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Updating nitrogen and sulphur fertiliser recommendations for spring and winter oats

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1. Abstract

A review of RB209 in 2016 highlighted the need for additional research on winter and spring oat fertilisation. It was emphasised that there were insufficient data available to derive robust nitrogen (N) recommendations for winter oats, but trends in the data available resulted in recommendations increasing by 40 kg N/ha for all SNS indices and soil types. However, N recommendations have not been updated for spring oats for many years due to no recent data being available. There were also no data regarding N timing application for winter or spring oats, with current winter oats advice being consistent with that of wheat. The lack of current, accurate information for oat agronomy alongside an increasing demand for oat products prompted this project to be commissioned by AHDB in 2018.

The aims of this study were to provide advice on the most appropriate nitrogen rates and timings, plus sulphur applications to optimise yield and milling quality of both winter and spring oats. This was addressed by carrying out analyses of previous data, gathering information on current oat agronomy and carrying out multiple nitrogen rate and timing experiments throughout the UK on winter (East and West Midlands) and spring oats (East Anglia and Scotland) across three harvest seasons.

Analysis of a database comprising data generated before the current project evidenced current N recommendations appear too low for winter and spring oats. This was supported by the results from the spring oats N rate trials, which indicated that current RB209 N rate advice could be increased above current recommendations where good moisture availability means that yield potentials are high. However, a site's likelihood of lodging should be taken into account. The winter oat N rate trials in Herefordshire suffered from high lodging prevalence, resulting in a low optimum N rate, whilst Nottinghamshire trials suffered from dry springs on sandy soils. Variety differences were evident but generally there were no significant interactions with N so optimum N rates were the same. The spring oat N rate trials in Fife, Scotland were high yielding, whilst yields were constrained by the lack of moisture in the Cambridgeshire site. Increasing N application above current RB209 N rate advice maintained high kernel content and ease of dehulling (hullability) in both winter and spring oats. However, depending on variety, specific weight can decrease, and screenings increase at higher N treatments, such that grain no longer meets milling specifications. It was concluded that N rate recommendations for winter oats should take account of the relationship found between optimum N rate and yield, whilst simplifying the tables by removing the soil type categories. For spring oats it appears that current recommendations are 25-30 kg N/ha too low.

A combined analysis of timing trials indicated that current RB209 winter oat timing recommendations appear appropriate for yield and grain quality. Conclusions for spring oats remain unclear, with more research needed, but it appears that applying at least 40 kg N/ha to the seedbed and the remainder by the start of stem extension leads to good spring oat yields more consistently. The results of the quality analyses showed that applying all the N in the seed bed resulted in higher specific weights in

Scottish trials. Sulphur applications were shown to significantly improve yield, especially on lighter soils. Overall, for the winter and spring oat varieties examined, variety had a greater effect on all grain quality traits measured than the timing of N treatment or addition of sulphur.

It is concluded that this project has made significant progress in providing knowledge for winter and spring oat agronomy required to update current RB209 recommendations, although, further research is needed to address several oat nutrition questions that were not within the scope of this project. Hence, a number of important research directions that should be investigated have been proposed, including further investigation into N timing applications for oat yield and quality and additional research on N recommendations for spring oats.

2. Introduction

The demand for oat products has been increasing steadily over the past two decades, with the total domestic consumption in the UK increasing from 497 to 958 kt in that time (Figure 2.1). The total amount of oats produced by growers has also increased during this time (Figure 2.1). However, due to the relatively small area of oats grown historically, there has been little investment in research on physiology or agronomy, and the products (e.g. herbicides) needed to grow the crop effectively.

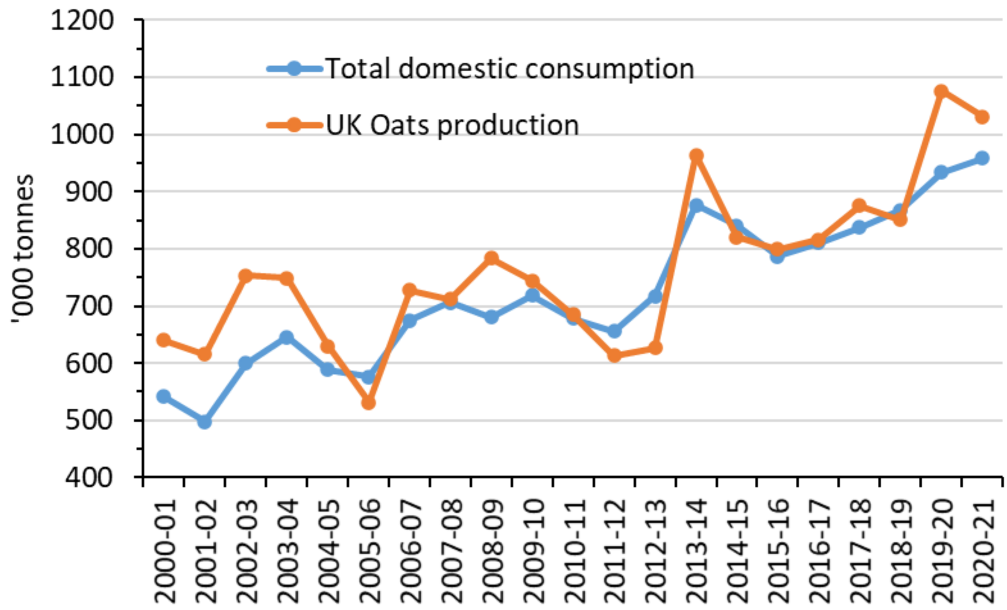


Figure 2.1 The total amount of oats produced and consumed in the UK ('000 t) in seasons (July – June) 2000-01 to 2020-21. Source: AHDB, Defra.

Increasing the competitiveness of oats requires knowledge of the optimum nitrogen (N) rate that on the one hand minimises environmental impact and at the same time maximises grower and milling industry benefits. It is important that, in addition to optimising grain yield, the end-use quality of that grain is also maximised.

The 2016 review of RB209 (Roques et al., 2016) concluded there was insufficient data to derive robust N recommendations for winter oats. However, evidence from work conducted as part of AHDB-funded research, as well as the evaluation of wider data analysed as part of the RB209 review, suggested that the RB209 recommendations in the 8th Edition were too low, resulting in an increase of 40 kg N/ha for all SNS indices and soil types being applied.

Although not considered as part of the 2016 review, there is also a need to take account of the effect of N on key milling quality traits: specific weight, kernel content, screenings (small grains that pass through a 2mm sieve) and the ease of de-hulling (hullability). Analyses carried out on winter oats in the Innovoat project (AHDB project 2113004) and by the PhD student Pilar Martinez (AHDB project 2113002) revealed that higher levels of N fertilisation increased both kernel content and hullability, but generally reduced specific weight, although this reduction was not linear and not seen in the variety Mascani. The reduction in specific weight with increased N rate seen in the Innovoat project was associated with a reduction in bimodality in grain size and an increased proportion of small grains, which is consistent with the conclusions of Browne et al. (2003). This reduction in specific weight (below the 52 kg/Hl target) could result in the rejection of a crop by the mill with consequent losses to the grower.

When spring oats were investigated for the RB209 review, no new data could be found (Roques et al., 2016). Consequently, N recommendations for spring oats have not been updated for many years, despite spring oats becoming increasingly popular, such as in East Anglia where blackgrass issues make them a useful alternative cropping option. In Scotland, spring oats make up around two thirds of oat production. These farmers are having to base important management decisions on outdated information, potentially resulting in poor quality oats leading to a significant amount of unrealised farm profit and hampering the expansion of the crop.

There were also no data for the RB209 review concerning N timing for either winter or spring oats (Roques et al., 2016). Currently, the advice for when to apply N to oats is consistent with that of wheat, but the specifications for milling oats are different with, for example, no target for grain protein content. Furthermore, it is not known whether oats achieve better yields and quality if they are fertilised like wheat (an emphasis on later timings) or barley (an emphasis on early timings to maximise tillers). It is likely that nitrogen timings that are optimal for yield are not necessarily optimal for milling quality. With an increasing emphasis on lowering inputs to meet environmental sustainability objectives, knowledge of optimal N timing as well as amount applied could result in oats with better grain quality.

As well as applications of N, sulphur (S) is another essential element to maintain cereal yields. As S deposition has decreased in the UK, the requirement for S has been well evidenced in deficient situations (e.g. Cussans et al., 2007). Applications of 25-50 kg SO_3/ha in the spring are recommended in RB209 for crops at risk of deficiency. However, the research carried out to reach this recommendation was not carried out in oats. It is reasonable to assume that oats would have a similar requirement to other cereals, but evidence is required to confirm this.

A project was commissioned by AHDB in 2018 to fill these knowledge gaps and provide updated guidance for growers. The project, reported here, is often referred to as ‘NoatS’.

Aim

To provide advice on the most appropriate nitrogen rates and timings, plus sulphur applications to optimise yield and milling quality of winter and spring oats.

Specific Objectives

1. Collate and analyse recent data on the effect of Nitrogen Rate and timing, and Sulphur on winter and spring oats yield and quality

2. Evaluate optimal Nitrogen rates and timings and Sulphur applications on winter oats yield

3. Evaluate optimal Nitrogen rates and timings and Sulphur applications on spring oats yield

4. Evaluate the impact of Nitrogen and Sulphur on the milling quality of oats. Specifically specific weight, screenings, kernel content and hullability.

5. Distil findings into farmer friendly guidelines and disseminate conclusions through AHDB and industry channels

3. Materials and methods

Review of previous data

Recent datasets were collated from project partners. Five spring oat (SO) and seven winter oats (WO) N timing trials were analysed (Table 3.1). Winter oats data on N rates had been reviewed as part of the 2016 AHDB-funded RB209 review and, although two response trials had been carried out in the subsequent season, it was decided that this would not affect the conclusions from the 2016 review. There were not enough relevant spring oats N response datasets to analyse.

Table 3.1 Datasets included in the review of recent winter and spring oats data.

Winter/ spring oats	**Sponsor**	**Harvest season**	**Location**	**Total N applied (kg/ha)**	**Treatment details including timings and amounts (kg N/ha) of N**
Winter	Senova/ IBERS	2014	Essex, UK	150	**6 varieties** (including 2 naked oats) **3** N **timings**: 1. Mid-March; 2. GS31 (mid-April); 3. Application timing 2 + 21 days **3 Timing treatments**: 1. 50 at each of the 3 timings; 2. 50 at timing 1 + 100 at timing 3; 3. 50 at timing 2 + 100 at timing 3
Winter	Richard-sons/ RAGT	2018	Cambri-dge, UK	190	**4 varieties; 2 sowing dates** (Sep + Oct); **2 seed rates** (200 & 400 seeds/m^2) at Oct sowing only; **2 N timings**: 1.Early March; 2.Early stem extension **2 timing treatments:** 1. 50% of total at each of 2 timings; 2. 30% at timing 1 then 70% at timing 2
Winter	Teagasc	2015	Carlow, Ireland	0 - 150	**1 variety:** Husky; **6 N rates**: 0 – 150 **4 N timings:** GS22, GS30, GS39-45, GS55-59 **21 N treatments:** Each N rate applied in 1 dose at each of N timings, except 0 N rate
Winter	Teagasc	2016 + 2017	Carlow, Ireland	0 - 150	**1 variety:** Husky; **6 N rates**: 0 – 150 **3 N timings:** GS25, GS30, GS32 **16 N treatments:** Each N rate applied in 1 dose at each of N timings, except 0 N rate
Winter	Teagasc	2016 + 2017	Carlow, Ireland	0 - 240	**1 variety:** Husky; **8 N rates**: 0 – 240 **2 N timings:** GS30, GS32 **16 N treatments:** Each N rate applied at either the 1st or 2nd timing or split between timings
Spring	Saaten Union	2017	Suffolk, UK	110	**3 varieties; 2 seed rates**; **1 N rate** **3 N timings:** Seedbed, GS13, GS30-31 **3 N treatments:** 1. 40 in deebed + 70 at GS13; 2. 40 in seedbed + 70 at GS 30-31; 3. 40 at GS13 + 70 at GS30/31
Spring	Teagasc	2015	Carlow, Ireland	0 - 150	**1 variety; 6 N rates:** 0 – 150 **4 N timings**: GS12-13; GS30; GS39-41; GS55 **21 N treatments:** Each N rate applied in 1 dose at each of N timings, except 0 N rate
Spring	Teagasc	2016	Carlow, Ireland	0 - 150	**1 variety; 6 N rates:** 0 – 150 **4 N timings**: Emergence; Tillering; GS30; GS32 **21 N treatments:** Each N rate applied in 1 dose at each of N timings, except 0 N rate
Spring	Teagasc	2016 + 2017	Carlow, Ireland	0 - 240	**1 variety:** Husky; **9 N rates**: 0 – 240 **2 N timings:** Emergence; GS30 **24 N treatments:** 0 – 150 (6 N rates) applied at GS30, with either 0, 30, 60 or 90 applied at emergence

The datasets were collated to carry out combined analyses. Despite investigating whether treatments not consistent across trials could be simplified and exploring statistical analyses such as semi-nested analyses to attempt to deal with treatments that were not present in all trials, it was concluded that the trial designs were too disparate to analyse together in one model. Therefore, subsets of the combined dataset were analysed to ask specific questions.

The following steps were carried out on each subset: Levene's test for equal variance; linear regression; post-hoc test of treatment significance; and Shapiro-Wilks test of normality.

Survey

Online surveys were set up to understand current N and S fertiliser practice for winter and spring oats. Two versions of the survey were available; one for advisors and the other for oat growers. The online survey platform, SmartSurvey, was used and surveys were open for entries between 29th August and 4th October 2018.

The advisors and farmers were asked questions on:

1. Location and area of winter/spring oats advised on or grown
2. Winter and spring oats seed rates and drilling dates advised/used
3. Current methods used to determine N rates/timings on oats
4. N rates/timings currently advised for/used on winter and spring oats
5. Current S nutrition advised for/used on winter and spring oats
6. Performance (yield, lodging, quality) of winter and spring oats crops advised on/grown

Following completion, summary statistics (means, ranges) were determined, and results summarised in charts and tables.

Experimental information

Experiments on spring and winter oats were conducted over three seasons, harvested in 2019, 2020 and 2021, and included both N rate and N timing experiments. N timing experiments also included a treatment without S application. In total, 19 N rate and N timing experiments (9 and 10, respectively) were carried out over the three seasons. The experiments were carried out across five regions located near ADAS Gleadthorpe in Nottinghamshire, ADAS Boxworth in Cambridgeshire, ADAS Rosemaund in Herefordshire, Saaten Union (SU) in Suffolk and Scottish Agronomy (SAG) in Fife (Table 3.2). An additional experiment was also carried out in Lincolnshire (OMEX) in 2021 as a replacement for the ADAS Boxworth N response experiment that was lost in 2020 due to drought.

In addition to the core sites of the ‘NoatS experiment, twelve additional SO and WO N Rate and Timing experiments were carried out at IBERS (Institute of Biological, Environmental and Rural Sciences, Aberystwyth University) and Carlow (Republic of Ireland, in association with Teagasc). These sites are described in the PhD thesis of Tudor (2022) so not detailed here, but are included for the results of Section 5: Implications for N and S fertiliser recommendations.

Three varieties were investigated in all N rate and timing experiments. Spring oat varieties were the same across both sites in the East Anglia region (Cambridgeshire and Suffolk) for both timing and rate experiments (Aspen, Canyon and WBP Elyann), but a single variety was changed for the same experiments in the Scottish site (from Aspen to Conway) to reflect varieties commonly grown in those regions. The Lincolnshire OMEX 2021 experiments contained Aspen and Canyon varieties only. The same winter oat varieties were used across both Nottinghamshire and Herefordshire regions for all the timing and rate experiments (Mascani, Penrose and RGT Southwark).

In the N rate experiments, a split plot design was used with six N rates (0 kg N/ha to above likely optimum) as the main plots and the varieties were fully randomised as sub plots within each main plot. In the N timing experiments, a fully randomised design was used. There were three replicates of each treatment combination in both N rate and timing experiments. Spring oat varieties were drilled to aim to establish 300 plants/m^2, with thousand grain weight (TGW), germination % and likely % establishment of each variety, appropriate for specific site conditions, being used to calculate the required seed rates. Winter oat varieties were drilled to aim to establish 275 plants/m^2, with the same parameters used to calculate seed rates.

For the N timing experiments, the total amount of N applied to each experiment was estimated from RB209. For spring oats experiments, all six treatments received 120 kg N/ha and consisted of a range of N applications across four different application timings, consisting of seedbed, GS13 (three leaves), GS30/31 (early stem extension) and GS37 (flag leaf emerging). One treatment had all N applied in the seedbed, and others were distributed differently across the four application timings. Treatment 1, with half N (60 kg/ha) applied in the seedbed and half at GS30/31 was replicated in treatment 6 but without S application at emergence of the third leaf (40 kg SO_3/ha) to assess the impact of withholding S application on oat yield and quality.

For winter oat timing experiments, 180 kg N/ha was added to each of the six treatments, again consisting of a range of N applications across four different application timings, but here at tillering, GS30, GS32 and GS39.

The N splits for the N rate experiments were applied as described in Table 3.3, Table 3.4, Table 3.5, Table 3.6, Table 3.7 and Table 3.8, and application dates and growth stages for the N timing trials are shown in Table 3.9, Table 3.10 and Table 3.11.

Table 3.2. Site details for core site experiments.

Identifier	Harvest Year	Site	Grid Reference	Soil type	Previous crop	Sow date
SO Rate Fife	2019	Scottish Agronomy, Fife	NO 325 001	Sandy Loam	Winter oilseed rape	10/04/19
SO Rate Cambridgeshire	2019	ADAS Boxworth, Cambridgeshire	TL 22223 60842	Clay Loam	Unknown	26/02/19
SO Timing Fife	2019	Scottish Agronomy, Fife	NO 325 001	Sandy Loam	Winter oilseed rape	10/04/19
SO Timing Suffolk	2019	Saaten Union, Suffolk	TL 70578 54601	Silty Clay	Winter wheat	02/03/19
WO Rate Nottinghamshire	2019	ADAS Gleadthorpe, Nottinghamshire	SK 54635 55766	Loamy Sand	Winter oats	23/10/18
WO Rate Herefordshire	2019	ADAS Rosemaund, Herefordshire	SO 53358 46207	Silty Clay Loam	Winter wheat	26/09/18
WO Timing Nottinghamshire	2019	ADAS Gleadthorpe, Nottinghamshire	SK 54635 55766	Loamy Sand	Winter oats	23/10/18
WO Timing Herefordshire	2019	ADAS Rosemaund, Herefordshire	SO 53358 46207	Silty Clay Loam	Winter wheat	26/09/18
SO Rate Fife	2020	Scottish Agronomy, Fife	NT 314 991	Sandy Clay Loam	Winter oats	01/04/20
SO Timing Fife	2020	Scottish Agronomy, Fife	NT 314 991	Sandy Clay Loam	Winter oats	01/04/20
SO Timing Suffolk	2020	Saaten Union, Suffolk	TL 70515 54934	Clay Loam	Winter wheat	26/03/20
SO Rate Fife	2021	Scottish Agronomy, Fife	NT 323 994	Silty Loam	Winter oats	22/03/21
SO Rate Cambridgeshire	2021	ADAS Boxworth, Cambridgeshire	TL 28538 77575	Silty Clay	Winter wheat	09/03/21
SO Rate Lincolnshire	2021	Heckington, Lincolnshire	TF 16813 46274	Sandy loam	Winter wheat	25/02/21
SO Timing Fife	2021	Scottish Agronomy, Fife	NT 323 994	Silty Loam	Winter oats	22/03/21
SO Timing Suffolk	2021	Saaten Union, Suffolk	TL 70436 54232	Loamy Sand	Winter wheat	25/02/21
WO Rate Nottinghamshire	2021	ADAS Gleadthorpe, Nottinghamshire	SK 56335 57583	Loamy sand	Carrots	07/10/20
WO Rate Herefordshire	2021	ADAS Rosemaund, Herefordshire	SO 53860 46223	Silty Clay Loam	Winter wheat	29/09/20
WO Timing Nottinghamshire	2021	ADAS Gleadthorpe, Nottinghamshire	SK 56335 57583	Loamy sand	Carrots	07/10/20
WO timing Herefordshire	2021	ADAS Rosemaund, Herefordshire	SO 53860 46223	Silty Clay Loam	Winter wheat	29/09/20

N Rate experiment information

Table 3.3. N application information for N rate experiments on winter oats at the Nottinghamshire and Herefordshire sites (2019 and 2021)

	Early March application (kg N/ha)	Early stem extension – 1st split (kg N/ha)	Early stem extension – 2nd split (kg N/ha) approx 2 weeks after 1st split	Total N applied (kg N/ha)
1	0	0	0	**0**
2	0	40	40	**80**
3	40	45	45	**130**
4	40	70	70	**180**
5	40	95	95	**230**
6	40	130	130	**300**

Table 3.4. N application for N rate experiments on spring oats in Cambridgeshire (2019)

	Seedbed application (kg N/ha)	Emergence 3 leaf stage (GS13) (kg N/ha)	GS30-31 (kg N/ha)	Total N applied (kg N/ha)
1	0	0	0	**0**
2	40	20	20	**80**
3	40	45	45	**130**
4	40	70	70	**180**
5	60	85	85	**230**
6	60	120	120	**300**

Table 3.5. N application for N rate experiments on spring oats in Cambridgeshire (2021)

	Seedbed application (kg N/ha)	Emergence 3 leaf stage (GS13) (kg N/ha)	GS30-31 (kg N/ha)	Total N applied (kg N/ha)
1	0	0	0	**0**
2	40	15	15	**70**
3	40	40	40	**120**
4	40	70	70	**180**
5	60	85	85	**230**
6	60	110	110	**280**

Table 3.6. N application for N rate experiments on spring oats in Lincolnshire (2021)

	Seedbed application (kg N/ha)	**Emergence 3 leaf stage (GS13) (kg N/ha)**	**GS30-31 (kg N/ha)**	**Total N applied (kg N/ha)**
1	0	0	0	**0**
2	40	15	15	**70**
3	40	40	40	**120**
4	40	70	70	**180**
5	60	80	80	**220**
6	60	120	120	**300**

Table 3.7. N application for N rate experiments on spring oats at the Fife site (2019 and 2020)

	Seedbed application (kg N/ha)	**Emergence 3 leaf stage (GS13) (kg N/ha)**	**GS30-31 (kg N/ha)**	**Total N applied (kg N/ha)**
1	0	0	0	**0**
2	40	10	0	**50**
3	40	30	30	**100**
4	40	50	50	**140**
5	60	60	60	**180**
6	60	80	80	**220**

Table 3.8. N application for N rate experiments on spring oats in Fife (2021)

	Seedbed application (kg N/ha)	**Emergence 3 leaf stage (GS13) (kg N/ha)**	**GS30-31 (kg N/ha)**	**Total N applied (kg N/ha)**
1	0	0	0	**0**
2	40	15	15	**70**
3	40	40	40	**120**
4	40	70	70	**180**
5	60	80	80	**220**
6	60	120	120	**300**

N Timing experiment information

Table 3.9. Application dates and growth stages for the N timing experiments. “”NA” indicates where data is not available.

