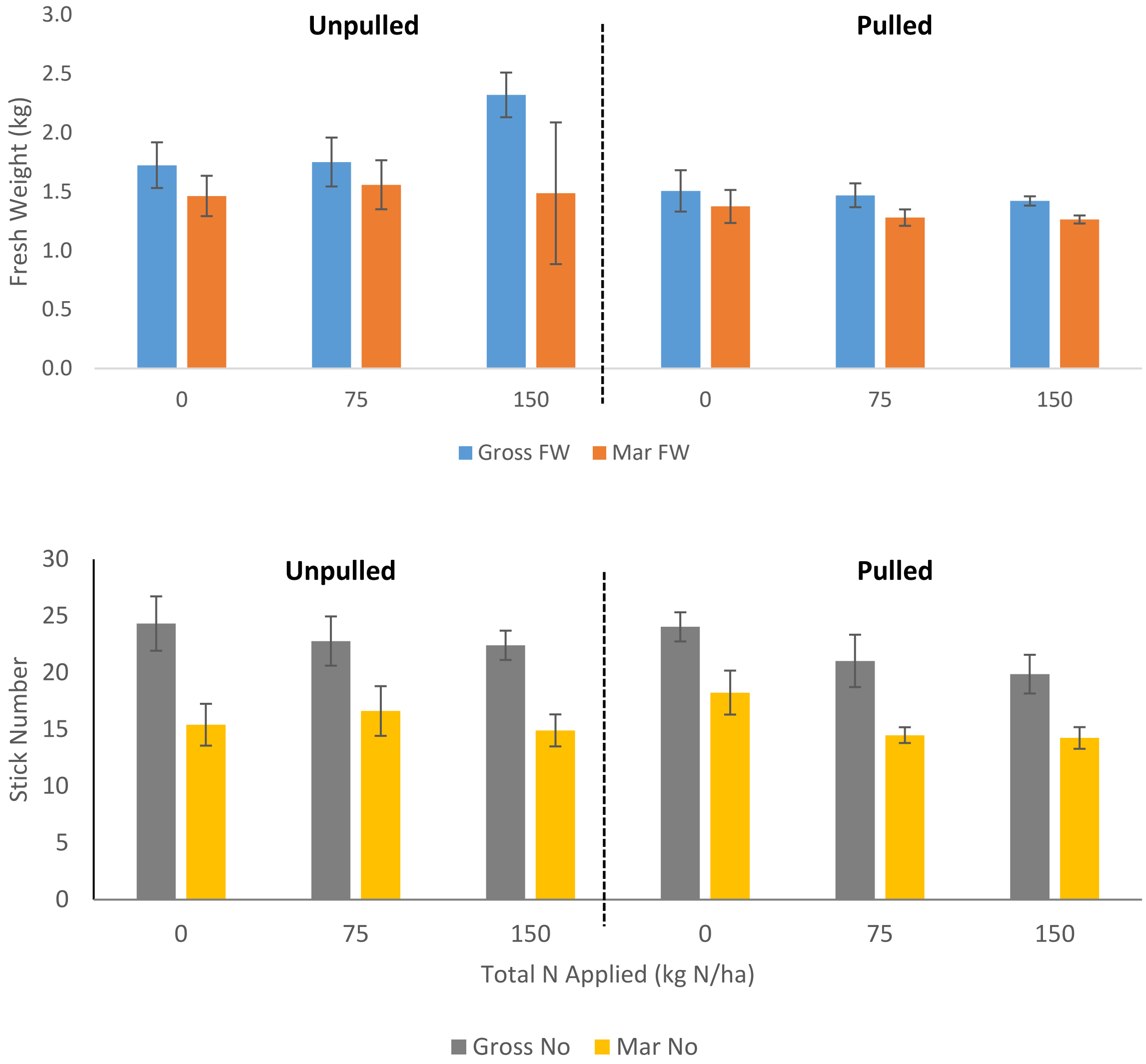

Figure 31. Yield performance from the pulled vs. unpulled trial at site 1.