Site	Sowing date	1st timing application	2nd timing application	3rd timing application	4th timing application
Winter oats					
Herefordshire 19	26/09/18	GS24-26, 8/3/19	GS30-31, 27/3/19	GS31-32, 10/4/19	GS39, 13/5/19
Nottinghamshire 19	23/10/18	GS24, 23/3/19	GS31-32, 1/5/19	GS32. 16/5/19	GS45-55, 30/5/19
Herefordshire 21	29/09/20	GS24, 09/03/21	GS30-31, 06/04/21	GS31-32, 23/04/21	GS39, 19/05/21
Nottinghamshire 21	07/10/20	GS24, 02/03/21	GS30, 23/03/21	GS32, 12/05/21	GS39, 26/05/21
Spring oats					
Fife 19	10/04/19	Seedbed, 31/03/19	GS13, 01/05/19	GS30-31, 21/05/19	GS37, 04/06/19
Suffolk 19	02/03/19	Seedbed, 3/3/19	GS13, 23/4/19	GS31, 21/5/19	GS37, 4/6/19
Fife 20	01/04/20	Seedbed, 03/04/20	GS13, 23/04/20	GS30-31, 26/05/20	GS37, 08/06/20
Suffolk 20	26/03/20	NA	NA	NA	NA
Fife 21	22/03/21	Seedbed, 31/03/21	GS13, 20/04/21	GS30-31, 28/05/21	GS37, 08/06/21
Suffolk 21	24/02/21	NA	GS13, 22/04/22	NA	NA

Table 3.10. N application for N timing experiments on winter oats in Nottinghamshire and Herefordshire sites (2019 and 2021)

No.	S application applied early March at tillering (kg SO_3/ha)	Early March application at tillering (kg N/ha)	GS30 – 1st split (kg N/ha)	GS32 – 2nd split (kg N/ha)	GS39 (kg N/ha)	Total N applied (kg N/ha)
1	40	40	70	70	0	**180**
2	40	90	90	0	0	**180**
3	40	0	90	90	0	**180**
4	40	90	0	90	0	**180**
5	40	0	50	90	40	**180**
6	0	40	70	70	0	**180**

Table 3.11. N application for N timing experiments on spring oats in Suffolk and Fife sites (2019, 2020 and 2021)

No.	S application (kg SO_3/ha) applied emergence 3 leaf	Seedbed N (kg N/ha)	Emergence – 3 leaf stage (GS13) (kg N/ha)	GS30/31(kg N/ha)	GS37	Total N applied (kg N/ha)
1	40	60	0	60	0	**120**
2	40	0	60	60	0	**120**
3	40	0	90	30	0	**120**
4	40	40	0	40	40	**120**
5	40	120	0	0	0	**120**
6	0	60	0	60	0	**120**

Assessments

Soil and Crop N Measurements

In January-February, soil samples were taken to 90 cm (or to the depth of soil for shallow soils) from the field experimental areas, care being taken to keep each 30 cm horizon separate. Soil cores were sent in a cool box to Hill Court Farm Research for measurement of soil mineral N (SMN) and Additionally Available N (AAN). These SMN and AAN measurements were used to calculate the soil total N reservoir. An estimate of crop N was also made from tiller counts or a photograph taken from above the crop of approximately $1m^2$ to estimate GAI. From these parameters, the amount of total applied N needed could be estimated to ensure that an N optimum for yield was reached along the N range in the N rate experiments.

Green area index

For the N rate experiments, photographs were taken of all varieties in one representative block of the N rate trial whilst carrying out sampling for SMN to determine green area index (GAI). The photograph was taken vertically above the crop to cover $\sim 1m^2$. Photographs of one representative block in both the N rate and timing experiments were taken just before harvest, taken at the end of the plot to ensure the majority of the plot was visible.

Pre-Harvest Measurements

These assessments were carried out at all sites in 2019 by a placement student, but only a subset of sites/treatments in subsequent seasons. Between GS59 and harvest, tiller counts were assessed on all plots. Three counts were carried out per plot by counting the number of fertile and infertile tillers in the rows on both sides of a 0.5 m rod. Using the row width, the number of fertile and infertile tillers per m^2 could be calculated. Height measurements were carried out between GS75 and harvest by taking height measurements of 10 random tillers per plot to the top of the panicle.

Pre-Harvest Sampling

These assessments were carried out at all sites in 2019 by a placement student, but only a subset of sites/treatments in subsequent seasons. Just before harvest, grab samples of about 20 shoots cut at ground level from five randomly chosen positions per plot were taken to give a total sample of around 100 shoots. The number of panicles were counted and separated from the straw. The fresh weight of both the panicles and straw were measured and then dried and weights recorded. Panicles were then threshed, the chaff put back with the straw and the dry weight of the grain recorded. Thousand grain weight (TGW) was calculated by weighing ~40 g grain and counting the number of grains (weight/number x 1000). Sub-samples of grain and 'straw + chaff' samples from each plot were then sent for N concentration analysis at Hill Court Farm.

Lodging at Harvest and Yield

The percentage areas affected by leaning (displaced by 9º and less than 45º from the vertical) and lodging (displaced by greater than 45º from the vertical) were recorded from when lodging first started and at harvest. The yield of all plots was recorded using a combine harvester. Samples from each plot were taken for determination of moisture content and specific weight using a Dickey-John GAC 2000 grain analysis computer. This information was used to calculate yield in tonne/ha adjusted to 15% moisture (national standard).

Grain quality analysis

In all experiments, 3 kg seed was retained from each plot and sent to IBERS, Aberystwyth University for grain analysis. Harvested grain was cleaned through a 3.5 mm and 2 mm sieve prior to analysis of grain quality. Screening percentages (grain <2mm) of all samples were recorded. Grain specific weight (kg/Hl) was measured using a chondrometer (Nileme, C288) on 3 replicate samples (approximately 500 ml) per field plot.

A riffle divider was used to obtain a representative 30g sub-sample, which was then separated by hand to remove any remaining free groats from the whole grains. The number of grains within the samples were determined using a seed counter (Data Count S-25) and TGW was calculated. To determine kernel content, the percentage of groat to the wholegrain, and hullability, the ease of which the husks are removed from the groats, the wholegrain samples were passed through a laboratory oat huller (Codema Model LH5095) set at 100 bar for 60 seconds. The output was separated into groats, broken groats, unhulled wholegrains and husks. All fractions were weighed and used to calculate kernel content and hullability percentages.

Kernel Content was calculated as:

Kernel Content (%) = 100 x (Groat weight (g) / (Initial weight (g) – Whole grain weight (g)))

Hullability (%) was calculated as:

Hullability (%) = 100 – (100 x Whole grain weight (g) / Initial weight (g))

Agronomic Inputs

N rate experiment plots received a non-N containing S fertiliser, for example as kieserite or potassium sulphate. S application to the N timing experiments was factored into the experiment, with all treatments but one receiving 40 kg/ha of SO_3 to the seedbed in the spring as potassium sulphate (18% S). No Nitrogen was to be applied by the farmer on the experimental plots. All other crop management inputs were carried out according to commercial farm practice to ensure that other nutrients were not limiting, and to control weed, pest, disease and lodging incidence. All other inputs were applied as per standard farm practice, including a comprehensive PGR programme.

Statistical Analysis

Analysis of Variance

All parameters in each experiment were analysed separately by General ANOVA in Genstat (VSN International Ltd), either as a randomised block design (N timing experiments) or as a split-plot design with N rate as the main plot and variety as the sub-plot (N rate experiments). The analyses tested for differences between varieties, differences between N rates or N timings and for any interaction between varieties and N rates or N timings, i.e. whether the response to N was different for each variety.

Grain Yield Response Curves and Deriving Economic Optimum (N_{opt}) Rates

The N requirement or economically optimum N rate (N_{opt}) is the rate at which any further increase in N rate will result in greater N fertiliser costs than the value of the additional grain produced. This is therefore dependent on the relative price of the grain and N fertiliser, or the breakeven ratio (BER): the amount of grain (kg) required to pay for one kg of fertiliser. In order to calculate the optimum N rate, it is necessary to mathematically describe the response of crop yield to N fertiliser. The relationship between applied N and yield is complex and usually typified by a rapid increase in yield at low N rates, followed by a levelling off of the yield response, and sometimes a reduction of yield at super-optimal N rates due to factors such as lodging. A linear plus exponential (LpE) function (see below) was chosen as being best at describing the range of N responses of UK cereals (George, 1984) and it has remained the standard for 30 years. The LpE function has four fitted parameters a, b, c & r which approximately (because they are strongly correlated) describe respectively the asymptote, the effect of omitting N, the slope of the asymptote, and the curvature of the response. In order to fit an LpE function information about the effects of five to seven levels of N on grain yield is required.

$$Y = a + br^N + cN \qquad \text{(LpE function)}$$

The fitting process did not use common values of parameters between sites or seasons; thus it was assumed that responses were unique to a site. To determine N_{opt} for each variety at each site the LpE function was fitted using a 'Parallel curve' approach. This involved a four-stage procedure:

i) Fit a common curve to all varieties (i.e. keeping a, b, c and r constant for all varieties at a site).
ii) Fit separate curves for each variety, with a common response but different intercepts (i.e. varying a but keeping b, c and r constant).
iii) Fit separate curves for each variety allowing a, b and c all to vary (i.e. just keeping r constant).
iv) Fit separate curves for each variety, allowing all parameters to vary.

The sums of squares explained at each stage was calculated, and a test was made of the improvement in fit over the previous model. If there was no significant improvement between two stages, then the previous model was taken as the best description of the data.

Estimates of N_{opt} values were derived from the fitted LpE parameters as follows:

$$Nopt = \frac{[\ln(k/1000 - c) - \ln(b(\ln r))]}{\ln r}$$

Where k is the breakeven price ratio between fertiliser N (p/kg) and grain (p/kg). A breakeven ratio of 5 was used in this study because this is used as a standard in the current version of RB209. The yield at each N_{opt} rate (Y_{opt}) was calculated from the fitted parameters.

REML

Where experiments used the same design and varieties, data were combined and REML (Residual Maximum Likelihood) analysis of multiple experiments was carried out in Genstat (VSN International Ltd).

Fertiliser recovery

The apparent recovery of fertiliser N and N utilisation efficiencies were calculated as follows for the N rate closest to the economically optimum N rate in each N experiment for each variety:

Fertiliser recovery (kg/kg) =

$$\frac{\text{N uptake (kg/ha)} - \text{N uptake (at NIL N) (kg/ha)}}{\text{Rate of fertiliser N applied (kg/ha)}}$$

4. Results

Objective 1: Review of recent pre-project data & Current farming practice

Review of recent data

For the winter and spring oats datasets available, a number of specific questions were tested. Due to the disparate nature of the dataset structures and treatments, each question was tested using data from one or two relevant experiments. In both winter (Table 4.1) and spring (Table 4.2) oats it was clear that splitting N, rather than applying it as one dose, boosted yield. Understanding the optimum N timing was more difficult; in both the winter and spring oats trials carried out in Ireland, the results of the 2015 experiments contradicted those carried out in 2016 and 2017 (Table 4.1,Table 4.2). The results of the winter oats trials sponsored by Senova/IBERS and Richardsons/RAGT both indicated that weighting the N to more applied at stem extension as opposed to tillering led to higher yields (Table 4.1).

Table 4.1 Results of an analysis of winter oats data collated from post-2015 experiments carried out in the UK and Ireland.

Question asked of data	Trial data included	Statistical test	Main results
Does applying N in two splits rather than one increase yield?	Teagasc WO N rate 2016 + 2017	Linear model with N split and N rate as factors; trial as random factor	Splitting N application into two increased yield by *c.* 0.6 t/ha. Increased N application leads to increased yield with no interaction with splitting applications
What is the best growth stage to apply N?	Teagasc WO N timing 2016 + 2017	Linear model with N timing and N rate as factors, trial as random factor. Growth stages; GS25, GS30, GS39, Tillering	Applying N at GS39 significantly reduced yield. Reducing N input below 90 Kg/ha reduced yield with no interaction between N rate and N timing of application.
What is the best growth stage to apply N?	Teagasc WO N timing 2015 (different growth stages tested to 2016 and 2017)	Linear model with N timing and N rate as factors. Growth stages GS22, GS30, GS39-45, GS55-59	Growth stage at N application significantly affects yield. Contrary to 2016 and 2017 trials Highest yields when N applied at GS39-45 although this did not significantly differ from GS22 and GS30. Increased N leads to increased yield with no interaction with growth stage.
Does weighting N split evenly across three applications compared to two increase yield?	Senova/IBERS 2014 N split	Linear model with variety and N split (50:50:50, 50:0:100, 0:50:100 KgN/ha at timings mid-March:GS31:GS31+21 days) as factors	Weighting of N split increases yield, with 50:0:100 being highest. Variety influences this interaction.
Does weighting N split towards stem extension increase yield?	Richardsons/ RAGT 2018 September and October drill dates	linear model with variety and N split weighting (30:70 or 50:50, at early march and stem extension) as factors, and project as a random factor (projects differ by seed rate and sowing date)	Splitting N rate 30:70 had the higher mean, but this was non-significant.

Table 4.2 Results of an analysis of spring oats data collated from post-2015 experiments carried out in the UK and Ireland.

Question asked of data	Trial data included	Statistical test	Main results
Does applying N in two splits rather than one increase yield?	Teagasc SO N rate 2016 + 2017	Linear model with N split and N rate as factors; trial as random factor	Splitting N application into two increased yield by *c.* 0.5 t/ha. Increased N application leads to increased yield with no interaction with splitting applications
What is the best growth stage to apply N?	Teagasc SO N timing 2016 + 2017	Linear model with N timing and N rate as factors, trial as random factor. Growth stages: emergence, GS30, GS32, Tillering	Growth stage at N application significantly affects yield. Highest yields when N applied at tillering or emergence. Increased N leads to increased yield with no interaction with growth stage.
What is the best growth stage to apply N?	Teagasc SO N timing 2015 (different growth stages tested to 2016 and 2017)	Linear model with N timing and N rate as factors. Growth stages GS12-13, GS30, GS39-41	Growth stage at N application significantly affects yield. Highest yields when N applied at GS30. Increased N leads to increased yield with no interaction with growth stage.
Does seed rate and variety impact yield response to N application timings?	Saaten Union 2017 N timing trials (325 and 420 Seed Rate)	Linear model with variety, seed rate and N timing treatment (seedbed and 3 leaf split application, and 3 leaf and GS30)	Only variety influenced yield

Results of current oats farming practice survey

The online surveys were completed by 39 advisors and 25 growers; an additional 51 advisor responses and 21 grower responses could not be used as they were incomplete. Responses came from advisors based in all English regions as well as Scotland and Wales (Figure 4.1a). Growers were less evenly spread; those farming in the East Midlands and East Anglia made up 54.2% of respondents (Figure 4.1b). The majority (>70%) of farms where oats were advised on/grown were under arable rotations. The total winter and spring oats areas that the agronomist respondents advised on was 6,450 ha and 4,190 ha, respectively, representing ~6.5% of the country's total oat area at the time. The individual growers reported their areas grown of winter and spring oats were 44 ha and 45 ha, respectively, on average, although some grew up to 300 ha per year.

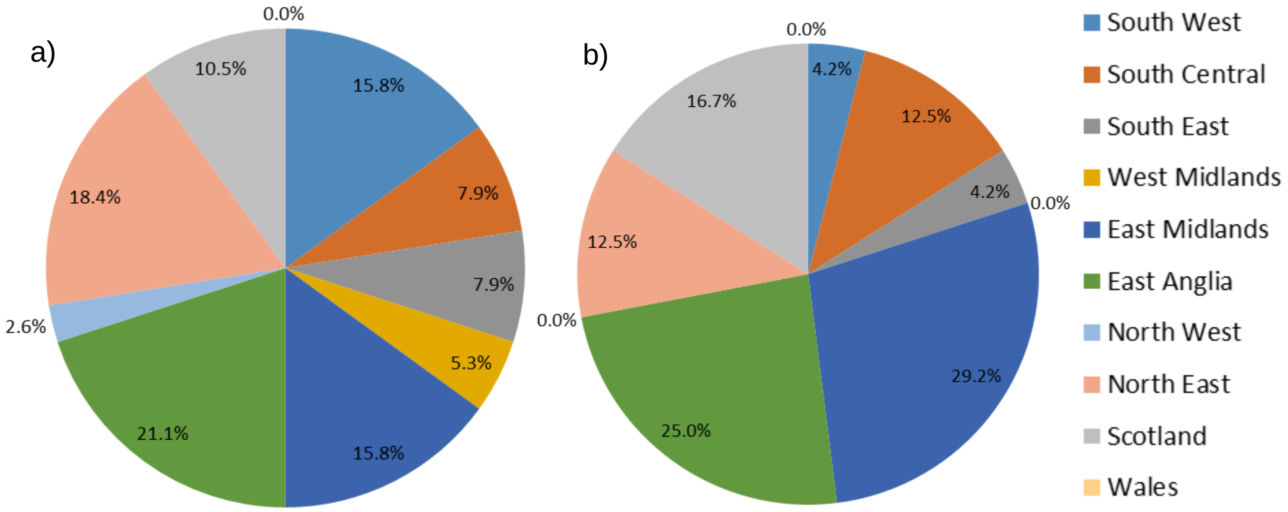


Figure 4.1. Location of a) advisors and b) growers that completed the oats current practice survey

The most popular varieties were Mascani winter oats and Canyon spring oats, with nearly half of growers reporting an increase in their spring oat area over the previous three years. Oats agronomists advised, on average, seed rates of 310 seeds/m^2 for winter oats and 346 seeds/m^2 for spring oats, rates lower than those reportedly used by growers (327 and 362 seeds/m^2 for winter and spring oats, respectively, on average). Drilling dates advised on/used were end September – mid-October for winter oats and mid-March – mid-April for spring oats.

Growers reported lodging incidence; levels were higher in winter than spring oats, but for both crops, nearly 40% of growers said their crops didn't suffer from any lodging (Figure 4.2). The average yields achieved, reported by growers, were 7.7 t/ha (range of 6.0 – 8.7 t/ha) for winter oats and 6.0 t/ha (range of 2.5 – 8.0 t/ha) for spring oats. The average grower-reported specific weights achieved were above the milling threshold of 50 kg/Hl (54 and 51 kg H/l for winter and spring oats, respectively). However, it was evident that specific weights were more variable and specifications more difficult to achieve in spring oats; the reported range was 45 – 56 kg/Hl.

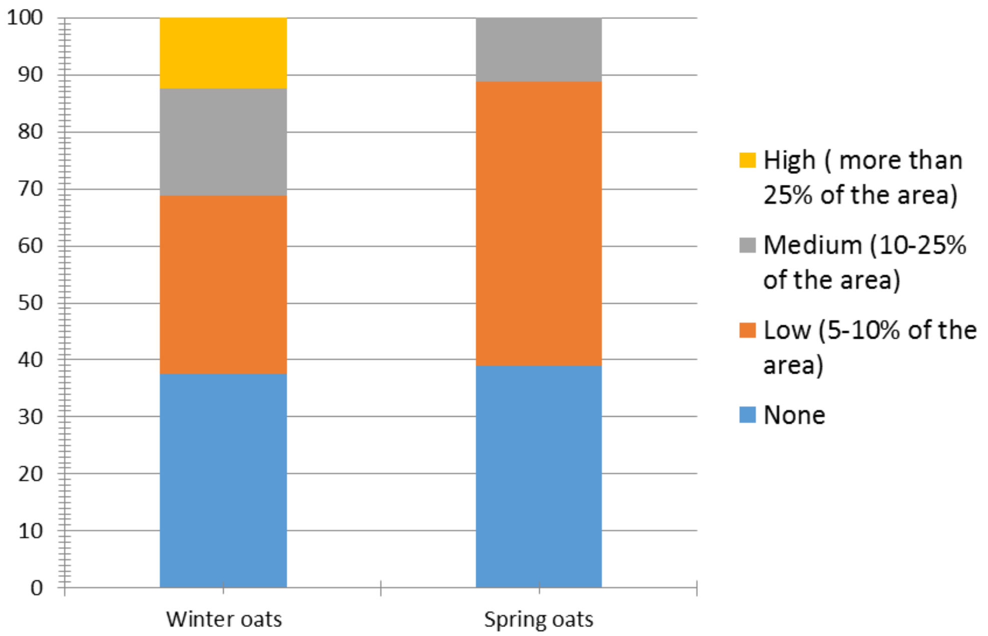


Figure 4.2. Proportions of growers reporting differing levels of lodging incidence in their winter and spring oats

In terms of N nutrition, the majority of advisors (83%) and growers (70%) relied on previous experience to determine N recommendations, with 23% of growers relying on advice from agronomists. A significant minority of advisors used the RB209 FAM (33%) or SMN (17%) method.

The average amount of N agronomists were advising to apply to winter and spring oats crops was 138 and 118 kg N/ha, respectively; in both cases more than growers reported applying (Table 4.3). The amount of SO_3 advised and applied to winter and spring oats was much more consistent at 40 and 36 kg SO_3/ha (Table 4.3).

Table 4.3 The mean (and range) total amount of N and SO_3 advised/used on winter and spring oats.

Fertiliser	**Respondent group**	**Winter oats**	**Spring oats**
Total kg N/ha	Advisors: Mean (range)	138 (75 – 170)	118 (85 – 175)
	Growers: Mean	125	102
Total kg SO_3/ha	Advisors: Mean (range)	40 (0 – 50)	36 (0 – 50)
	Growers: Mean	38	36

Advisors generally followed RB209 timings for winter oats; over half recommended N be applied at tillering and all recommended some at early stem extension and/or early stem extension + 2 weeks. Some (25%) advisors recommended that some N should be applied to winter oats at flag leaf emergence, and only one advised some be applied during grain filling.

For spring oats, the vast majority (88%) of advisors recommended some N be applied in the seedbed, and where this was recommended, the average amount was 47% of the total; 14% of advisors recommended 100% N be applied to the seedbed. Half the advisors recommended some N be applied at tillering and 81% recommended some at early stem extension and/or early stem extension + 2 weeks, with more recommending the earlier of those two timings. A small proportion of advisors recommended N at flag leaf emergence and the same advisor who advised N during grain fill in winter oats advised the same for spring oats.

Objective 2: Evaluate optimal nitrogen rates and timings and sulphur applications on winter oats yield

Environmental conditions: SMN & Rainfall

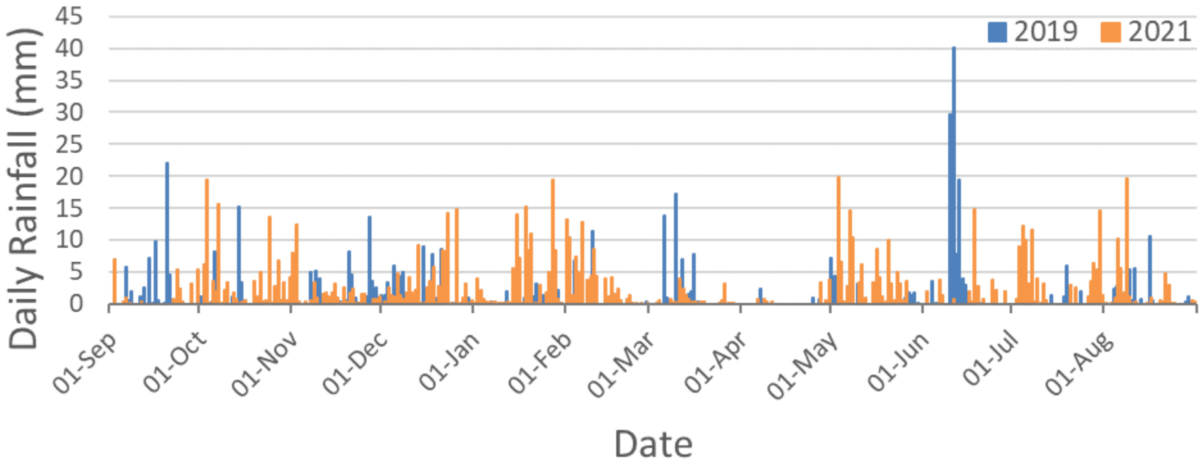
Information on the soil mineral nitrogen (SMN), additional available nitrogen (AAN) and the soil nitrogen supply (SNS) index for the core sites can be found in Table 4.4. This information was gathered by analysis of soil samples before N application to determine the amount of N that would be recommended using the current version of RB209 compared to the actual economic N rate that was determined from these experiments. All sites and experiments in the Nottinghamshire area across both 2019 and 2021 had a low SNS Index of 0 compared the sites in Herefordshire, which had a consistent SNS Index of 1 across all experiments in the area.

Table 4.4 SMN, AAN and the SNS index estimated from the AHDB Nutrient Management Guide for each core winter oats experiment.

Rate/ Timing	Site	Year	SMN 0-30 cm (kg/ha)	SMN 30-90 cm (kg/ha)	AAN (kg/ha)	SNS Index (FAM)
Rate	Nottinghamshire	2019	19	18	28	0
Rate	Herefordshire	2019	10	19	20	1
Timing	Nottinghamshire	2019	17	18	26	0
Timing	Herefordshire	2019	10	19	20	1
Rate	Nottinghamshire	2021	5	2	25	0
Rate	Herefordshire	2021	10	21	26	1
Timing	Nottinghamshire	2021	5	2	25	0
Timing	Herefordshire	2021	10	21	26	1

Rainfall data for the winter oats sites can be seen in Figure 4.3. This information is relevant in providing context to the results that follow in this report. At the Nottinghamshire site, rainfall from 1st September to 31st August in 2019 amounted to 491 mm in 2019 and 782 mm in 2021. Rainfall over the same time period at the Herefordshire site was 644 mm in 2019 and 754 mm in 2021.

a)



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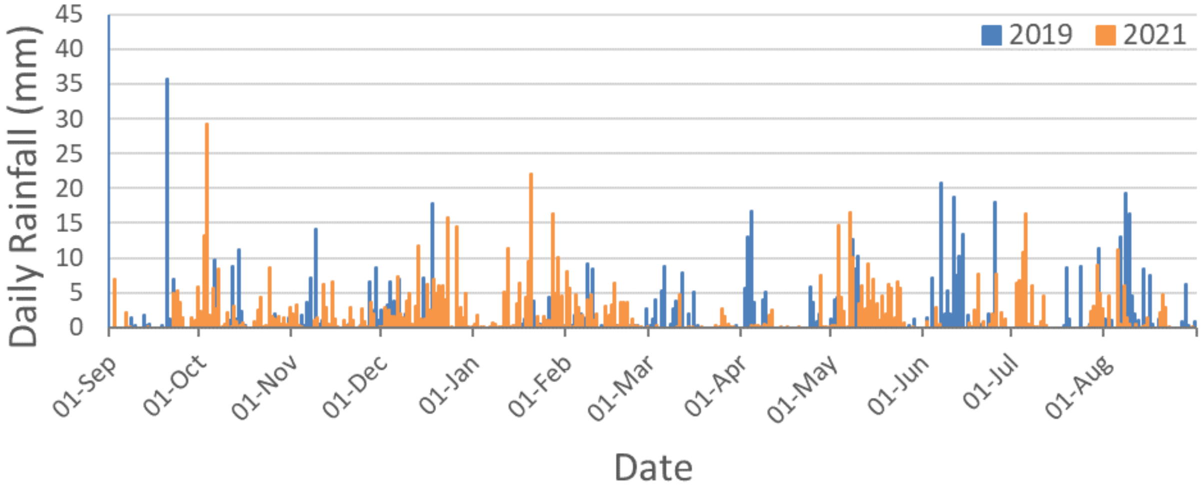


Figure 4.3. Rainfall data for the winter oats sites in a) Nottinghamshire and b) Herefordshire in the harvest seasons 2019 and 2021.

Economic optimum N rates and causes of yield differences

The Nottinghamshire site had an unusually low N optimum (N_{opt}) in both experimental years, at 19.86 and 34.53 kg N/ha in 2019 and 2021, respectively (Figure 4.4). In 2019, there was a significant difference between the yields of the three varieties tested (p<0.001), with Mascani being lowest and RGT Southwark being greatest, but the shape of the N response curves were similar. The same N response curve was fitted for all three varieties in 2021. In 2019 and 2021, there was a lack of response to increasing N application on yield over the very low N_{opt}. This could be explained by the very low yields achieved at the Nottinghamshire sites in both experimental years, at 5.79 and 5.56 t/ha at N_{opt} in 2019 and 2021, respectively (Table 9.1, Appendix). This site saw very low numbers of grains/panicle, one of the key components of grain yield, at an average of only 15 and 22 grains per panicle in 2019 and 2021, respectively (Table 9.6, Appendix). The low spring rainfall in 2019 and 2021 could also be explanatory for these low yields (Figure 4.3), as well as the low SNS index of 0

(Table 4.4). Figure 9.1 (Appendix), which compares crop height vs lodging prevalence showed no response in crop height with increasing N rates and no large differences in lodging. Overall, crops were unusually short at around 74 cm tall, likely as a result of the low moisture availability.

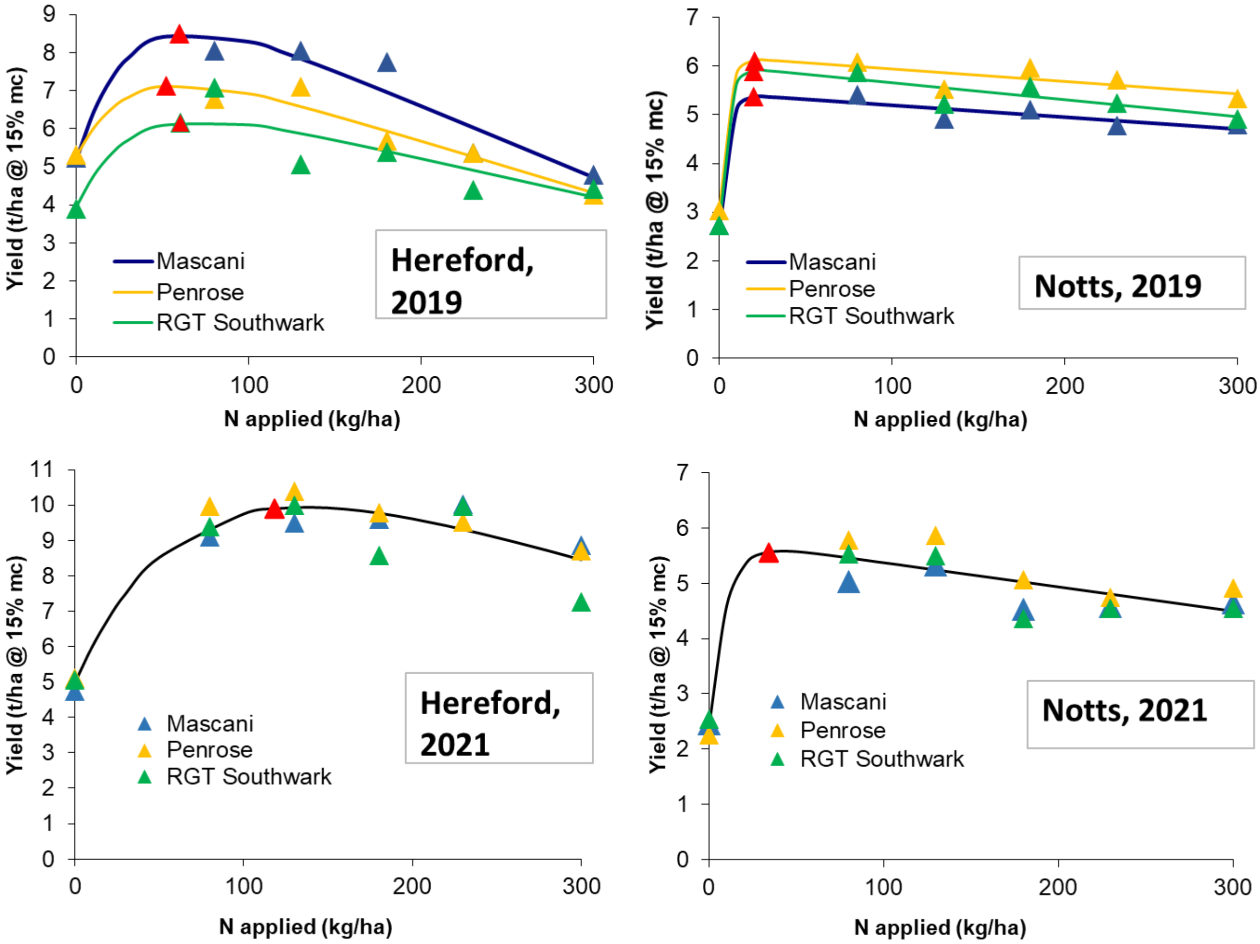


Figure 4.4 Yield response to N applied to three varieties of winter oats for experiments carried out in Herefordshire and Nottinghamshire in harvest seasons 2019 and 2021. Blue, yellow and green coloured triangles are mean yields achieved at N rates from 0 to 300 kg N/ha. Coloured lines are the fitted N response curves for those varieties; a black line signifies only 1 curve was statistically justified. Red triangles denote the calculated economic optimum N rate (BER = 5).

Yields were much greater at the Herefordshire site, at an average of 7.26 t/ha at N_{opt} in 2019 and 9.89 t/ha in 2021 (Table 9.2, Appendix). However, N_{opt} was still relatively low in 2019, at 57.4 kg N/ha in 2019, but greater in 2021, at 118 kg N/ha. Varieties differed significantly in 2019 (p<0.001), with Mascani having a significantly greater yield than Penrose and RGT Southwark. Despite this, Mascani was not noticeably better in the parameters most influential on grain yield (panicles/m^2, thousand grain weight (TGW) and grains/panicle; Table 9.7, Appendix), but had a potentially reduced lodging prevalence compared to the other varieties (Figure 4.5). Crops at the Herefordshire site were very tall in 2019, at an average of 146 cm. This led to significant amounts of crop lodging, up to 90% in some instances. No differences were seen between varieties in 2021 (p= 0.097).

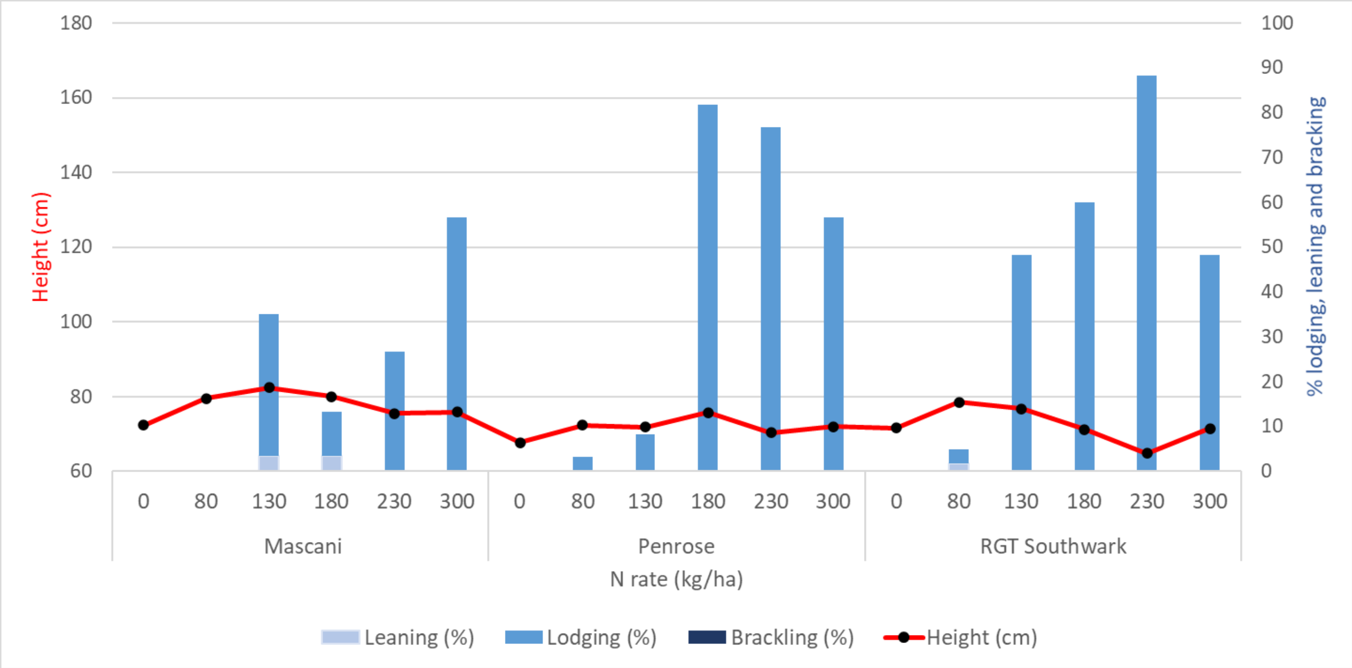


Figure 4.5. Impacts of N rate and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Herefordshire 2019 N rate trial on winter oats.

At the Nottinghamshire site, there was a significant effect of variety on the total N uptake (kg/ha) in the 2019 trial year (p<0.001), with RGT Southwark taking up the least (Table 9.9, Appendix). In 2019, there was also a varietal effect on nitrogen harvest index (NHI), being lowest in Mascani and highest in RGT Southwark, meaning, for RGT Southwark, more nitrogen was partitioned into the grain compared to the straw and chaff. An increasing N rate decreased the NHI from 71% at 0 kg N/ha to 58% at 300 kg N/ha. There was no effect of variety in 2021 on any N parameters tested (Total N uptake, Grain N%, Straw and chaff N% and NHI; Table 9.11 Appendix), reflecting the yield differences in Figure 4.4, although increasing the N rate did significantly increase N uptake and grain and straw/chaff N%.

The Herefordshire site crops had a generally higher N uptake (kg/ha) and a greater NHI compared to that seen in Nottinghamshire, potentially further explaining yield differences. At the Herefordshire site, there was a significant effect of variety on total N uptake in both experimental years (Table 9.10, Table 9.12, Appendix), with Mascani consistently showing the greatest N uptake and RGT Southwark the lowest. Mascani also had the highest N% in 2019, but no varietal differences were seen in any other N parameters in this year or in 2021. Increasing N rate had no impact on NHI at the Herefordshire site.

Total N uptake data at N rates common across seasons, i.e. 0 and 180 kg N/ha, were combined and analysed using REML. At nil N, there was a significant (P<0.001) difference between the total N taken up at different sites, with ~25 kg/ N/ha more N taken up from the soil at Herefordshire than Nottinghamshire in both seasons (Figure 4.6). This contrasts with the SMN testing data (Table 4.4) which indicated slightly more N available to the Nottinghamshire than Herefordshire site in 2019.

Varieties did not take up significantly different amounts of N at the nil N rate. At the 180 kg N/ha rate, the Nottinghamshire crops in 2019 and 2021 took up similar amounts of N in both seasons (Figure 4.6; equivalent to a fertiliser recovery of 0.57 kg/kg), whereas at the Herefordshire site, much more N was taken up in 2021 (fertiliser recovery of 0.68 kg/kg) than 2019 (fertiliser recovery of 0.34 kg/kg). It was evident at all sites that Mascani was the variety with the greatest level of fertiliser recovery, although there was a significant (p=0.025) interaction (Figure 4.7).

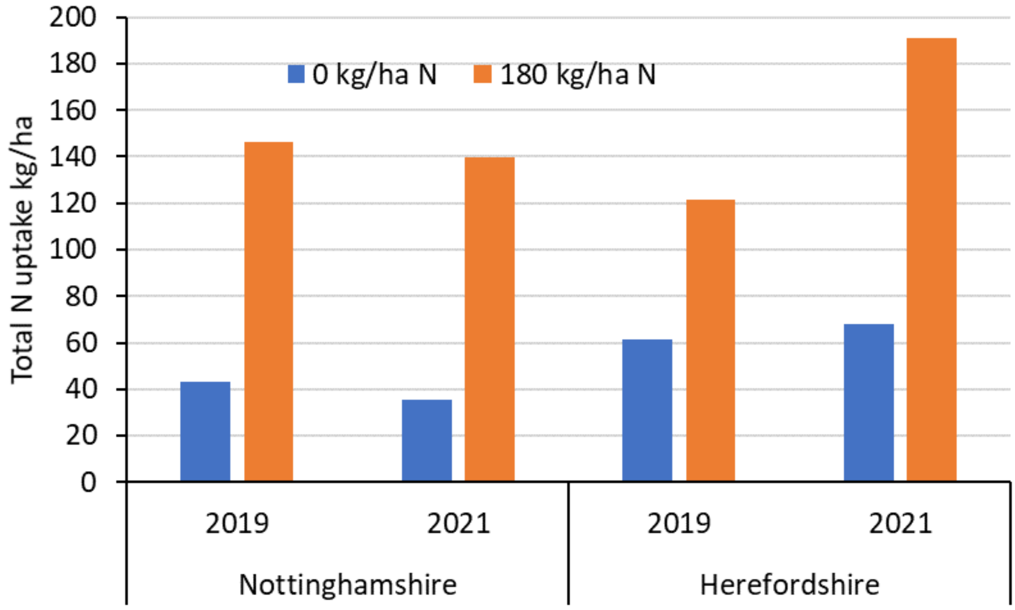


Figure 4.6 Average total N taken up by Nottinghamshire and Herefordshire crops in 2019 and 2021 with either 0 or 180 kg/ha N applied.

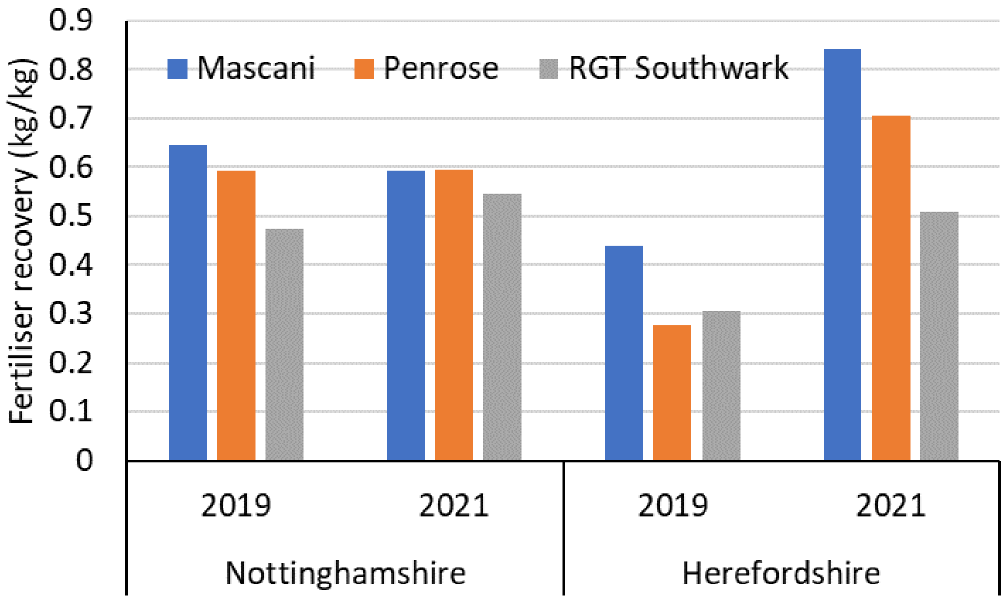


Figure 4.7 Fertiliser recovery (kg/kg) of varieties Mascani, Penrose and RGT Southwark, grown at Nottinghamshire and Herefordshire sites in 2019 and 2021.

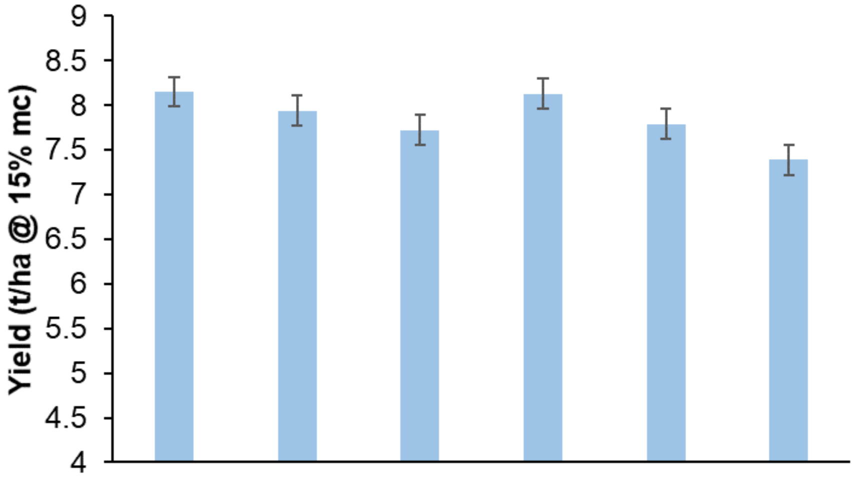
Effect of N timings and S on yield and yield differences

As with the N rates experiment at the same sites and during the same years, the Nottinghamshire site had lower yields overall, with an average of 6.1 and 6.8 t/ha in 2019 and 2021 (Table 9.13, Appendix), respectively, compared to 7.6 and 10.65 t/ha at the Herefordshire site (Table 9.14, Appendix). Mascani showed the highest yields again at the Herefordshire site in 2019 at 9.1 t/ha ($p<0.001$), with no differences between varieties in 2021 ($p=0.20$). The greater yield seen in Mascani in 2019 seems likely due to a reduced lodging prevalence compared to the other two varieties (Figure 9.3, Appendix).

When each experiment was analysed separately, there was no significant difference in the yields among any of the N timing treatments either at the Nottinghamshire or Herefordshire sites in either experimental year (2019 and 2021; $p>0.05$).

From individual site analysis of N uptake and partitioning data from harvest year 2019, there was a significant effect of variety at both the Nottinghamshire and Herefordshire site (Table 9.21, Table 9.22, Appendix). Mascani had the greatest N uptake (kg/ha) of all varieties at both locations, further explaining its greater yields. N timing treatment had a significant effect on the N uptake and NHI at the Nottinghamshire site, with treatment 4 (an equal split between N at tillering (GS25) and GS32) resulting in the greatest N uptake and treatment 5 (no N at tillering and a late application at GS39) resulting in the highest NHI (Table 9.21 Appendix). Unlike that seen in the rate experiments, N uptake was relatively similar between the Nottinghamshire and Herefordshire sites.

Data from all sites and years were combined for REML analysis (Figure 4.8). The REML analysis revealed significant variety ($p=0.003$) and treatment ($p<0.001$) main effects. The timing treatment difference was driven by the low yield of treatment 6 where no S had been applied (Figure 4.8); the differences between the other treatments were not statistically significant. Arithmetically, the highest yields were achieved with current RB209 timings (treatment 1) and treatment 4 (an equal split between N at tillering (GS25) and GS32 and yields were reduced where no N was applied at tillering (Figure 4.8). Treatment 1 gave the highest N uptake and fertiliser recovery.



Treatment	1	2	3	4	5	6
GS25	40	90		90		40
GS30	70	90	90		50	70
GS32	70		90	90	90	70
GS39					40	No S
	N applied (kg/ha)					

Figure 4.8 Mean yields (t/ha @ 15% mc) of winter oats fertilised with 180 kg N/ha split between different timings (GS25 30, 32, 39) and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from two experiments carried out in Herefordshire and two in Nottinghamshire in harvest seasons 2019 and 2021 analysed using REML resulting in predicted means, Error bars are +/- 1 SED.

Objective 3: Evaluate optimal nitrogen rates and timings and sulphur applications on spring oats yield

Environmental conditions: SMN & Rainfall

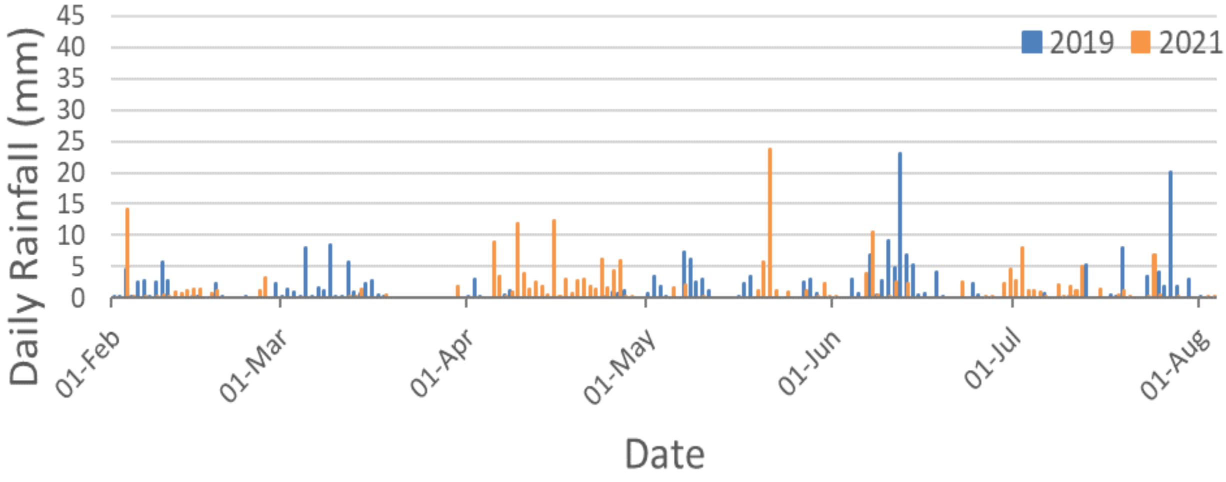
SMN, AAN and SNS Index information for core spring oats sites can be found in Table 4.5. The Fife site in 2019 had the greatest SNS Index at 2 compared to all other experiments, driven by high SMN in the topsoil. All other SNS Indexes were uniform, with an Index of 1.