5 Discussion

5.1 Crown Contributions to Early Growth

The 2021 trials represent the first complete set of trials for this project where both harvests and N applications were completed as planned. However, the general findings of the first year of this project coincide on the whole with the findings from 2022 which were based on a single harvest at the start of the season. Whilst N offtake was significantly different between sites (c. 24 – 26 kg N/ha vs. 37 – 105 kg N/ha) this range relatively corresponds with the first harvest offtake recorded in the 2021 season (c. 50 – 78 kg N/ha at site 1, 40 – 60 kg N/ha at site 2). However, in both the 2020 and 2021 trials there was no significant impact of total N application on N offtake for this harvest. Additionally, there was significant N offtake even at 0 kg N/ha application – for example, c. 120 kg N/ha was taken off soils with a background level of 48.6 kg N/ha at 0 kg N/ha application, indicating that substantial internal reserves of nitrogen are available to the crop (although this does include N offtake from later crops which may have utilised N cycling from leaves from the first harvest).

These data would suggest that early growth is heavily reliant on nitrogen reserves in the crown rather than the uptake of new nitrogen from the soil. Given the extensive development of the crown and storage of carbohydrates as an energy source it is likely that corresponding nutrients will be stored to support the new season's growth. *Bistorta bistoroides* (a close relative of rhubarb in the same botanical family) shows the accumulation of a nitrogen-rich amino acid in underground rhizomes, with increasing concentrations under "luxury" nitrogen levels for use as a nitrogen source during subsequent regrowth (Lipson *et al*., 1996). The uptake and conversion of inorganic nitrogen into organic forms is a multi-stage, energy intensive process whereby nitrate is transported to the leaves where it is reduced to ammonia before incorporation into amino acids (and ultimately) proteins. This process is very energy expensive, from the active uptake from the soil to reduction and synthesis in the leaves. Therefore, it would be more energetically efficient for rhubarb to uptake nitrogen from the soil during the summers months and complete the conversion to a form for storage when high light/temperature and development of the canopy and root system is at a peak rather than utilise energy reserves in the crown for new nitrate uptake in the spring – particularly before the canopy has developed before the first leaf flush.

While these data would suggest that pre-emergence N applications do not necessarily impact subsequent yield, there may still be some benefit from early spring applications – especially as there is anecdotal evidence from growers that harvests can be adversely affected where nitrogen applications are limited. Furthermore, without specific guidance as to when the transition from internal to external nitrogen reserves (e.g. when the crown is depleted), there is a risk that delaying N applications could lead to short-term N limitations on growth.

It is noteworthy that there is different response to nitrogen between the second and third harvests at the two sites. At site 1, a significant response in N offtake is seen with increasing N application, particularly at timing category B where total applied N (at the point of harvest) was greater due to the early small N application. However, at site 2 offtake during the second harvest was relatively consistent between treatments, except for a minor decrease at 0 kg N/ha. This would suggest that the crop was more responsive to N application (and less able to rely on internal reserves at site 1 compared with site 2 leading to the greater response. The third harvest at both sites shows a significant response to N application.

These data would suggest that the point at which a crown→soil transition in N reliance occurred between harvest 1 and 2 at site 1, and between harvest 2 and 3 at site 2. It is noteworthy that the transition at each site is not necessarily linked with point in the season – the second harvest at site 2 was a month later than site 1, although at this stage the crop was still utilising internal nitrogen reserves. The timing of this transition is likely to be subject to the influence of current season growth rates, the development of the canopy and available N in the crown (as impacted by the previous season's growth) and therefore may be difficult to predict with any certainty. As such, the use of a pre-emergence application may be of benefit to ensure that adequate soil N is available when the transition occurs.

An additional aspect not examined in these figures is the proportion of N stored from the previous season. Given that current practices may meet (or exceed) N requirements of the crop (see the literature review in the SF 172 2019 report) it is likely that the crops used for this trial had ample supplies of N in the previous season to ensure strong reserves for the following spring. However, under conditions where poor reserves are set aside – either due to weak crop growth or suboptimal N application – there is a potential risk that the crowns could be depleted sooner (and therefore require greater or earlier N applications) to ensure that sufficient yields are produced. Whilst this aspect will be tested in the final year of the project (as discussed below) the impact of the N status of the crown as bridging multiple seasons is likely to make determining the onset of crown N depletion difficult.

Overall, these results suggest that crowns reserves are likely to be sufficient to supply early N requirements, most likely until the canopy and root system have developed to the point at which new uptake of N from the soil can be carried out at sufficient pace. Whilst applications of N before this point may be unrequired, the need to ensure sufficient soil reserves are in place is likely to continue to promote early N applications, particularly where growth in the previous season is likely to have limited N uptake and storage reducing the availability of reserves in the following spring.