The rainfall information for the spring oats core sites can be seen in Figure 4.9. At the Suffolk site, rainfall from 17th March to 31st August amounted to 241 mm in 2019, 251 mm in 2020 and 256 mm in 2021. From 1st February until 3rd August, the Cambridgeshire site received 234 mm in 2019 and 219 mm in 2021. Finally, the Fife site received 382 mm, 255 mm and 297 mm of rainfall over the 2019, 2020 and 2021 seasons, respectively, from 1st April until 8th September.

Table 4.5 SMN, AAN and the SNS index estimated from the AHDB Nutrient Management Guide for each core spring oats experiment. "NA" indicates data are not available.

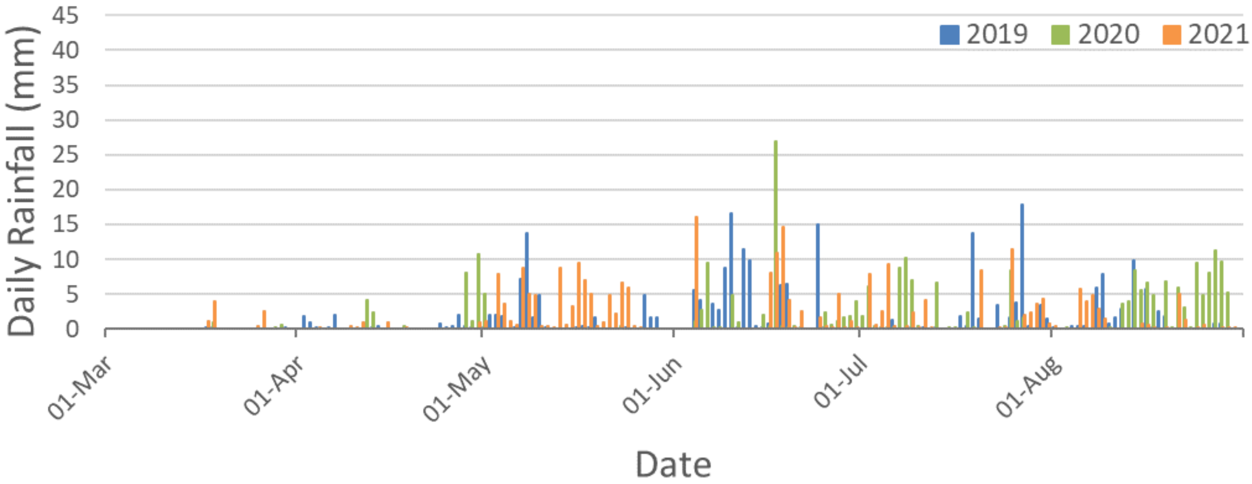
Rate/ Timing	Site	Year	SMN 0-30 cm (kg/ha)	SMN 30-90 cm (kg/ha)	AAN (kg/ha)	SNS Index (FAM)
Rate	Fife	2019	65	33	38	2
Rate	Cambridgeshire	2019	14.2	NA	NA	1
Timing	Fife	2019	65	33	38	2
Timing	Suffolk	2019	60.8	NA	NA	1
Rate	Fife	2020	11	10	21	1
Timing	Fife	2020	11	10	21	1
Timing	Suffolk	2020	21	46	44	1
Rate	Fife	2021	7	3	26	1
Rate	Cambridgeshire	2021	18	92	44	1
Rate	Lincolnshire	2021	3	3	11	1
Timing	Fife	2021	7	3	26	1
Timing	Suffolk	2021	NA	NA	NA	1

a)



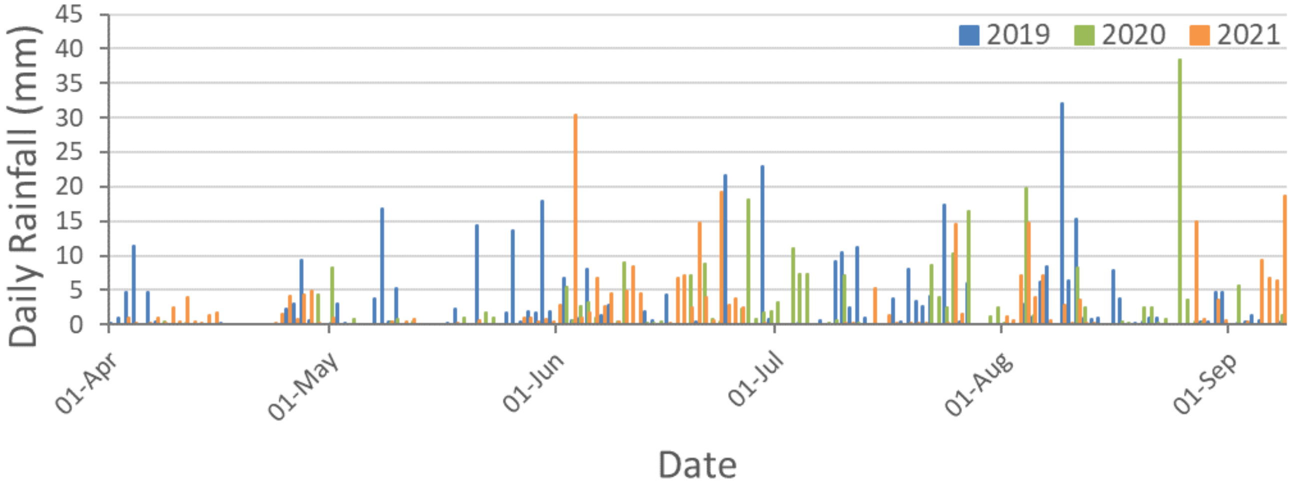
Daily Rainfall (mm)
2019
2021
01-Feb
01-Mar
01-Apr
01-May
01-Jun
01-Jul
01-Aug
Date

b)



Daily Rainfall (mm)
2019
2020
2021
01-Mar
01-Apr
01-May
01-Jun
01-Jul
01-Aug
Date

c)



Daily Rainfall (mm)
2019
2020
2021
01-Apr
01-May
01-Jun
01-Jul
01-Aug
01-Sep
Date

d)

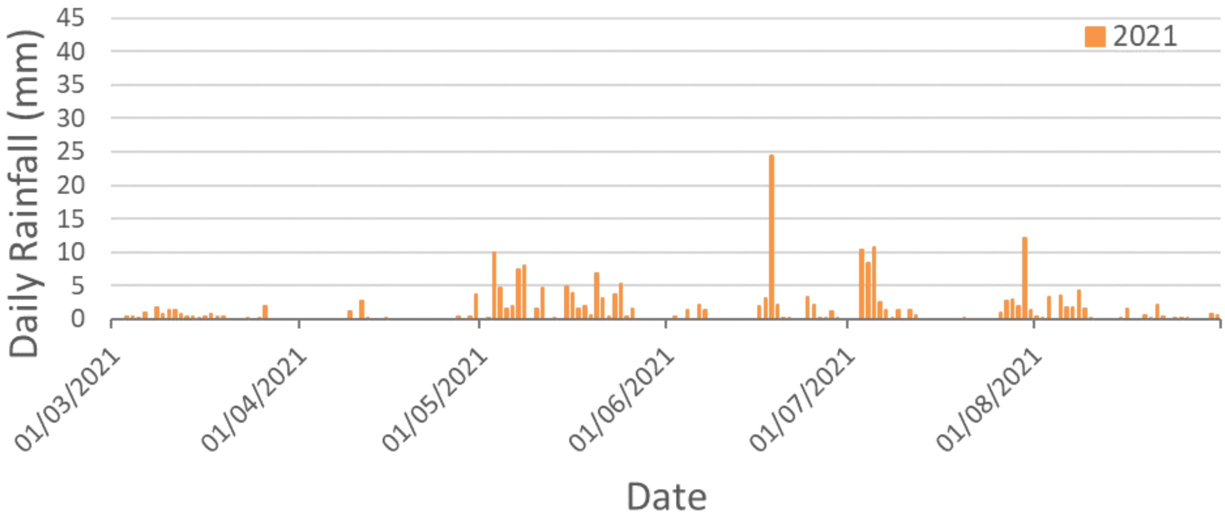


Figure 4.9. Rainfall data for the spring oat sites in a) Cambridgeshire, b) Suffolk, c) Fife and d) Lincolnshire in the harvest seasons 2019-2021.

Economic optimum N rates and causes of yield differences

The Fife site achieved good yields at N_{opt}, at an average of 7.65 t/ha in 2019 (Table 9.23, Appendix), 8.29 t/ha in 2020 (Table 9.25, Appendix) and 7.96 t/ha in 2021 (Table 9.26, Appendix). In all years, there was a significant response to increasing N rate (p<0.05) (Figure 4.10). N_{opt} varied throughout the trial years, being lowest in 2020 at an N_{opt} of 110 kg/ha, with little increase in yield above this rate. On the other hand, N_{opt} was extremely high in 2021 at 240 kg/ha, driven mostly by an increase in panicles/m^2 at this rate. There were significant differences between varieties (Canyon, Conway and WBP Elyann) in the 2019 and 2020 trials (p<0.001), largely driven by yield differences in Canyon, being much lower in 2019 but greater in 2020. However, no large differences in any yield parameters or lodging (Figure 9.5, Appendix) were evident. An N response curve could not be fitted for Canyon in both 2019 and 2020.

Yields at the Cambridgeshire site were much lower than in Fife, at an average of 5.39 t/ha at N_{opt} in 2019 and 5.08 t/ha in 2021. A low N_{opt} of 86 kg N/ha was reached in 2019, and yield, height and lodging (Figure 9.4 Appendix) was very consistent across all N rates and varieties. There was no response to N in 2021; this could be explained by the very high level of N in the soil (Table 4.5).

The site in Lincolnshire produced good yields at an average of 7.96 t/ha at N_{opt}, which was very similar for both Aspen and Canyon varieties at an average N_{opt} of 123 kg/ha. This site saw large increases in yield parameters rising from 0 to 70 kg/ha N through increases in grains/panicle (32 to 42) and panicles/m^2 (458 to 575), explaining the large increase in yield.

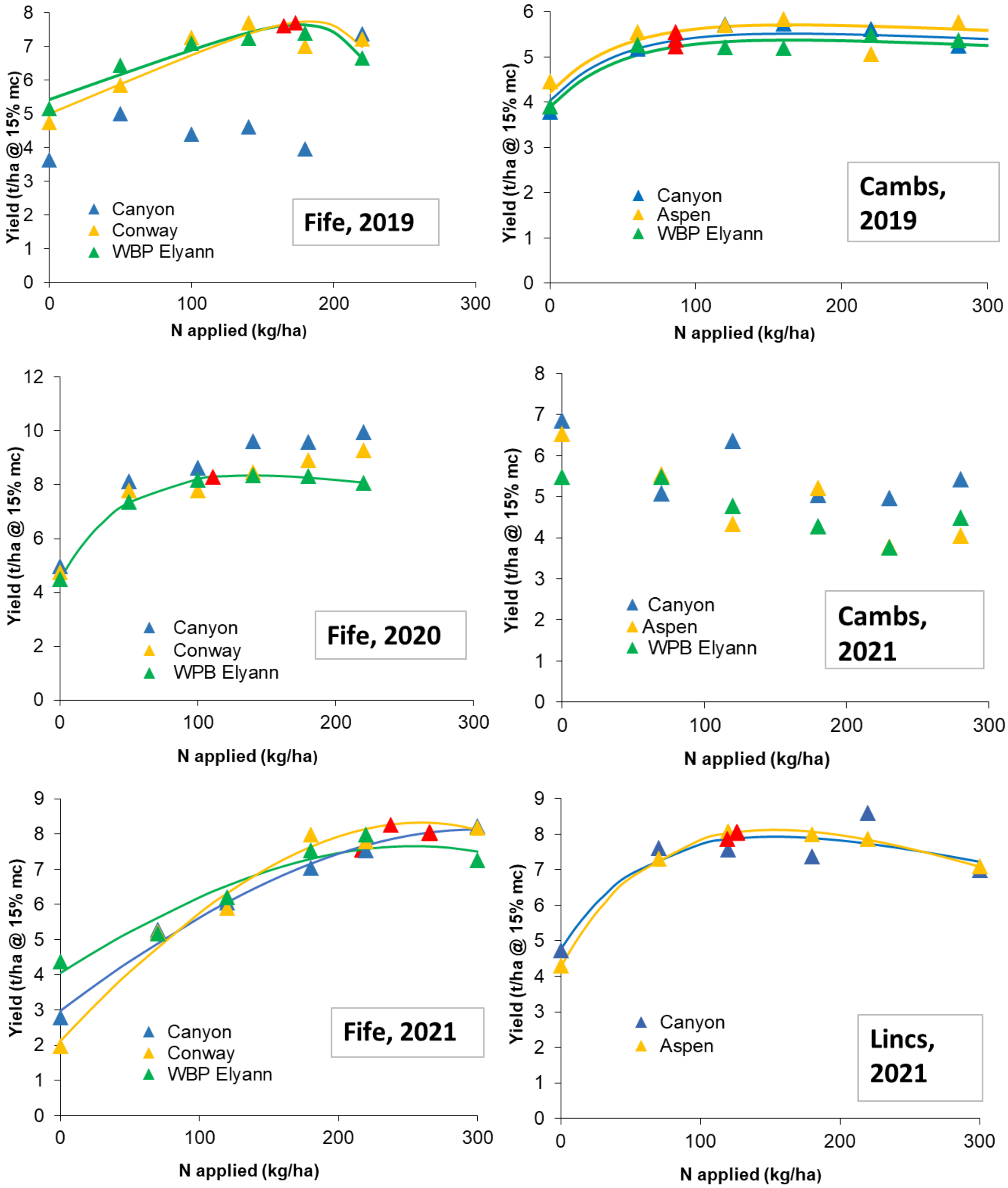


Figure 4.10 Yield response to N applied to different varieties of spring oats for experiments carried out in Fife, Cambridgeshire and Lincolnshire in harvest seasons 2019, 2020 and 2021. Blue, yellow and green coloured triangles are mean yields achieved at N rates from 0 to 300 kg N/ha. Coloured lines are the fitted N response curves for those varieties; a black line signifies only 1 curve was statistically justified. Red triangles denote the calculated economic optimum N rate (BER = 5). For Fife, 2020, it was not possible to fit curves to Canyon and Conway as yields did not plateau.

There were large differences in the amount of N taken up at the 0 kg N/ha N rate (Figure 4.11) which generally reflected the measured soil N availability (Table 4.5) apart from the 2019 Fife trial, where the soil N measurement gave much higher results than the actual N taken up at nil N.

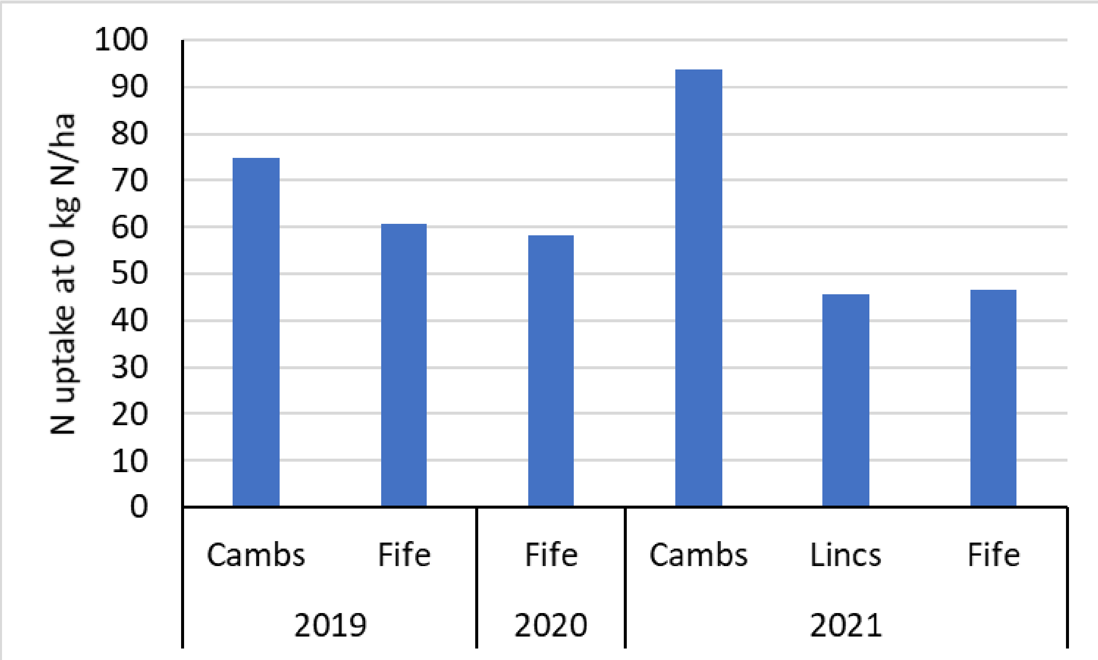


Figure 4.11 Average total N taken up at 0 kg N/ha N rate at each of the spring oats experimental sites.

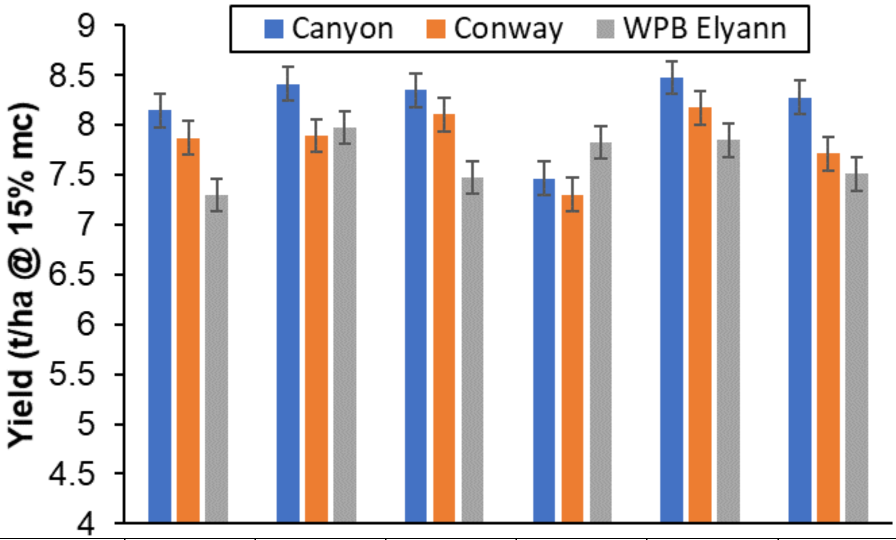
N uptake and N partitioning data were analysed separately for the Fife and Cambridgeshire sites due to differences in N rates and varieties. In Fife, variety had a significant effect on N uptake (kg/ha) across all experimental years (2019-2021; Table 9.33, Table 9.35, Table 9.36 Appendix). Conway showed the greatest N uptake in 2019 and 2020, but the lowest in 2021 (where only 0 and 120 kg N/ha was analysed). Conway also showed the greatest Grain N% in all years ($p<0.001$). There was a significant response in N uptake to increasing N rate in all years ($p<0.05$). NHI was greatest in 2020, which also showed the greatest yields, at an average of 91%. NHI significantly differed by variety in 2019 and 2020, but was inconsistent across years, with Canyon having the lowest NHI in 2019 but greatest in 2020.

In the Cambridgeshire 2019 trial, the only varietal effect was seen in grain N%, which was greatest in Canyon, closely followed by Aspen (Table 9.34 Appendix). Increasing N rate significantly increased N uptake, grain N% and straw/chaff N% but reduced NHI, which was highest at 0 kg N/ha (Table 9.34 Appendix).

Effect of N timings and S on yield and yield differences

Experimental data from SO timing experiments were combined across all years for REML analysis. Data from Fife and Suffolk were kept separate due to the different varieties tested, and potential impacts of weather and climate, on yields.

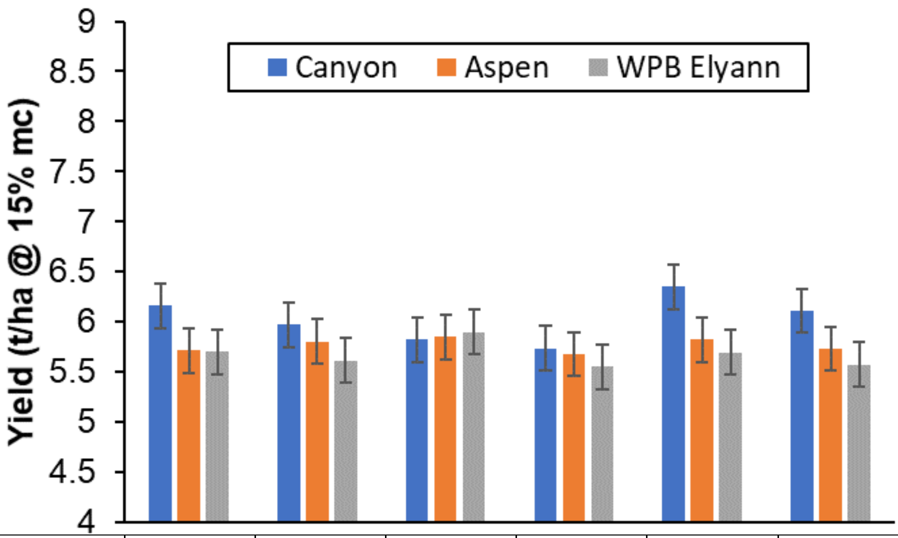
In the experiments carried out in Fife, there was a significant interaction between variety and treatment (N timing) on yield (Figure 4.12). Canyon usually showed the highest yields, apart from in treatment 4, where some N was held until application at GS39 (flag leaf blade all visible). There were no effects of treatment on the height of the crops, harvest index (HI) or panicles/m^2. There were, however, treatment effects on fertiliser recovery, which was the highest when all N was applied in the seedbed in treatment 5.



Treatment	**1**	**2**	**3**	**4**	**5**	**6**
Seedbed	60			40	120	60
GS13		60	90			
GS31	60	60	30	40		60
GS39				40		No S
	N applied (kg/ha)					

Figure 4.12 Mean yields (t/ha @ 15% mc) of three spring oats varieties fertilised with 120 kg N/ha split between different timings (Seedbed, GS13, 31, 39) and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from three experiments carried out in Fife in harvest seasons 2019, 2020 and 2021 analysed using REML resulting in predicted means, Error bars are +/- 1 SED.

In the experiments carried out in Suffolk, there was also a significant interaction between variety and treatment on yield (*Figure 4.13*). Again, Canyon had consistently the highest yield across all treatments apart from treatment 3, where most N was applied at GS13 (emergence 3-leaf stage) and some at GS31 (first node detectable in stem elongation). In the East Anglian experiments, there was also no effect of treatment on crop height, HI or panicles/m^2 and treatment had no effect on fertiliser recovery, although the highest value was from all N applied in the seedbed, like seen in Fife.



Treatment	1	2	3	4	5	6
Seedbed	60			40	120	60
GS13		60	90			
GS31	60	60	30	40		60
GS39				40		No S
	N applied (kg/ha)					

Figure 4.13 Mean yields (t/ha @ 15% mc) of three spring oats varieties fertilised with 120 kg N/ha split between different timings (Seedbed, GS13, 31, 39) and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from three experiments carried out in Suffolk in seasons 2019, 2020 and 2021 analysed using REML resulting in predicted means, Error bars are +/- 1 SED.

Fife and Suffolk sites were also analysed separately for effects on N uptake and partitioning. No differences were seen across any N parameters analysed in Fife in 2019 or 2020 because of timing treatment (N uptake, grain N%, straw/chaff N% and NHI; Table 9.47, Table 9.49 Appendix). However, varietal differences were seen in all N parameters measured; Conway had the greatest N uptake and NHI over both experimental years, not consistent with the highest yields seen. In Suffolk in 2019, the only significant effect was of N timing treatment on total N uptake (kg/ha; Table 9.48), where treatment 5 (all N in the seedbed) resulted in the greatest N uptake, consistent with the highest yield seen in Figure 4.13. The lowest N uptake was seen in treatment 2, where N application was split equally between GS13 and GS31.

Objective 4: Evaluate the impact of nitrogen and sulphur on the milling quality of oats

Effect of N rate on milling quality of winter oats

A significant variety effect was obtained for all grain quality traits measured in each trial (Table 9.50, Table 9.51, Table 9.52, Table 9.53, Table 9.54, see Appendix) as shown in Figure 4.14. Across all trials and treatments, RGT Southwark had a lower kernel content and hullability and higher screenings, but also a higher specific weight. Penrose had a lower specific weight but high kernel content and hullability and low screenings. Mascani had a high specific weight, kernel content, and hullability and low screenings. A significant effect of treatment was found for all traits at most sites. In general, the response of grain quality traits was not linear in response to nitrogen.

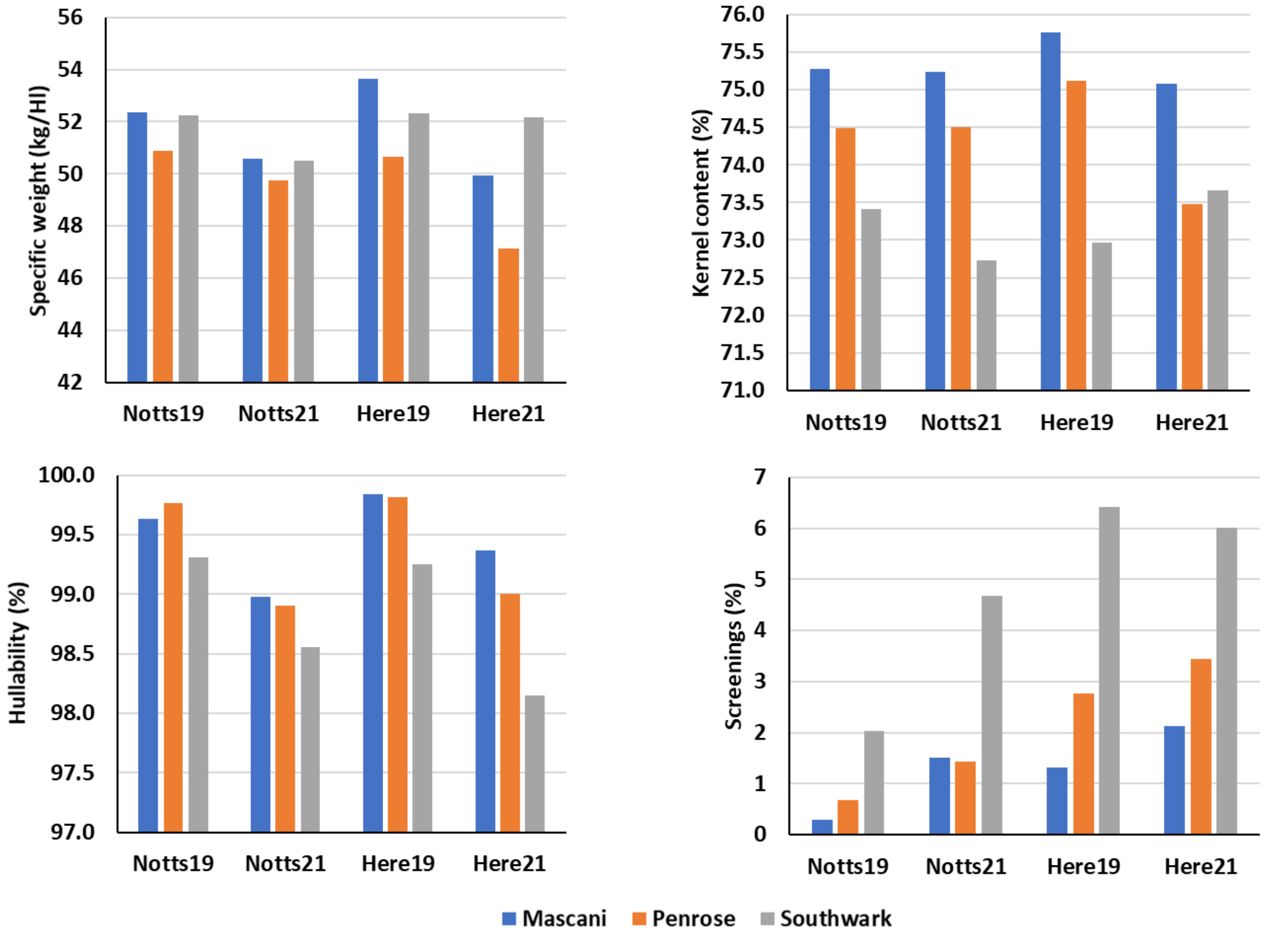


Figure 4.14. Mean specific weight (kg/hl), Kernel Content (%), hullability (%), screenings (%)) of three winter oats varieties across N response treatments for experiments carried out in Herefordshire (Here19, Here21) and Nottinghamshire (Notts19, Notts21) in harvest seasons 2019 and 2021.

A significant effect of N treatment on specific weight was found in all trials except for the trial in Nottinghamshire in 2019. In general, as the rate of N application increased, specific weight decreased. A significant treatment by variety interaction was found in the two trials in Herefordshire; the difference in specific weights between treatments was much greater for Penrose than for either Mascani or RGT Southwark. Although at the highest N treatments, specific weight values were lower than milling specifications for some varieties and trials, the values for specific weight at the grain yield N_{opt} were all above 50 kg/hl, except for Penrose at the highest yielding site in Herefordshire 2021 (Figure 4.15, Table 4.6).

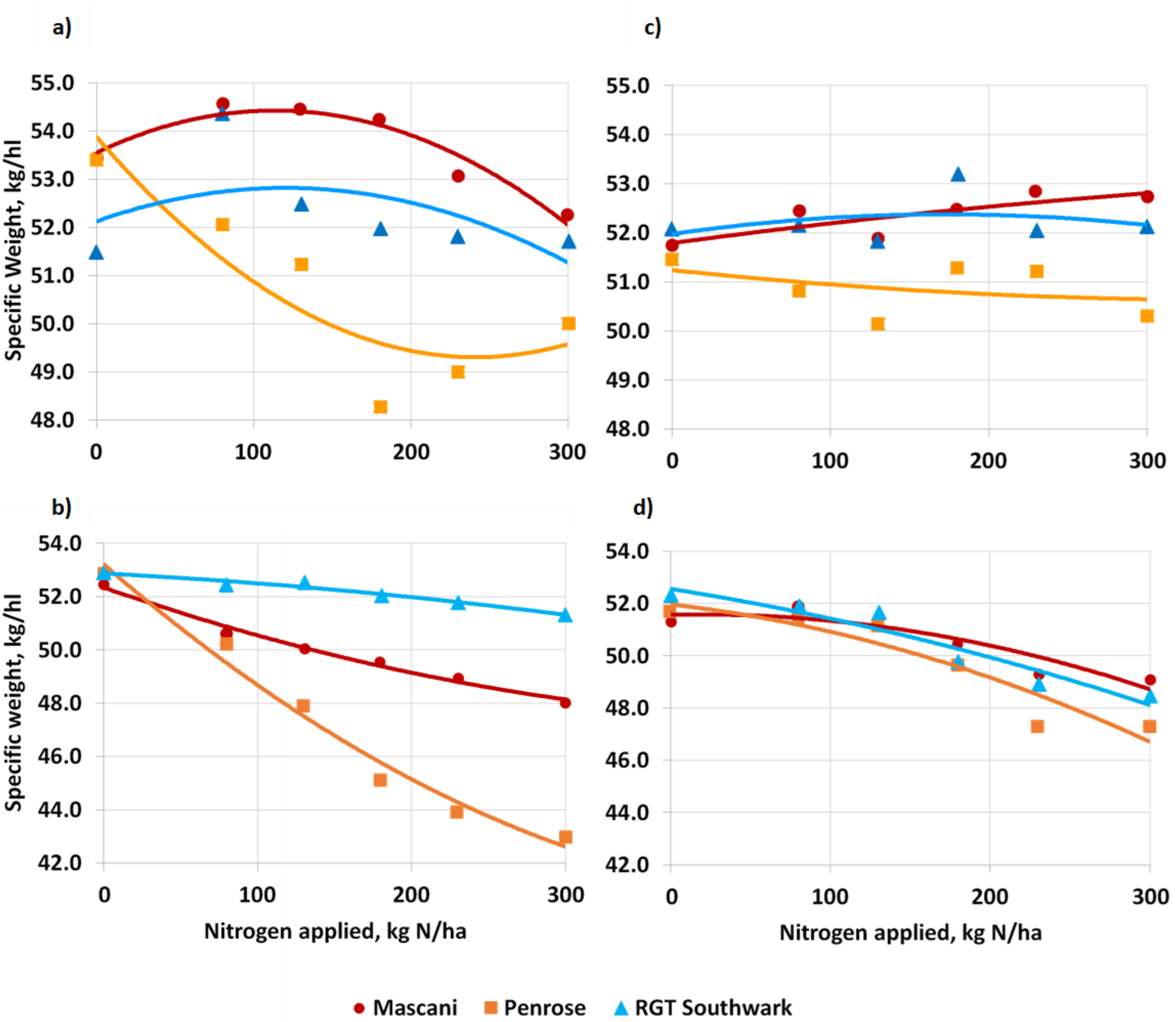


Figure 4.15. Response of Specific Weight (kg/hl) to N applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire (a, b) and Nottinghamshire (c, d) in harvest seasons 2019 (a, c) and 2021 (b, d). Symbols indicate the variety mean specific weight achieved at N rates from 0 to 300 kg N/ha and the lines represented a fitted second order polynomial curve to the data.

Kernel content increased as the rate of N application increased in the two trials in Herefordshire (Figure 4.16). A significant treatment by variety interaction was also found in these two trials, with the kernel content of Penrose being more stable across treatments than Mascani or RGT Southwark. There was no significant effect of treatment on kernel content in the Nottinghamshire trial in 2019 but a decrease in kernel content with increasing N application in 2021. Values for kernel content at the grain yield N_{opt} are shown in Table 4.6 and Table 9.53 (Appendix). A poor relationship was found between specific weight and kernel content for these four trials (Figure 4.17), suggesting that specific weight is not a good predictor for milling yield.

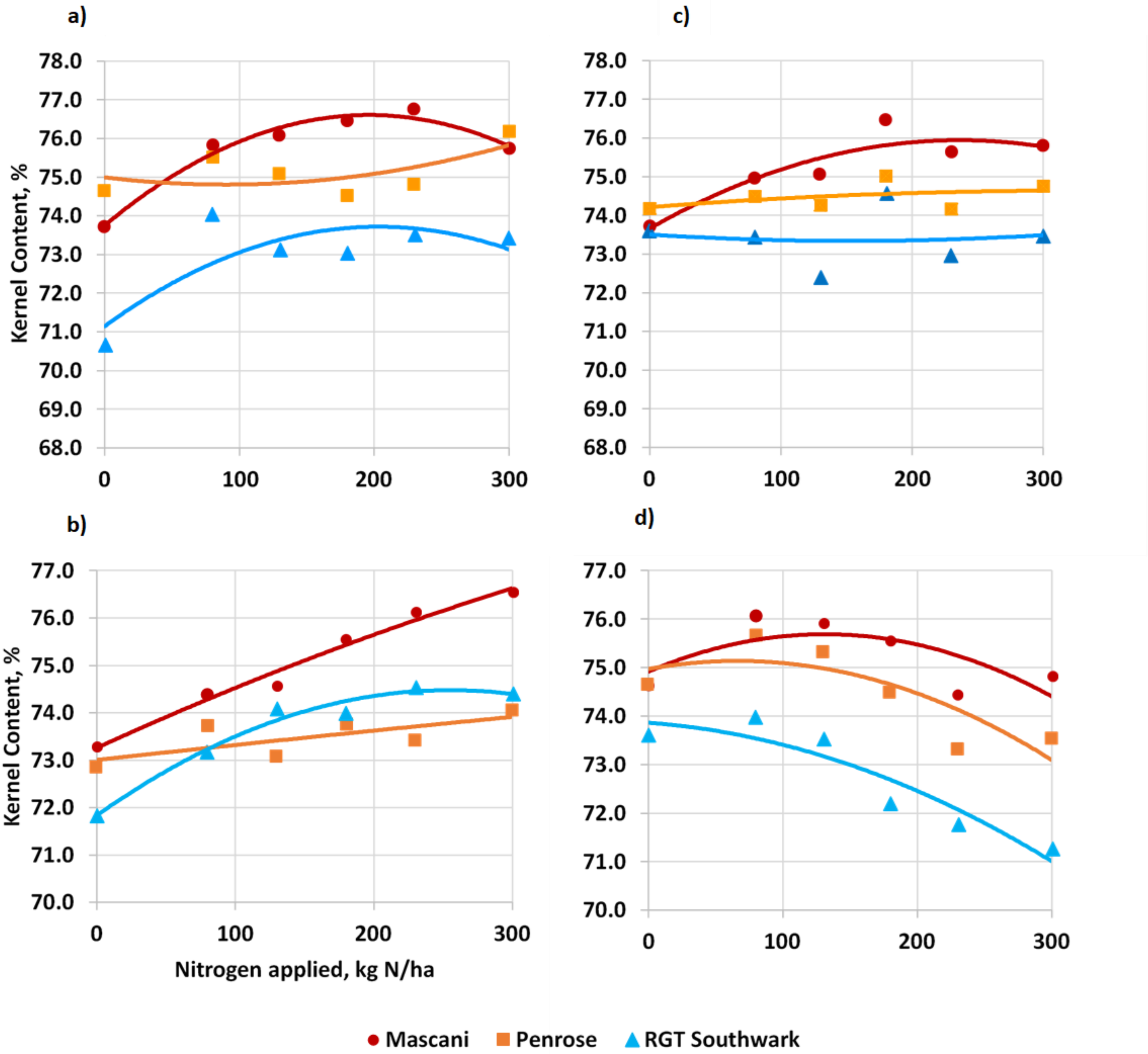


Figure 4.16. Response of Kernel Content (%) to N applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire (a, b) and Nottinghamshire (c, d) in harvest seasons 2019 (a, c) and 2021 (b, d). Symbols indicate the variety mean kernel contents achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data.

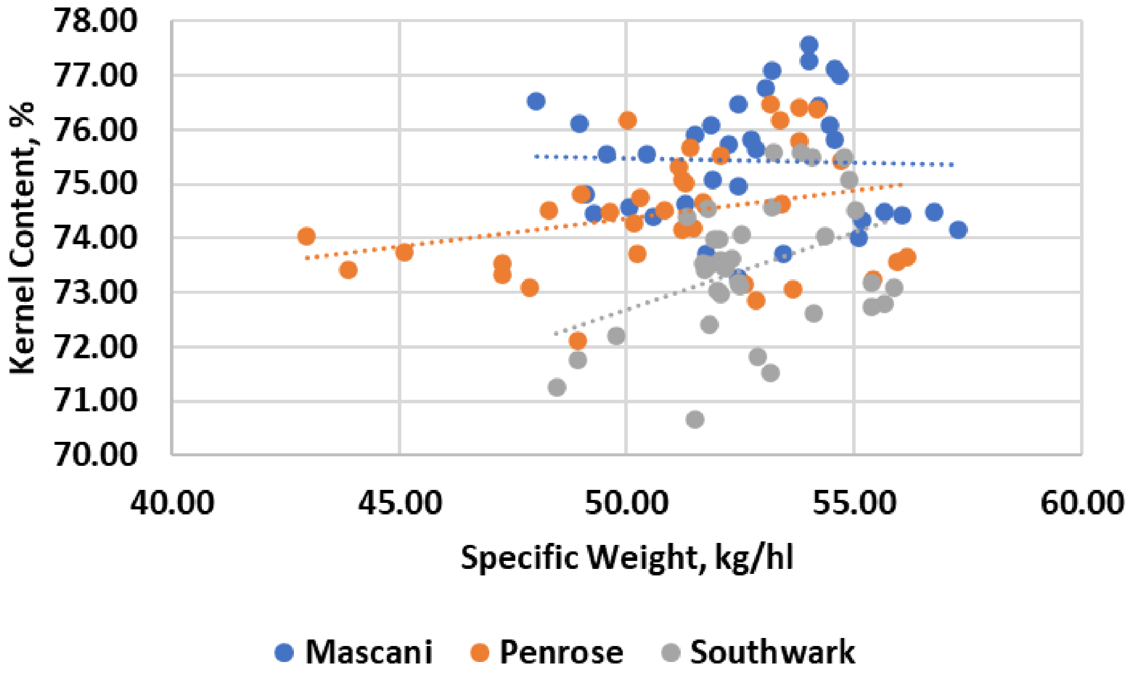


Figure 4.17. Relationship between Specific Weight and Kernel content in three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire and Nottinghamshire in harvest seasons 2019 and 2021. Dotted lines indicate linear regression line for each variety.

Hullability significantly increased as the rate of N application increased in all four trials. Although there was a significant effect of treatment in all trials, the range in hullabilities between treatments was relatively small, with values of less than 98% hullability only found at the no N treated plots, except for RGT Southwark in Herefordshire 2021 (Figure 4.18).

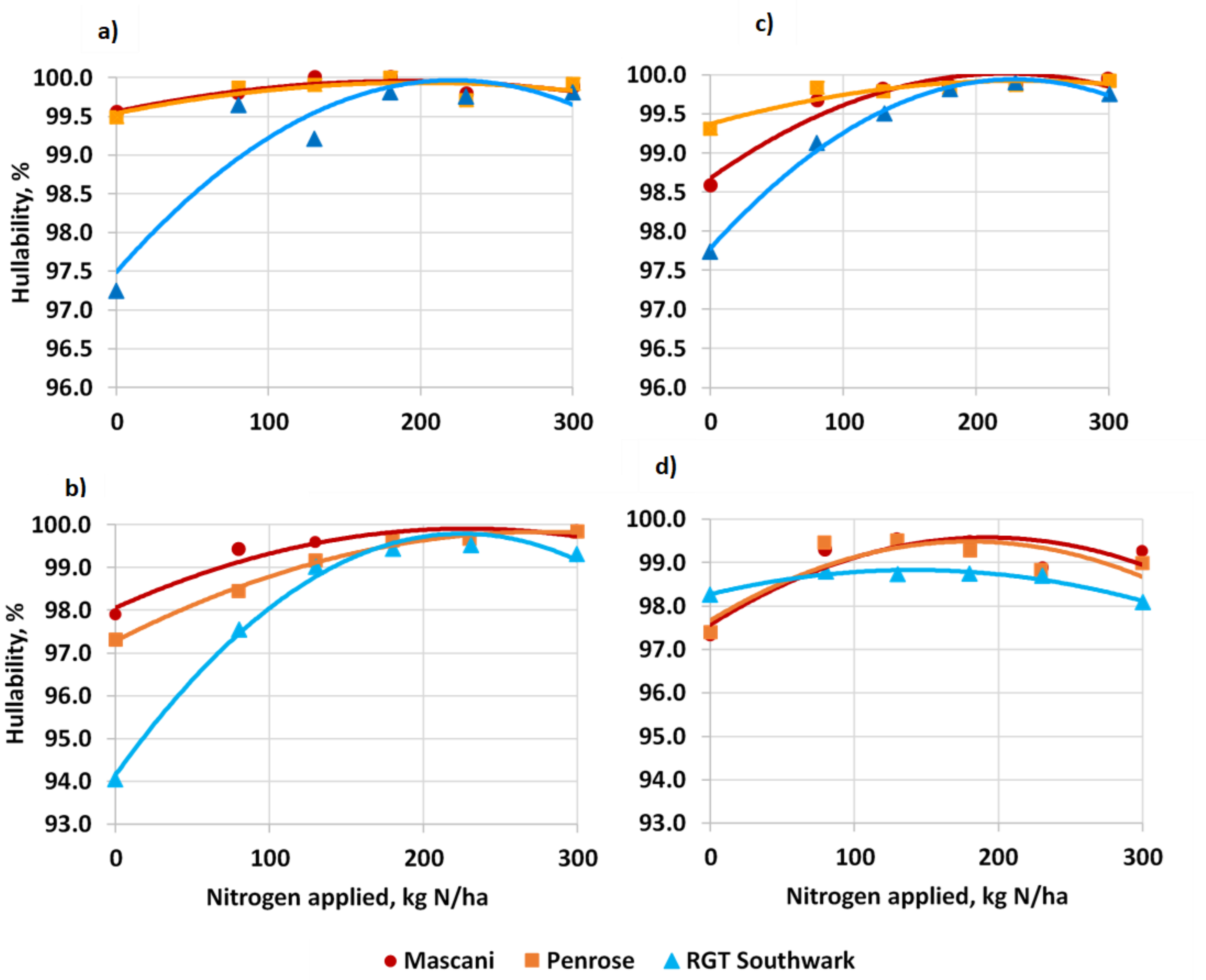


Figure 4.18. Response of Hullability (%) to N applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire (a, b) and Nottinghamshire (c, d) in harvest seasons 2019 (a, c) and 2021 (b, d). Symbols indicate the variety mean hullabilities achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data.

Screenings % is a measure of the proportion of harvested grain that passes through a 2 mm sieve, which increased significantly in all trials as the rate of N application increased. There was a significant interaction between variety and treatment, with the increase in screenings at higher N applications being much higher for RGT Southwark than for either Mascani or Penrose. At the N_{opt}, all varieties had screenings of 6% or less (Figure 4.19).

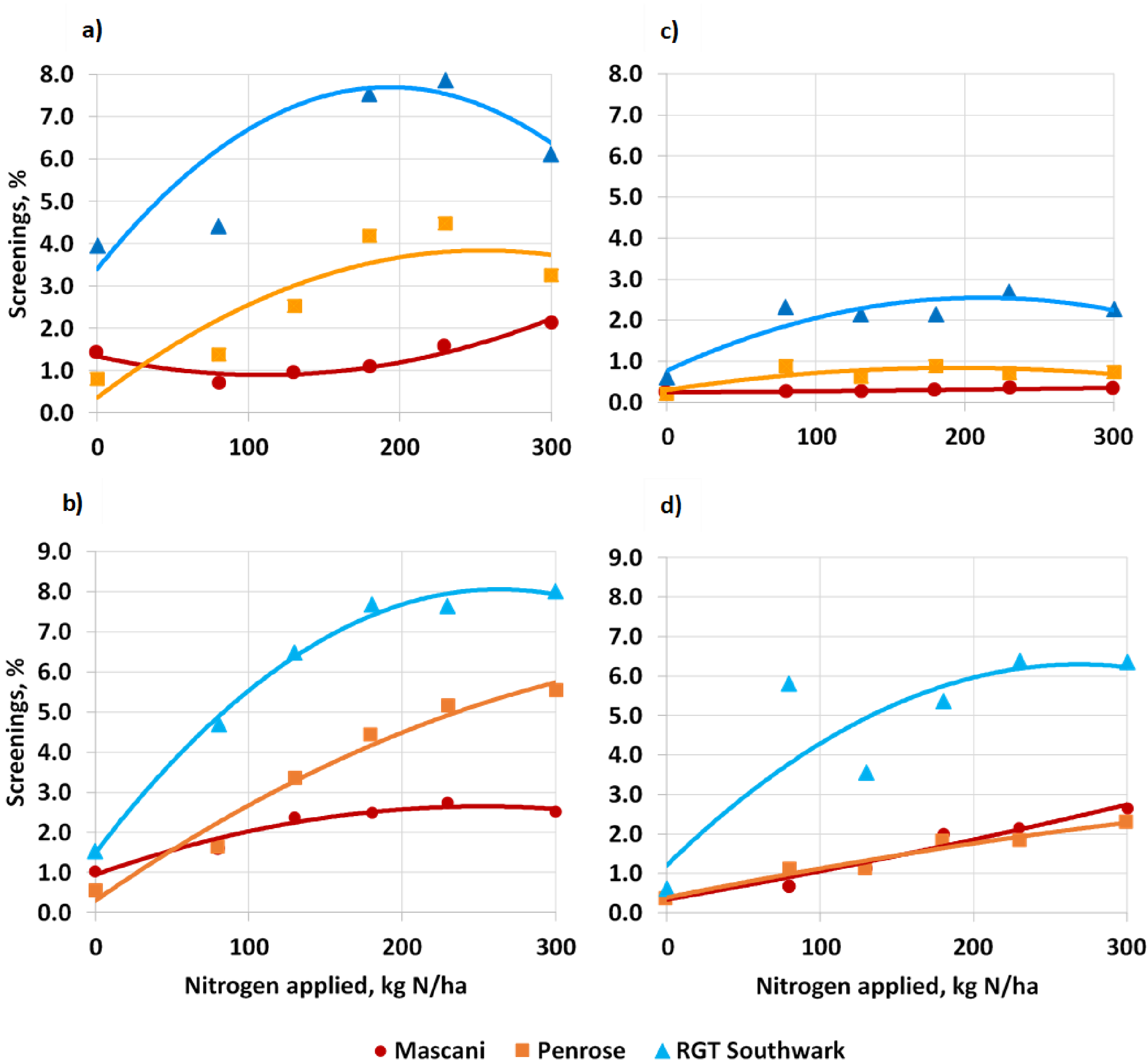


Figure 4.19. Response of Screenings (%) to N applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire (a, b) and Nottinghamshire (c, d) in harvest seasons 2019 (a, c) and 2021 (b, d). Symbols indicate the variety mean screenings achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data.