5.2 Effect of Application Timing

In terms of yield outputs, the use of alternative timings (favouring either pre-emergence or postharvest applications) has not had a significant effect on yield at either site this season. At site 1, both application timings showed relatively comparable trends in response to N application although high variability between treatments make identification of even minor trends difficult. At site 2, however, timing category B (postharvest applications only) showed a more positive response to N application that timing category A – particularly at the second harvest – although only in a minor way. This data could suggest that a greater response to N will be seen when applied earlier in the season, and this matches with observations at the site that areas that did not receive early N applications showed reduced yield. It is also noteworthy site 2 also had significantly greater N offtake in the leaf partition, particularly at the third harvest in September. This means that overall N cycling from cut leaves may be have been reduced as more was present in the canopy, increasing the reliance of the crowns on soil N. However, given that the crown is liable to provide an early buffer of stored N the timing of N applications may be less relevant than the total applied – particularly in crops where growth in the previous season has been strong and the crowns have ample stores to promote early season growth.

5.3 N Requirements

Overall, results from this season have demonstrated that that there has not been a significant correlation between N response, yield output or N offtake. However, given that significant N offtake has occurred even at 0 kg N/ha treatments, it is likely that the crop requires significant amounts of N to achieve target yields. Given that the crown is likely to provide a burst of N for early development, it would be necessary to look at N applications over multiple seasons in order to fully appraise N requirements over the lifespan of the crop. Whilst this will be addressed in trials in the 2022 season (as discussed below) it is difficult to provide specific guidance at this point for N requirements for rhubarb. However, minor trends across both sites indicate that peak response may fall between 180 – 240 kg N/ha given that responses have levelled out at this stage. Furthermore, increases in gross stick number and weight which have not translated through to marketable outputs (most commonly as a result of oversized sticks) this would imply that applications beyond this level may approach “luxury” levels of N application whereby increased leaf matter is seen without a proportion increase in marketable yield, reducing nitrogen use efficiency. However, given that high N availability in the summer may feed forward into the early spring growth, some level of “luxury” availability may need to be achieved beyond replacing that taken up by the leaves and sticks – especially in conditions where cycling of N from cut leaf material is reduced (e.g. dry weather).

6 Conclusions

Results from the 2021 season have confirmed earlier findings that there is likely to be significant contributions from the crown for early growth rather than relying on external sources for new uptake. This means that pre-emergence applications may be less likely to have a positive effect than applications later in the spring after initial harvests. However, as it is likely to be difficult to identify the point at which crown reserves are depleted (which may vary in response to conditions in both the current and past season), and to mitigate the risk of weak crowns, some early applications may be beneficial. Furthermore, whilst we have been unable to demonstrate a clear response between N application and yield, these data would suggest that optimum applications are around 180- 240 kg N/ha although this will require further testing in order to full appraise the validity of this figure.

7 Plans for the 2022 Season

A key activity for the 2022 season will be the collection of a single limited harvest from the trial sites used in 2021. This will enable tracking of yield outputs from the various N treatments into a second year to test for any further response. This will be particularly beneficial in identifying any suboptimum N applications which have reduced yields in subsequent years due to offset in the first season by the crown reserves.

In order to further test the N response of rhubarb, aspects of the 2021 trial will be repeated for a second year. This will only be carried out at a single site to maximise focus (site 2 from the 2021 season), and will be limited to total N applications at 0, 120, 180, 240 and 300 kg N/ha as this is most likely to cover the range of which N applications are optimum. Timing category A and B will be used for these treatments, in addition to replication of timing category C. However, treatments here will be rationalised to 60, 180 and 300 kg N/ha to ensure parity with the category A and B trials. Harvest data will be collected over three harvests in 2022, followed by a single harvest in spring 2023 to allow validation of any interseasonal effects on N offtake.

8 Acknowledgements

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

9 References

Lipson, D. A., Bowman, W. D., & Monson, R. K. (1996). Luxury uptake and storage of nitrogen in the rhizomatous alpine herb, Bistorta bistortoides. *Ecology*, *77*(4), 1277-1285.

10 Appendices