Thousand grain weight (TGW) showed a significant decrease in all trials as the rate of N application increased (Figure 4.20). This is likely a consequence of the higher grain yields at higher N application levels due to a greater number of grains per panicle, resulting in either an increase in tertiary grains in each spikelet or poorer grain filling. A close negative relationship was found between TGW and screenings percentage (Figure 4.21); therefore, conditions that resulted in low TGW were associated with high screenings.

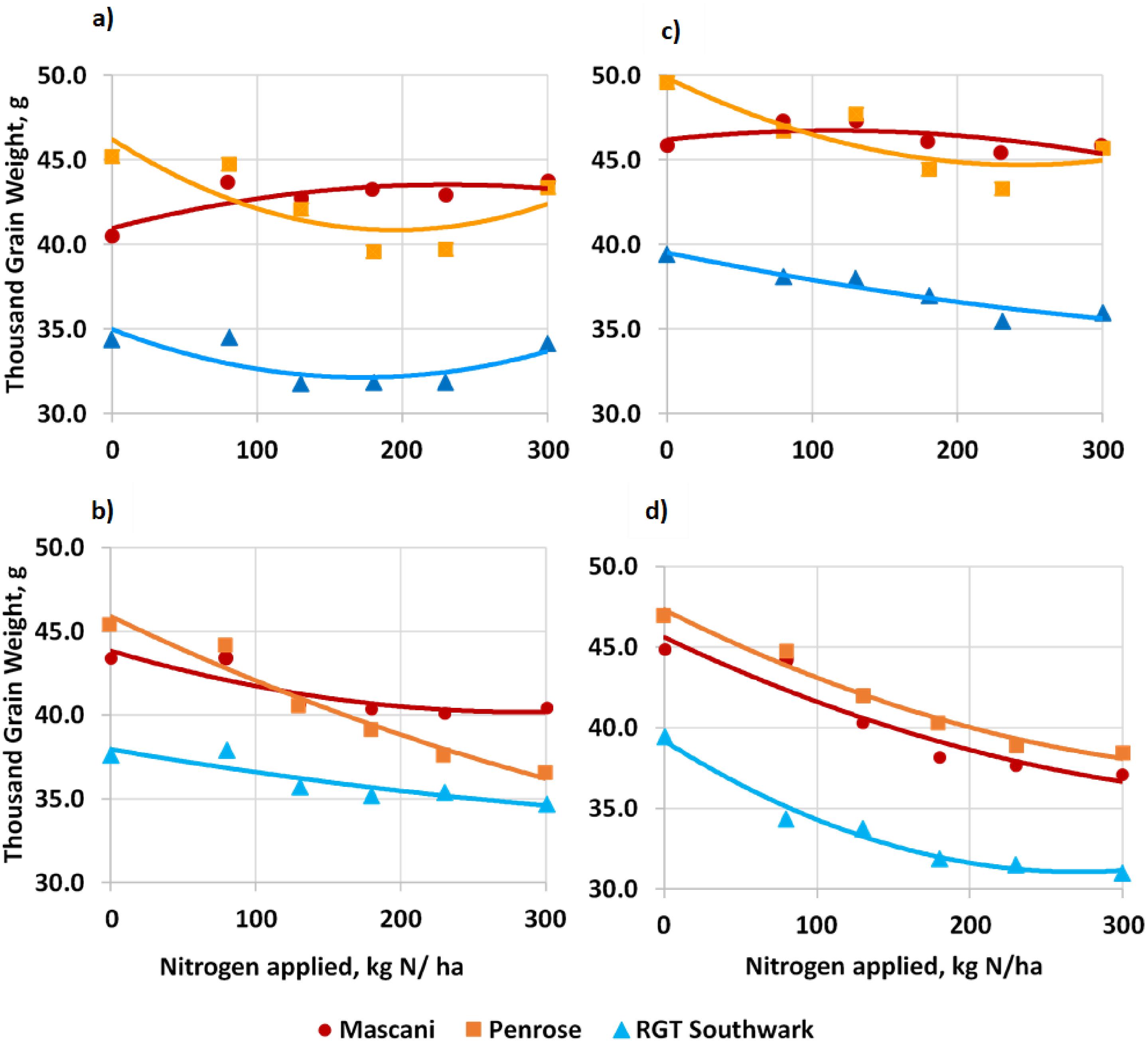


Figure 4.20. Response of Thousand Grain Weight (TGW, g) to N applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire (a, b) and Nottinghamshire (c, d) in harvest seasons 2019 (a, c) and 2021 (b, d). Symbols indicate the variety mean TGWs achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data.

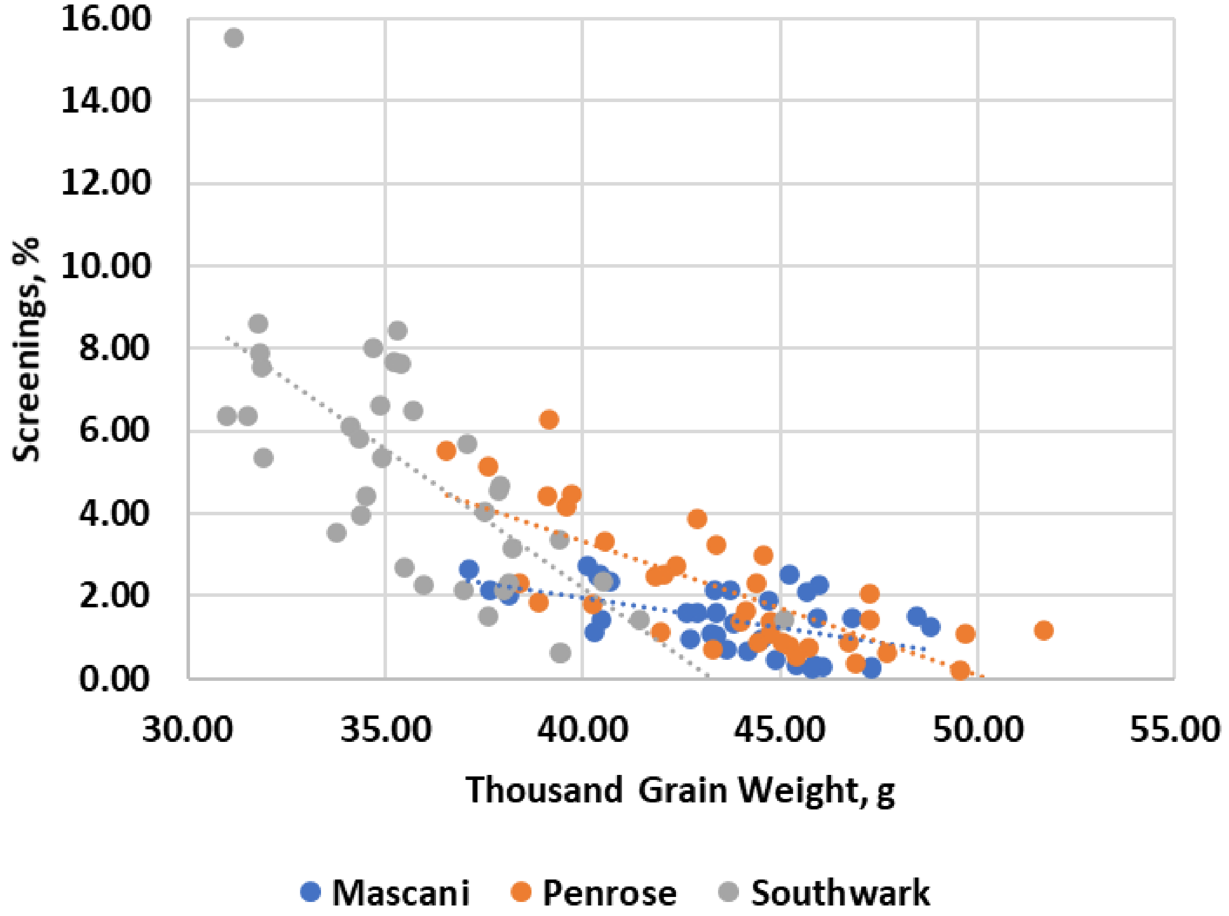


Figure 4.21. Relationship between Thousand Grain Weight and Screenings in three varieties of winter oats (Mascani, Penrose and RGT Southwark) for experiments carried out in Herefordshire and Nottinghamshire (in harvest seasons 2019 and 2021). Dotted lines indicate linear regression line for each variety.

Table 4.6. Mean variety values of Screenings (%), Specific Weight (kg/hl), Kernel Content (%) and Hullability (%) at the Nopt for grain yield determined from N response experiments carried out in Herefordshire and Nottinghamshire in harvest seasons 2019 and 2021. N rates from 0 to 300 kg N/ha applied to three varieties of winter oats (Mascani, Penrose and RGT Southwark).

	Trial year	location	N_{opt} kg N/ha	Yield at N_{opt} t/ ha @ 15% moisture	Screenings % at N_{opt}	Specific Weight kg/hl at N_{opt}	Kernel Content % at N_{opt}	Hullability at N_{opt}
Mascani	2019	Herefordshire	60	8.40	1.00	54.1	75.0	99.7
Penrose	2019	Herefordshire	52	7.05	1.50	52.1	74.6	99.8
Southwark	2019	Herefordshire	60	6.05	5.70	52.8	72.3	98.7
Mascani	2019	Nottinghamshire	20	5.40	0.30	52.0	74.0	99.1
Penrose	2019	Nottinghamshire	20	6.10	0.50	51.1	74.3	99.5
Southwark	2019	Nottinghamshire	20	5.80	1.00	52.2	73.6	98.2
Mascani	2021	Herefordshire	118	9.90	2.00	51.1	74.9	99.6
Penrose	2021	Herefordshire	118	9.90	2.80	48.1	73.3	99.0
Southwark	2021	Herefordshire	118	9.90	6.00	52.5	73.9	98.5
Mascani	2021	Nottinghamshire	35	5.50	0.46	51.3	75.1	98.0
Penrose	2021	Nottinghamshire	35	5.50	0.46	51.7	75.0	98.0
Southwark	2021	Nottinghamshire	35	5.50	2.80	52.3	73.6	98.3

Effect of N rate on milling quality of spring oats

For the response to N in spring oats, data from the Fife site, and that from Eastern England (Cambridgeshire and Lincolnshire sites) were analysed separately due to different varieties being tested at the two locations in addition to the large geographical distance, resulting in very contrasting climate and soils. This resulted in contrasting site means for grain quality both between sites and years (Table 4.7). For example, the site mean values for specific weight and kernel content were much lower in the Cambridgeshire and Lincolnshire site in 2021 than in 2019 or the values in Fife in 2019, 2020 and 2021. In Fife, however, the site mean values for specific weight and kernel content were much lower in 2019 than in 2020 or 2021.

Table 4.7. Site means across varieties and nitrogen treatment at each location (Cambridgeshire, Lincolnshire, and Fife) in 2019, 2020 and 2021.

	Cambs19	Cambs21	Lincs21	Fife19	Fife20	Fife21
Specific Weight kg/Hl	53.7	48.5	46.7	51.3	55.3	54.8
Kernel Content, %	73.6	70.0	70.7	73.0	76.8	75.2
Hullability, %	98.1	95.5	98.1	97.7	99.4	97.2

Individual trial treatment and variety results are presented in Table 9.55, Table 9.56, Table 9.57, Table 9.58, and Table 9.59 (See Appendix). A significant effect of variety was obtained in all three years of trials carried out at the Scottish site in Fife. Over all N treatments and trials, Conway had the highest hullability and lowest screenings in all trials, whilst Canyon had the highest TGW and Specific Weight and WPB Elyann had the highest kernel content. Similarly, in the Cambridgeshire and Lincolnshire trials, there was a significant effect of variety in all traits, with Canyon having the lowest hullability and kernel content in all three trials and WPB Elyann the highest kernel content but lowest specific weight.

Figure 4.22 shows a combined analysis for the effect of N application on Specific Weight (kg/Hl), Kernel Content, and Hullability across the two trials in Cambridgeshire. No interaction between variety and treatment was observed. In response to N treatment, specific weight decreased, and kernel content and hullability increased. Figure 4.22 also shows a combined analysis for the effect of N application on thousand grain weight (TGW, g) and screenings across the two trials in Cambridgeshire. Screenings % increased with increasing application of N and this was mirrored by a decrease in TGW. However, the values for screenings obtained were all very low and below those that would cause issues for acceptance for milling oats.

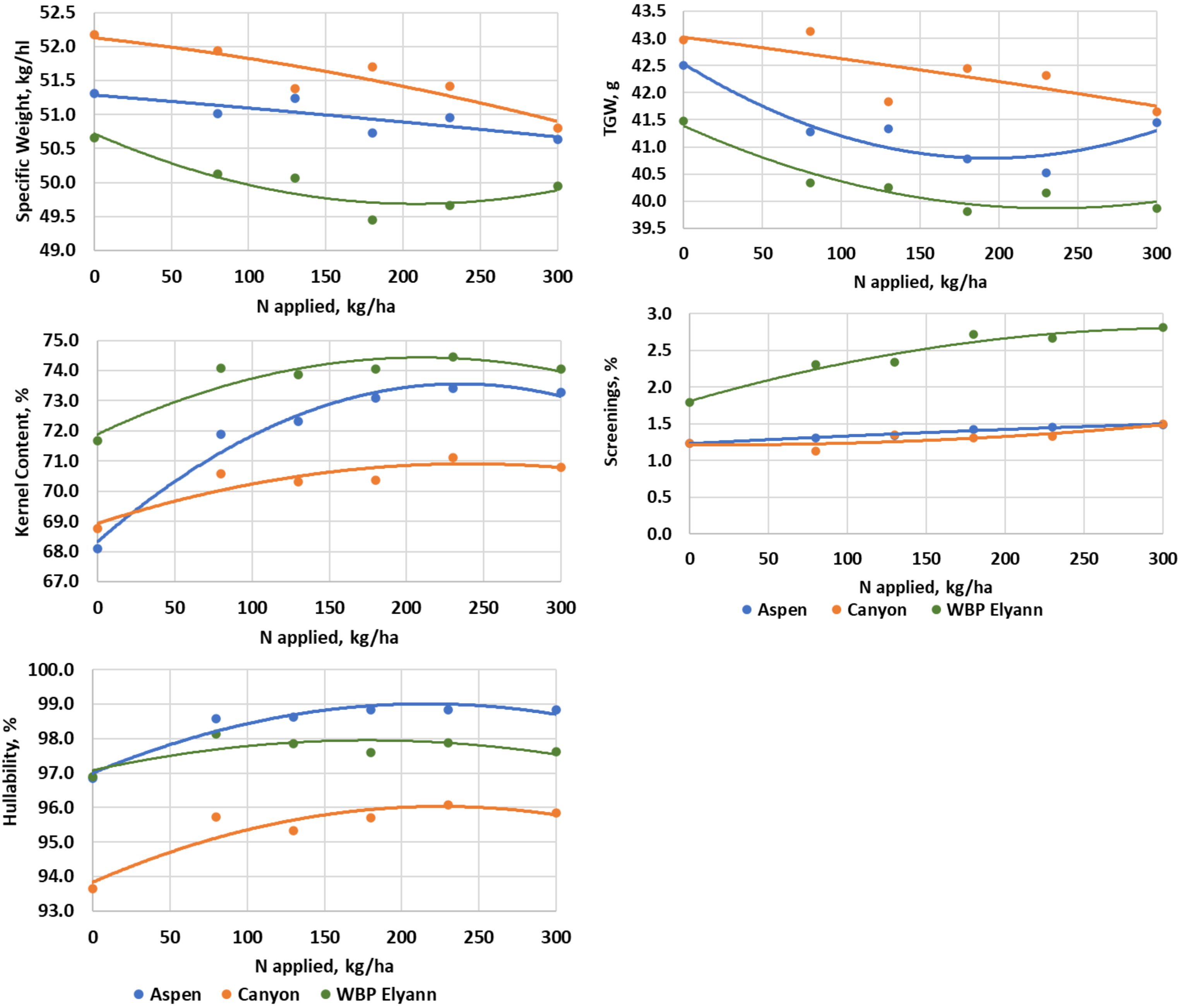


Figure 4.22. The response of Specific Weight (kg/hl), Kernel Content (%), Hullability, Thousand Grain Weight (TGW, g) and Screenings (%) to applied nitrogen of three spring oat varieties (Aspen, Canyon and WPB Elyann). Symbols indicate the variety mean values achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data. Mean values from three experiments carried out in Eastern England (Cambridgeshire and Lincolnshire) in harvest seasons 2019 and 2021.

Figure 4.23 shows a combined analysis for the effect of N application on Specific Weight (kg/hl), Kernel Content and Hullability across the three trials in Fife. In response to N treatment, specific weight decreased, and kernel content and hullability increased. A significant variety by treatment interaction was observed for specific weight with the response to increasing N greater in WPB Elyann than in the other two varieties. Although the response of Kernel Content to increasing N was significant in 2020 and 2021, and for hullability in all three years, the effect of variety is very clear.

Figure 4.23 also shows a combined analysis for the effect of N application on thousand grain weight (TGW, g) and screenings across the three trials in Scotland. Screenings % significantly increased with increasing application of N in all 3 trials and this was mirrored by a significant decrease in TGW. As with the trials in Cambridgeshire, the values for screenings obtained were all very low and below those that would cause issues for acceptance for milling oats.

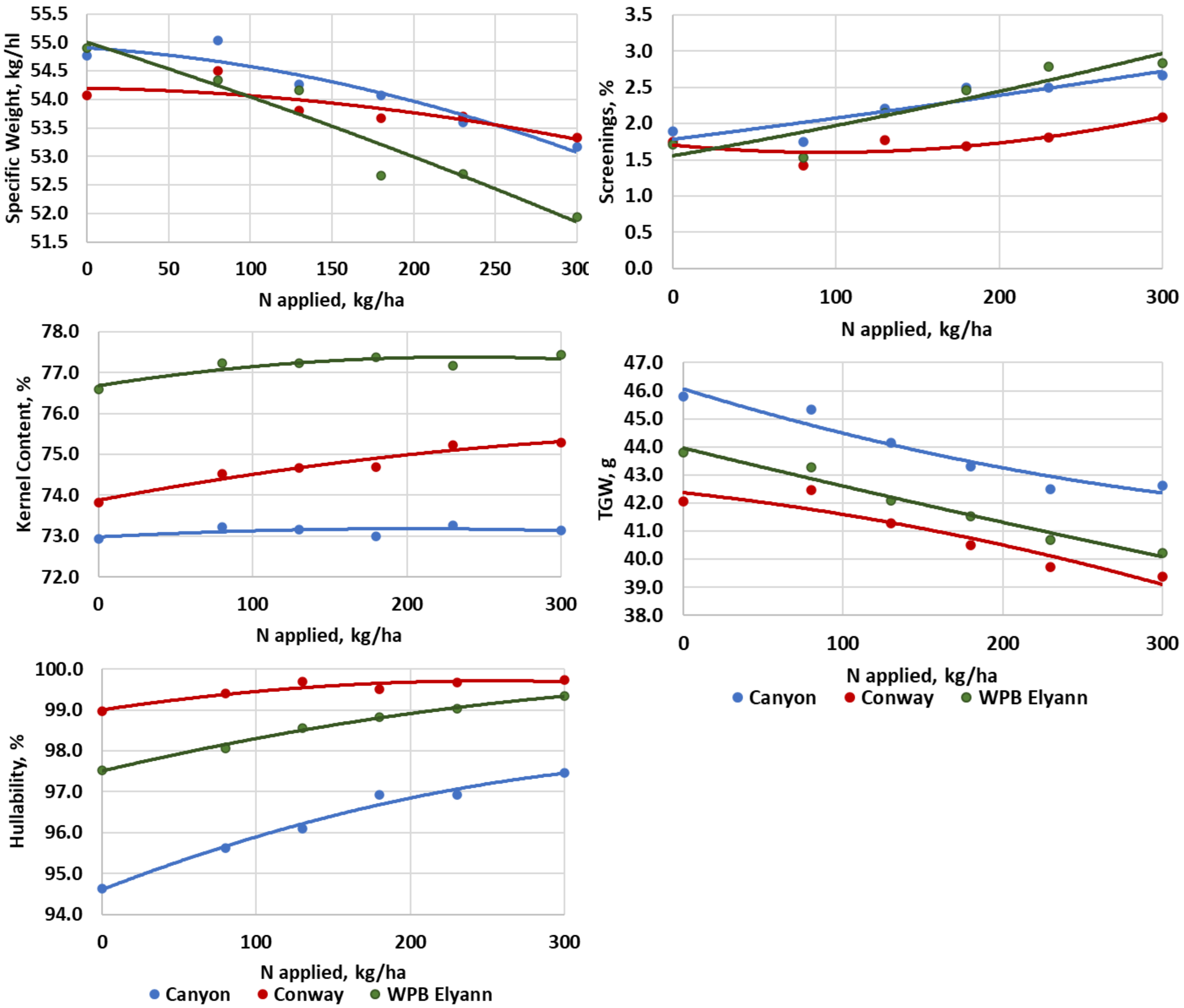


Figure 4.23. The response of Specific Weight (kg/hl), Kernel Content (%), Hullability (%), Thousand Grain Weight (TGW) and Screenings (%) to applied nitrogen (N) of three spring oat varieties (Canyon, Conway and WPB Elyann). Symbols indicate the variety mean values achieved at N rates from 0 to 300 kg N/ha and the lines represent a fitted second order polynomial curve to the data. Mean values from three experiments carried out in Fife in harvest seasons 2019, 2020 and 2021.

Values for specific weight, kernel content, hullability and screenings at the grain yield N_{opt} for each trial and variety are shown in Table 4.8 for all those trials where it was possible to calculate such an N_{opt}. Despite the very high N_{opt} for grain yield obtained in Fife in 2021, high grain quality was found at such levels of N application. In Cambridgeshire and Lincolnshire where the N_{opt} values of N application were much lower, kernel contents were lower, but these reflected the lower values obtained in those trials.

Table 4.8. Mean variety values of Screenings (%), Specific Weight (kg/hl), Kernel Content (%) and Hullability (%) at the N_{opt} for grain yield determined from N response experiments carried out in Fife, Cambridgeshire and Lincolnshire in harvest seasons 2019, 2020 and 2021. N rates from 0 to 300 kg N/ha applied to three varieties of spring oats at each site. "na" indicates varieties and trials where no Nopt could be determined from the grain yield data at those sites.

Trial Location	Year	Variety	N_{opt}	Yield at N_{opt} t/ ha @ 15% moisture	Screenings at N_{opt}	Specific Weight at N_{opt}	Kernel Content at N_{opt}	Hullability at N_{opt}
Fife	2019	Canyon	na	na	na	na	na	na
Fife	2019	Conway	173	7.7	3.05	51.3	75.9	99.5
Fife	2019	WPB Elyann	165	7.6	3.48	50.6	75.9	99.1
Fife	2020	Canyon	na	na	na	na	na	na
Fife	2020	Conway	na	na	na	na	na	na
Fife	2020	WPB Elyann	111	8.3	2.49	54.8	78.5	99.0
Fife	2021	Canyon	266	8.0	2.14	55.2	74.1	95.8
Fife	2021	Conway	238	8.3	0.84	54.4	74.8	99.6
Fife	2021	WPB Elyann	217	7.6	1.44	53.8	77.7	98.7
Cambs	2019	Aspen	86	5.5	1.40	54.5	72.4	98.9
Cambs	2019	Canyon	86	5.3	1.20	55.1	72.3	96.8
Cambs	2019	Conway	86	5.1	2.00	52.4	75.6	98.7
Cambs	2021	Aspen	na	na	na	na	na	na
Cambs	2021	Canyon	na	na	na	na	na	na
Cambs	2021	Conway	na	na	na	na	na	na
Lincs	2021	Aspen	126	8.1	0.40	50.2	72.2	99.5
Lincs	2021	Canyon	119	7.9	0.49	50.7	72.3	97.5

Effect of N timing on milling quality of winter oats

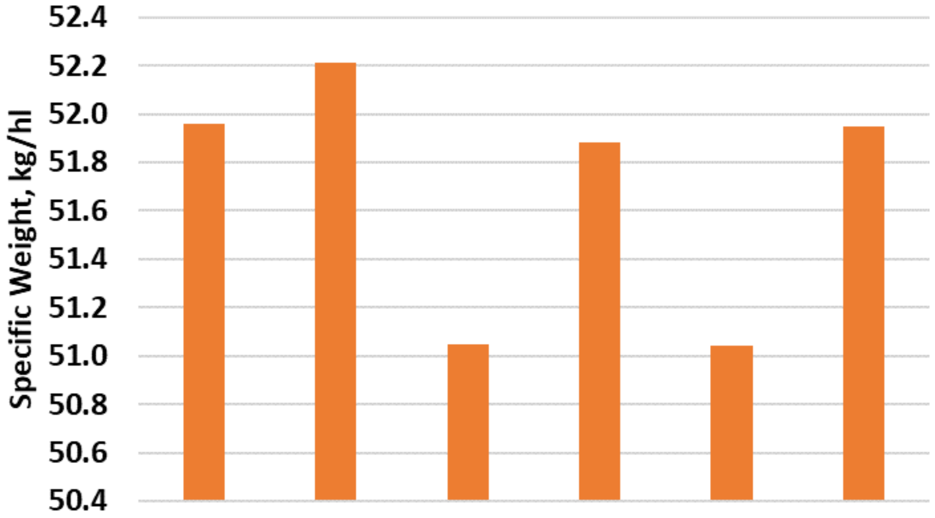
For the winter oat N timing experiments carried out in Nottinghamshire and Herefordshire, a significant variety effect was obtained for all grain quality traits measured in each trial as summarised in the cross-trial analysis in Table 4.9. Across all trials and treatments, RGT Southwark had a lower kernel content and higher screenings. Penrose had a lower specific weight but high kernel content and hullability and low screenings. Mascani had a high specific weight, kernel content and hullability and low screenings.

Table 4.9. Variety mean values across sites, treatments and years for winter oat N timing experiments as predicted by REML

	SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Mascani	52.41	75.74	99.22	1.379	42.42
Penrose	50.02	74.5	99.26	2.351	41.4
RGT Southwark	52.62	73.48	99.1	6.027	34.8
S.E.D.	0.46	0.28	0.03	0.52	0.60
Variety p value	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment p value	<0.001	0.142	0.277	0.005	<0.001
variety x treatment p value	0.320	0.612	0.448	0.157	0.025

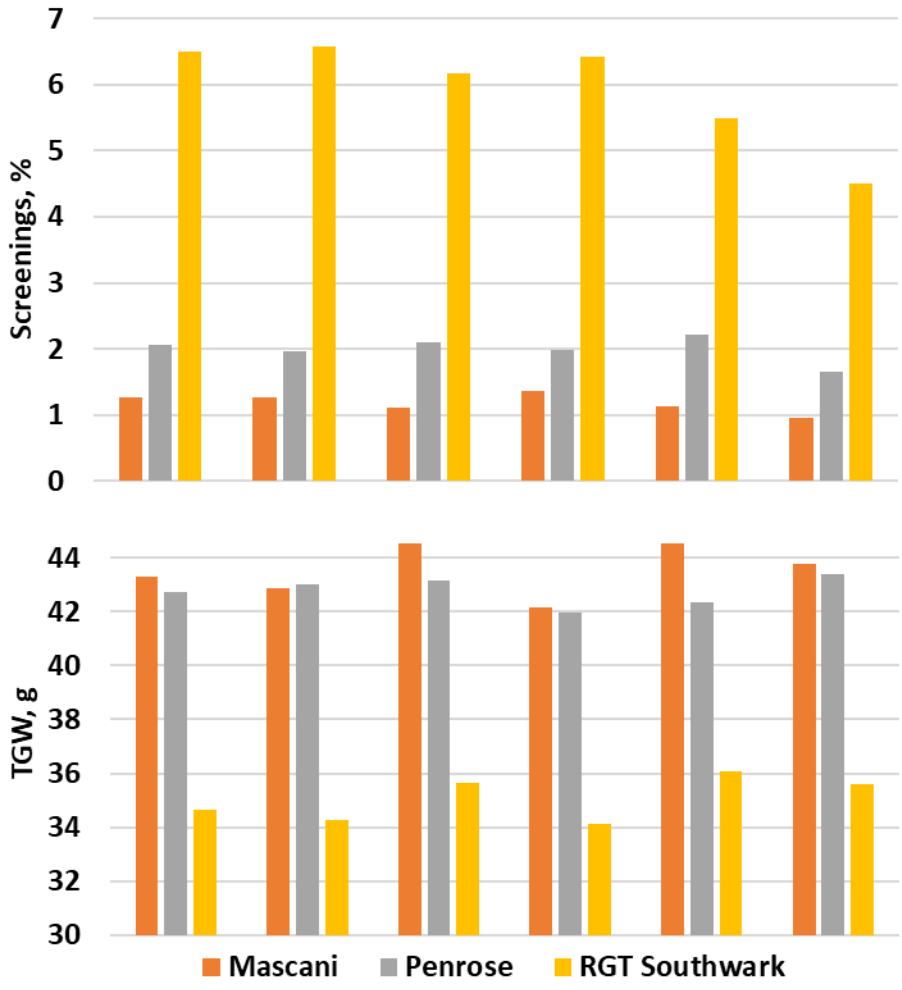
Across trials, no significant treatment effect was obtained for N timing treatment or for the effect of sulphur for either kernel content or hullability. A significant effect of treatment was found for specific weight (Figure 4.24) with lower specific weights found for treatments where no N was applied at the earliest time point, GS25. No effect of sulphur was found on specific weight.

A significant effect of sulphur was however obtained for screenings and thousand grain weight (Figure 4.25). Screenings were lower and thousand grain weight higher in all three varieties for all the treatment without S (treatment 6) as compared to the control (treatment 1). Thousand grain weight was also significantly higher in treatments 3 and 5 where no N was applied at GS25.



Treatment	1	2	3	4	5	6
GS25	40	90		90		40
GS30	70	90	90		50	70
GS32	70		90	90	90	70
GS39					40	No S
	N applied (kg/ha)					

Figure 4.24. Mean specific weight (kg/hl) of three winter oat varieties (Mascani, Penrose and RGT Southwark) fertilised with 180 kg N/ha split between different timings and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from two experiments carried out in Herefordshire and two in Nottinghamshire in harvest seasons 2019 and 2021 analysed using REML resulting in predicted means. SED = 0.197



Treatment	1	2	3	4	5	6
GS25	40	90		90		40
GS30	70	90	90		50	70
GS32	70		90	90	90	70
GS39					40	No S
	N applied (kg/ha)					

Figure 4.25. Variety mean screening % and Thousand Grain Weight (TGW, g) of three winter oat varieties (Mascani, Penrose and RGT Southwark) fertilised with 180 kg N/ha split between different timings and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from two experiments carried out in Herefordshire and two in Nottinghamshire in harvest seasons 2019 and 2021 analysed using REML resulting in predicted means. SED: TGW = 0.688, Screenings = 0.531

Effect of N timing on milling quality of spring oats

Data from Fife and Suffolk were analysed separately due to different varieties being tested at the 2 sites in addition to the large geographical distance resulting in very contrasting climate and soils.

A significant effect of variety was obtained in all three years of trials carried out at the Fife site. Conway had the highest hullability and lowest screenings in all trials, whilst Canyon had the highest TGW and Specific Weight and WPB Elyann had the highest kernel content (Figure 4.26). In a combined REML analysis across years for the Fife site, specific weights were significantly higher when all the N was applied in the seedbed (Figure 4.27). Hullability was significantly different between treatments, with treatments 3 and 5 having significantly higher hullability than the other treatments. No significant differences were obtained between treatments for kernel content, screenings or TGW. No significant effect of sulphur was found for any quality trait measured. Overall, variety choice was more significant for grain quality than timing of N application.

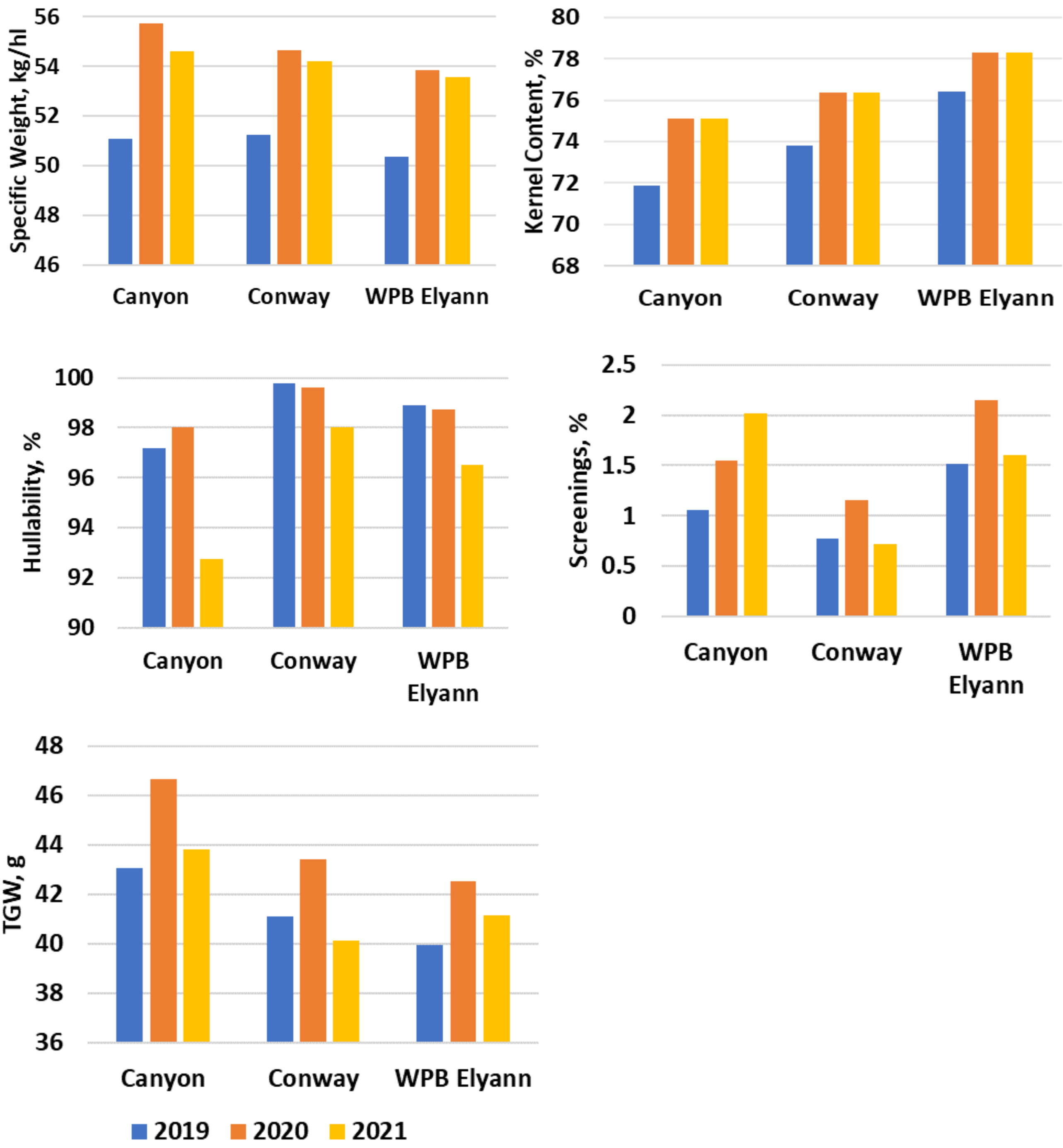
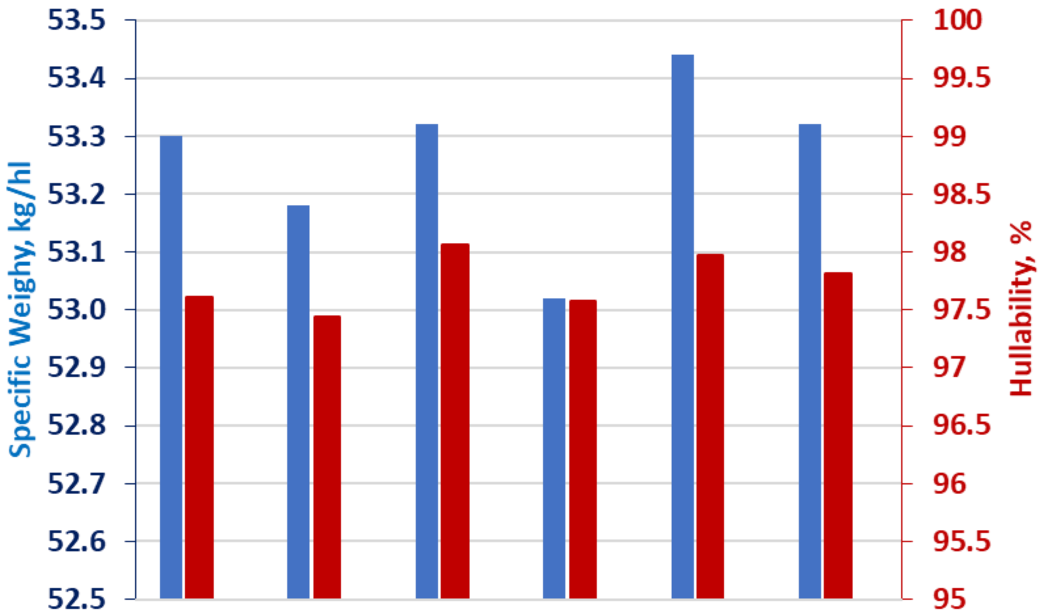


Figure 4.26. Mean specific weight (kg/hl), Kernel Content (%), hullability (%), screenings (%) and thousand grain weight (TGW, g) of three spring oats varieties (Canyon, Conway and WPB Elyann) across N timing treatments. Data from three experiments carried out in Fife in harvest seasons 2019, 20202 and 2021.



Treatment	1	2	3	4	5	6
Seedbed	60			40	120	60
GS13		60	90			
GS31	60	60	30	40		60
GS39				40		No S
	N applied (kg/ha)					

Figure 4.27. Mean specific weight (kg/hl) and hullability (%) of three spring oat varieties (Canyon, Conway and WPB Elyann) fertilised with 120 kg N/ha split between different timings (Seedbed, GS13, 31, 39) and with 40 kg SO_3/ha, apart from treatment 6 labelled 'No S'. Data from three experiments carried out in Fife in harvest seasons 2019, 2020 and 2021 analysed using REML resulting in predicted means.

In the experiments carried out in Suffolk, again, a significant effect of variety was obtained in all three years of trials, with Canyon having the lowest hullability and highest Specific Weight and TGW in all trials, whereas WPB Elyann had the highest kernel content and screenings (Figure 4.28). In a combined REML analysis across years for the Suffolk site, TGW was significantly higher when all the nitrogen was applied in the seedbed in treatment 5 (Figure 4.29). No significant differences were obtained between treatments for specific weight, kernel content or hullability. A significant effect of sulphur was found for TGW and screenings, with TGW lower and screenings higher when no S was applied (Figure 4.29). No effect of S was found on specific weight, kernel content or hullability. Like that seen in the Fife sites, variety choice was more significant for grain quality than timing of N application.

There was, however, a significant effect of site, with specific weights, kernel contents and TGWs being much lower in Suffolk compared to Fife. Hullability and Screenings did not differ as much between sites (Table 4.10, Table 4.11, Figure 4.30).

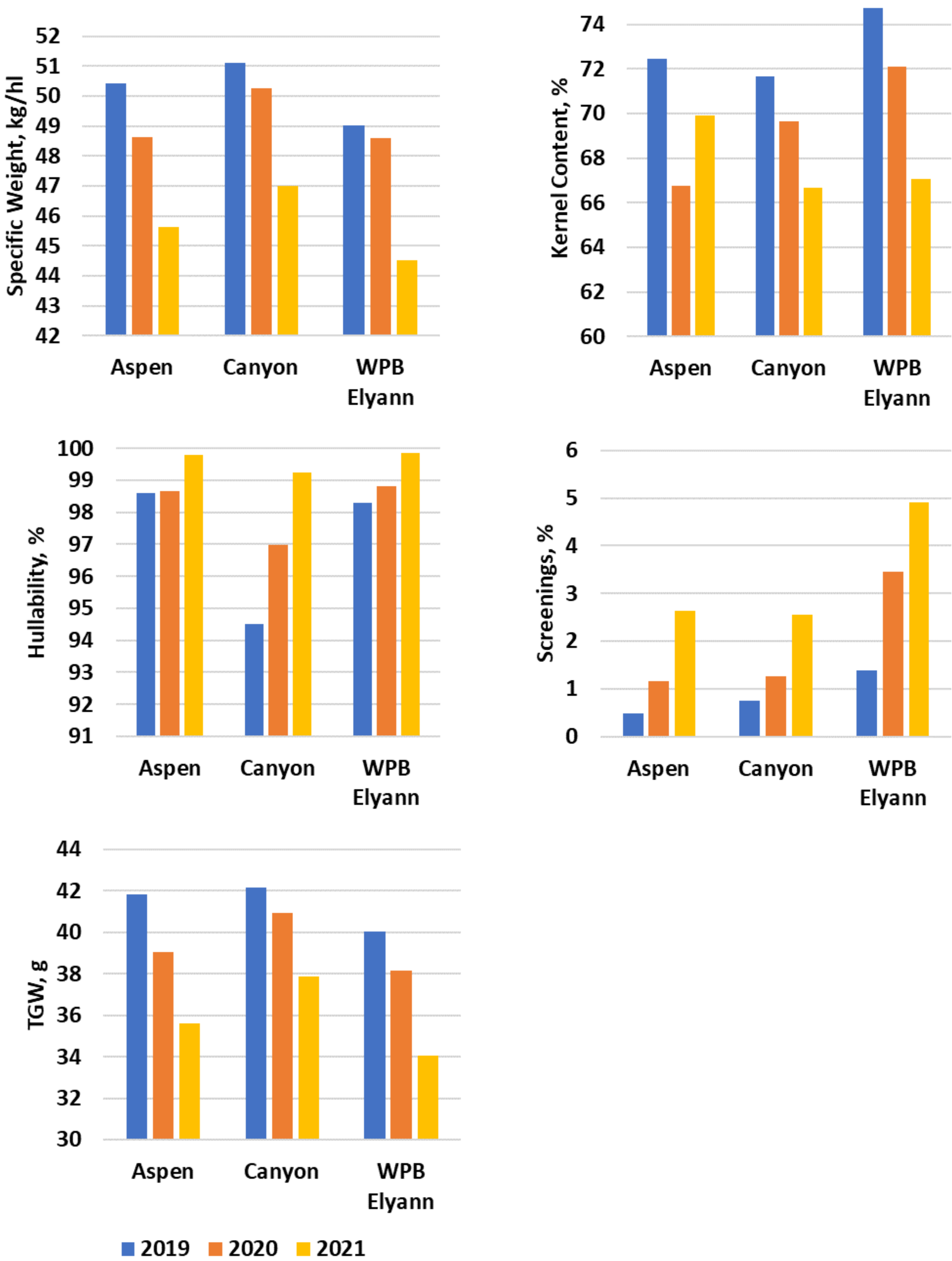
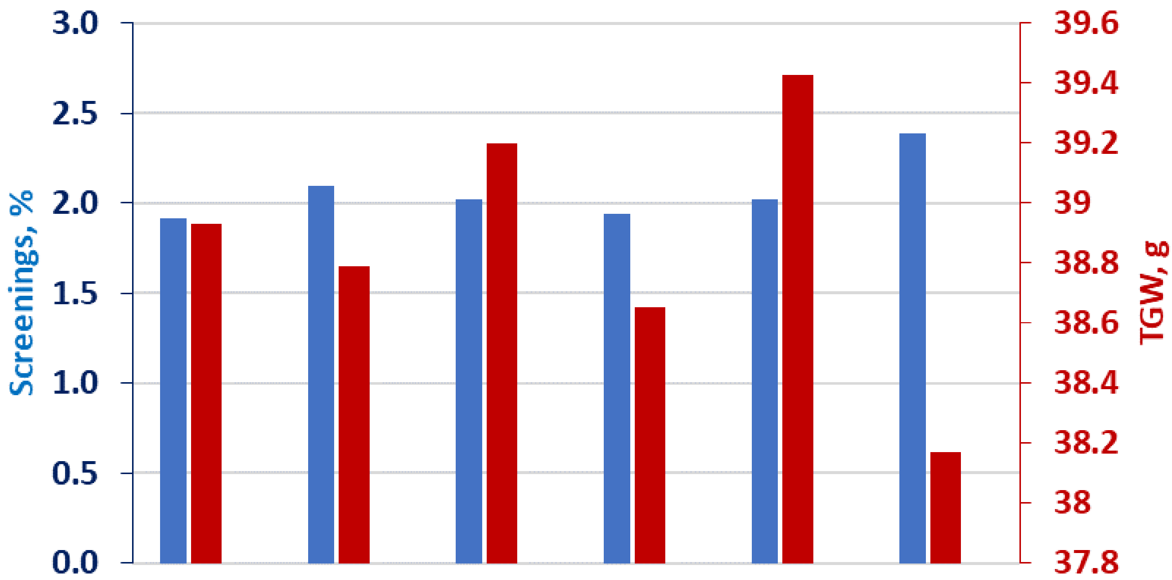


Figure 4.28. Mean specific weight (kg/hl), Kernel Content (%), hullability (%), screenings (%) and thousand grain weight (TGW, g) of three spring oat varieties (Aspen, Canyon and WPB Elyann) across N timing treatments. Data from three experiments carried out in Suffolk in harvest seasons 2019, 2020 and 2021



Treatment	1	2	3	4	5	6
Seedbed	60			40	120	60
GS13		60	90			
GS31	60	60	30	40		60
GS39				40		No S
	N applied (kg/ha)					

Figure 4.29. Mean specific weight (kg/hl) and hullability (%) of three spring oat varieties (Canyon, Conway and WPB Elyann) fertilised with 120 kg N/ha split between different timings (Seedbed, GS13, 31, 39) and with 40 kg SO_3/ha, apart from the treatment labelled 'No S'. Data from three experiments carried out in Fife in harvest seasons 2019, 2020 and 2021 analysed using REML resulting in predicted means.

Table 4.10. Mean values across treatments and years as predicted by REML for spring oat trials conducted in Fife

	SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Conway	53.36	74.93	98.98	0.887	41.55
Canyon	53.85	73.42	96.26	1.529	44.51
WPB Elyann	52.58	77.21	97.99	1.751	41.19
Variety p value	<.001	<.001	<.001	<.001	<.001
Treatment p value	0.036	0.673	0.012	0.282	0.628
variety x treatment p value	0.712	0.988	0.027	0.662	0.843

Table 4.11. Mean values across treatments and years as predicted by REML for spring oat trials conducted at Suffolk Site

	SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Aspen	48.38	69.61	98.92	1.482	38.78
Canyon	49.41	69.33	97.09	1.564	40.45
WPB Elyann	47.29	71.38	98.93	3.151	37.35
Variety p value	<.001	0.032	<.001	<.001	<.001
Treatment p value	0.124	0.39	0.585	0.046	0.002
variety x treatment p value	0.103	0.825	0.36	0.878	0.63

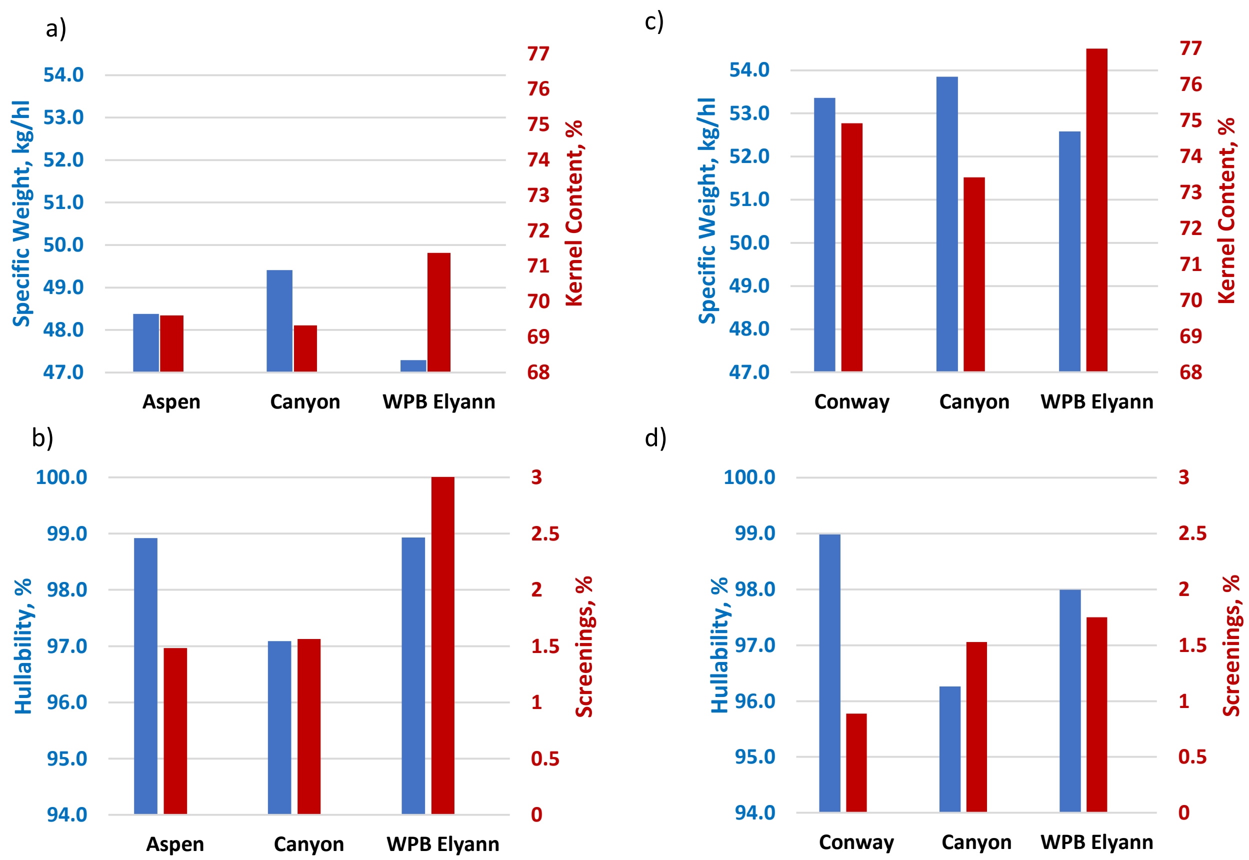


Figure 4.30. Mean specific weight (kg/hl), Kernel Content (%), hullability (%), screenings (%) and thousand grain weight (TGW, g) of three spring oat varieties) across N timing treatments and years. Mean data from three experiments carried out in Suffolk (a, b) with Aspen, Canyon and WPB Elyann and in Fife (c, d) with Canyon, Conway and WPB Elyann in harvest seasons 2019, 2020 and 2021.

5. Implications for N and S fertiliser recommendations

Winter oats optimum N rate

Current winter oats recommendations

Winter oats N recommendations were updated following the 2016 review of RB209, where there was an increase of 40 kg N/ha added to rates on all soil types at all SNS indices. Below is the winter oats N recommendation table copied from the current version of RB209 (2022_220224). In addition to the table, there is also advice to reduce rates by 40 kg N/ha if lodging risk is high. Unlike for other cereals, there is currently no 'standard' yield or adjustments with yield increases for winter oats.

Table 5.1 Winter oats N recommendation table from the current version of RB209 (2022_220224)

Crop	Soil category	N recommendation (kg N/ha)						
		SNS Index						
		0	1	2	3	4	5	6
Oats	Light sand soils	150	110	80	20–60	0–40	0	0
	All other mineral soils	190	160	130	100	70	0–40	0
	Organic soils	–	–	–	100	70	0–40	0
	Peaty soils	–	–	–	–	–	0–40	

In order to assess whether and how current winter oats recommendations in RB209 should be updated, the following questions were considered:

- Are the N rates currently recommended appropriate?
- Should there be adjustments made to N rates based on expected yields?
- How should winter oats N rate recommendations be updated?
- Should adjustments be recommended based on lodging risk?
- What account should be taken of effects of N on quality?

Comparison of recommended N rate against experimental data

The RB209 N rates that would have been recommended for the winter oats sites in this project ('Core NoatS') and for twelve additional winter oats trials carried out in the UK and Ireland since 2016 were determined (Table 5.2). Mean site data across varieties were used rather than individual site*variety data.

Table 5.2 Average RB209 recommended N rates (from SMN analysis; kg/ha); actual optimum N rates (N_{opt}; kg/ha); and yield at N_{opt} (t/ha) for winter oats measured in Core NoatS and Additional trials

Crop type	Dataset	Average recommended N rate (*range)* (kg/ha)	Average actual N_{opt} (*range*) (kg/ha)	Average yield at N_{opt} (*range*) (t/ha)
Winter oats	Core NoatS	175 (*160 – 190*)	57 (*20 - 118)*	7.13 (*5.4 – 9.9*)
	Additional trials	168 (*100 – 190*)	161 (*94 – 227*)	9.04 (*6.8 – 11.9*)

The average N rates recommended were 175 and 168 kg N/ha for the NoatS core and additional sites, respectively (Table 5.2), ranging from 100 to 190 kg N//ha. For the core NoatS trials, the average actual optimum N rate determined by the experiments was a lot lower than the recommended rate at 57 kg N/ha, with the highest N_{opt} being only 118 kg N/ha. Reasons for this have been explored in Section 4. The average actual optimum N rate of the additional trials was only 7 kg N/ha lower than the rate that would have been recommended by RB209 (Table 5.2), although the highest N_{opt} determined was 227 kg N/ha, nearly 40 kg N/ha higher than the highest N rate recommended for winter oats. Optimum N rates above 200 kg N/ha are not unusual; results from a number of trials had to be excluded from this dataset because the calculated N_{opt} was higher than the maximum N rate tested (200-250 kg N/ha).

As well as the average N_{opt} of the core NoatS trials being lower than the additional sites, so was the average yield (7.13 t/ha for NoatS sites; 9.04 for additional sites; Table 5.2). The relationship between yield at the optimum N rate and the N_{opt} deviation from the associated RB209 recommendation was determined (Figure 5.1). When the data from the NoatS and additional sites were combined, there was a significant (R^2 = 0.74) positive relationship. The intercept (the point at which RB209 recommendations are closest to actual N_{opt}) is at 9.1 t/ha, although the data indicated that around 8.5 t/ha was the yield at which the recommendation was optimised (Figure 5.1). This suggests the ‘standard’ yield for oats from which N adjustments for different yields could be made, although this may be considered too high relative to average on-farm yields, benchmark yields and ‘standard’ yields of other crops in RB209.

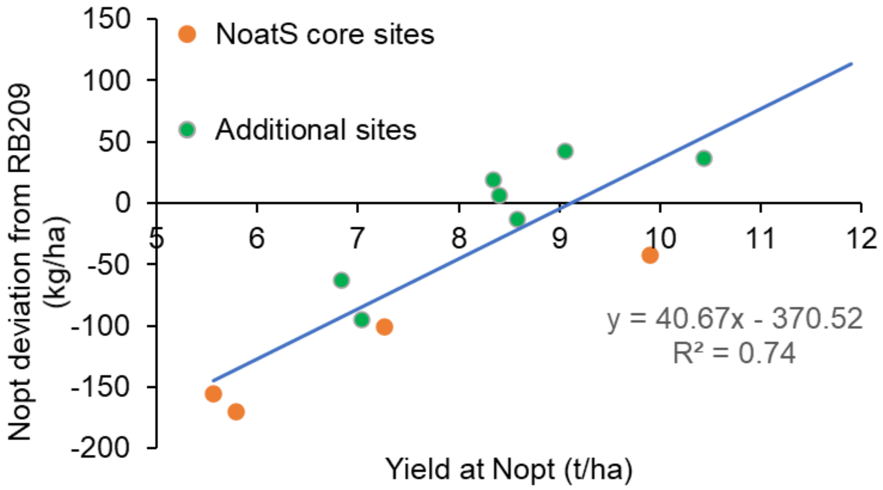


Figure 5.1 Relationship between yield measured at the optimum N rate (N_{opt}) and the N_{opt} deviation from the RB209 recommendations (using SMN analysis; N_{opt} – RB209) for Winter oats. Each point is the average for an individual site-year.

Do fertiliser N requirements vary according to site yield potential?

There was a significant (R^2 = 0.58) positive relationship between yield and the optimum N rate when winter oats 'NoatS' and additional sites data were combined (Figure 5.2a); with each additional tonne of yield, the optimum N rate increased by 24.8 kg N/ha. The N requirements of these experiments were estimated, where data were available, as:

Estimated crop N requirement = soil N supply[1] + (optimum N rate x fertiliser recovery[2])

[1]where data were available, SNS was total crop N offtake where 0 kg N/ha was applied. Otherwise, an estimate measured with soil analysis was used.
[2]fertiliser recovery is assumed to be 0.6 as standard.

Ideally, the crop N demand would have been estimated as the total crop N offtake at the optimum N rate, but very few of the experiments had both straw and grain N% data available, which could have been used with an estimate of nitrogen harvest index to calculate total crop N offtake. Consequently, the standard fertiliser recovery of 0.6 was used, which was reasonable as the fertiliser recovery calculated from the four winter oats NoatS trials was 0.65. Not all experiments had either N offtake at nil N or estimates of soil N available, so fewer datapoints were available than for the analysis of optimum N rate. However, there was still a significant positive relationship between yield and estimated crop N demand (Figure 5.2b). The slope was slightly shallower than that of the relationship between yield and optimum N rate, at an increase of 20.9 kg N/ha per tonne of yield.

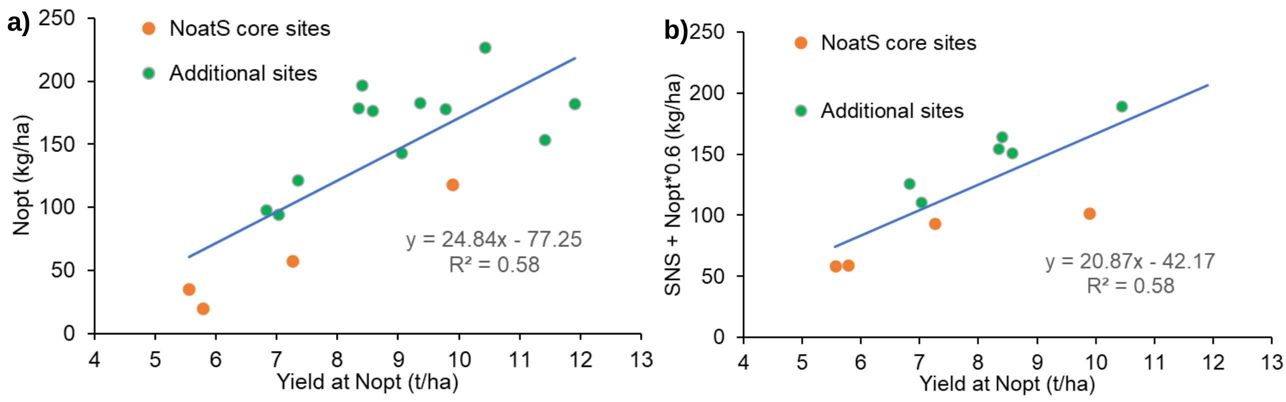


Figure 5.2 Relationship between winter oats yield measured at the optimum N rate (N_{opt}) and a) the N_{opt} and b) the crop N requirement (N_{opt} x fertiliser recovery (0.6) plus the soil N supply estimated by soil measurement). Lines were fitted by regression to combined NoatS core sites and Additional sites data. Each point is the average for an individual site-year.

How should winter oats N recommendations be updated?

Although the optimum N rates of the 'NoatS' trials were, typically, a lot lower than those recommended by RB209, those of the additional trials were very similar, on average. The current RB209 recommended rates, which includes the 40 kg N/ha uplift resulting from the 2016 RB209 review, appear generally sensible, but have limitations. The strong relationships found in Figure 5.1 and Figure 5.2 suggests that there should be adjustments to winter oats N recommendations based on estimated yields as is done for other cereals in RB209. Each additional tonne of yield was associated with 20.9 kg/ha extra N required by the crop or 24.8 kg/ha increase in N_{opt}. At a fertiliser recovery rate of ~0.6, this is likely to quate to 35-40 kg N/ha of fertiliser.

It is proposed that the winter oats N recommendation table be replaced with one using the same format as that found for spring barley i.e. N rate recommendations based on expected yield and SNS index only. It is considered that separate recommendations for light sands and all other mineral soils is unnecessary; the SNS index accounts sufficiently for differences in soil N supply and yield adjustment for any difference in expected yield resulting from different soil types.

Retaining a comment about considering adjusting N rates based on lodging risk would be sensible. However, although lodging at the Herefordshire NoatS site was significant at the highest N rates, this impacted some varieties more than others and would not have caused a problem at the recommended rate. Therefore, variety height and lodging risk should be taken into account, as well as previous experience.

What account should be taken of effects of N on quality of winter oats?

A significant effect of variety was found for all the grain quality traits assessed. In this study, Mascani was compared to 2 more recently released winter oat varieties, Penrose and RGT Southwark with a significant variety effect found for all traits measured (specific weight, kernel content, hullability, screenings and thousand grain weight). Across treatments, RGT Southwark had a lower kernel content, hullability and higher screenings. Penrose had lower specific weight but high kernel content and hullability and low screenings. Mascani had high specific weight, kernel content, and hullability and low screenings. Although significant differences were found between trials, varieties performed similarly in each trial. This confirmed previous N trial results conducted in the InnovOat project (AHDB PR627) using the 4 winter oat varieties Mascani, Tardis, Balado and Gerald which also identified a strong varietal effect on the response of grain quality traits to N application.

At all sites, there was a significant effect of treatment with screenings, kernel content and hullability all increasing in response to N application, whereas specific weight decreased at higher N treatments (Figure 5.3). The response of these milling quality traits is not linear in response to N and the biggest difference overall in kernel content between treatments was between the no added N control and the 80 kg N/ ha treatment. Specific weight continued to fall in a curvi-linear manner, with the lowest specific weights found at the highest N treatments. Specific weight and kernel content showed a poor correlation suggesting that specific weight is not a good predictor of milling yield. At the N_{opt} for each trial, kernel contents were greater than 72% for every variety and specific weights were above 51 kg/ hl apart from Penrose at Herefordshire 2021. However, at N application rates above the N_{opt}, specific weights in some varieties are below milling industry specifications at N applications above current RB209. A significant interaction between variety and treatment was also found with Mascani, confirmed to have excellent milling quality across all treatments and trials.

Higher N application rates result in a combination of more grains per panicle and more panicles/m^2, but this is accompanied by a decrease in the mean thousand grain weight. In some varieties, this results in a proportion of smaller grain in some varieties with the consequence of an increase in screenings (Figure 5.3).

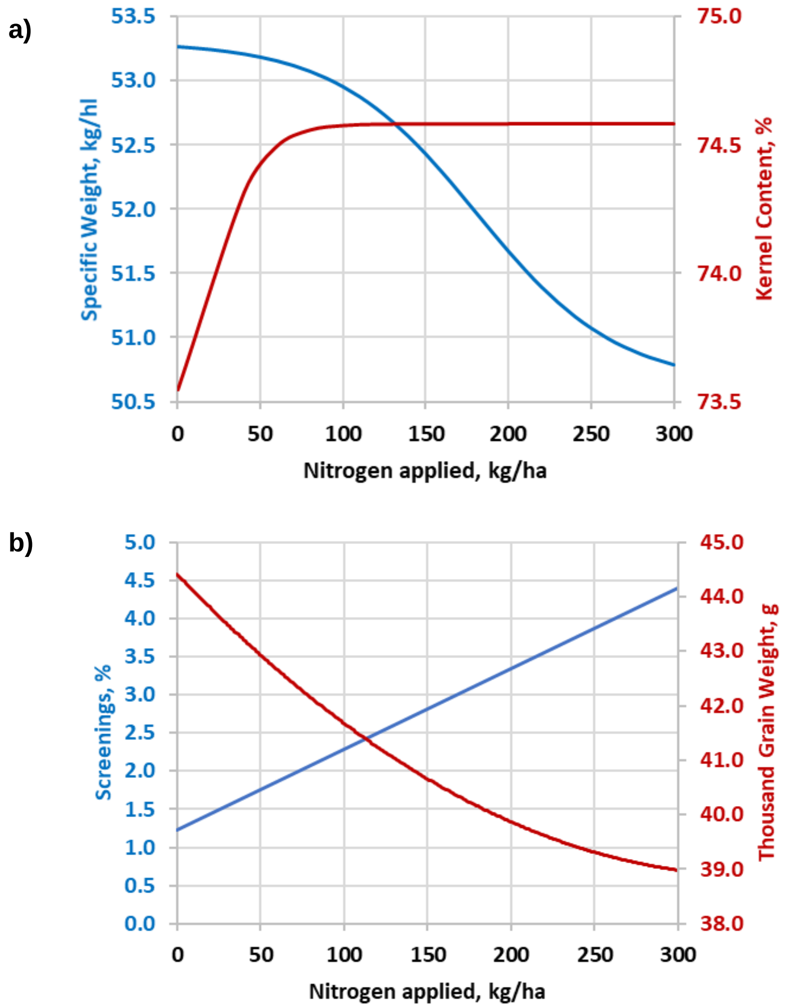


Figure 5.3. Curves fitted to overall means for a) specific weight and kernel content and b) thousand grain weight and screenings across trials and varieties for the response to N application for the winter oats Mascani, Penrose and RGT Southwark.

Spring oats optimum N rate

Current spring oats N recommendations

N recommendations for spring oats have not been updated for many years. Below is the spring oats N recommendation table copied from the current version of RB209 (2022_220224). Unlike for winter oats, there is no advice on adjusting N rates when there is a high lodging risk. There is no 'standard' yield or adjustments with yield increases for spring oats.

Table 5.3 Spring oats N recommendations from the current version of RB209 (2022_220224)

Soil category	N recommendation (kg N/ha)						
	SNS Index						
	0	1	2	3	4	5	6
Light sand soils	90	60	30	0–30	0	0	0
All other mineral soils	140	110	70	40	0–30	0	0
Organic soils	–	–	–	40	0–30	0	0
Peaty soils	–	–	–	–	–	0	

Comparison of recommended N rate against experimental data

The RB209 N rates that would have been recommended for the six spring oats sites in this project ('Core NoatS') and for eight additional winter oats trials carried out in the UK and Ireland since 2016 were determined (Table 5.4). Mean site data across varieties were used rather than individual site*variety data.

The average RB209 recommended rate for the Core NoatS trials was 128 kg N/ha (Table 5.4), compared to an average actual optimum N rate of 154 kg N/ha for these trials. The range of actual N_{opts} was much larger than the recommendations, ranging from 86 to 240 kg N/ha. The average yield at the actual optimum N rates was 7.54 t/ha. The results of the additional N response trials were very similar to those of the Core NoatS trials (Table 5.4); the average fitted optimum N rate was 30 kg N/ha higher than the average RB209 recommended rate with a similar range in optimum N rates and yields at the optimum (Table 5.4).

The relationship between yield at the optimum N rate and the N_{opt} deviation from the associated RB209 recommendation was determined (Figure 5.4) but found to be insignificant (R^2 = 0.0072). However, it could be seen from the relationship that at all yield levels, the actual optimum N rate was higher than that recommended by RB209.

Table 5.4 Average RB209 recommended N rates (from SMN analysis; kg/ha); actual optimum N rates (N_{opt}; kg/ha); and yield at N_{opt} (t/ha) for spring oats measured in Core NoatS and Additional trials

Crop type	Dataset	Average recommended N rate (*range*) (kg/ha)	Average actual N_{opt} (*range*) (kg/ha)	Average yield at N_{opt} (*range*) (t/ha)
Spring oats	Core NoatS	128 (*70 – 140*)	154 (*86 – 240*)	7.54 (*5.4 – 8.3*)
	Additional trials	122 (*110 – 140*)	152 (*89 – 227*)	7.16 (*5.3 – 9.0*)

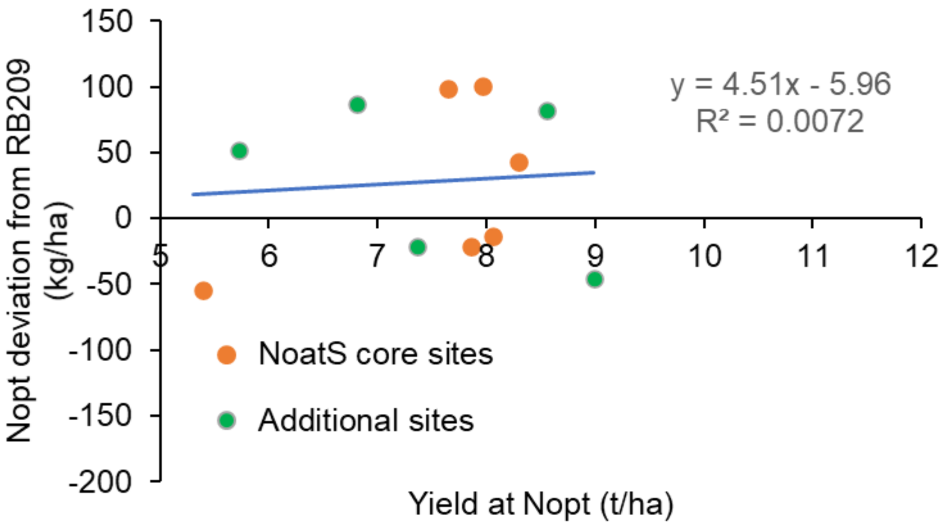


Figure 5.4 Relationship between yield measured at the optimum N rate (N_{opt}) and the N_{opt} deviation from the RB209 recommendations (using SMN analysis; N_{opt} – RB209) for Spring oats. Each point is the average for an individual site-year.

Do fertiliser N requirements vary according to site yield potential?

Unlike in winter oats, there was no significant relationship in spring oats between yield at the optimum N rate and either the optimum N rate or the estimate of crop demand (determined as described above; Figure 5.5). The data were very scattered with large ranges in the optimum N rates and crop requirement at similar yield levels.

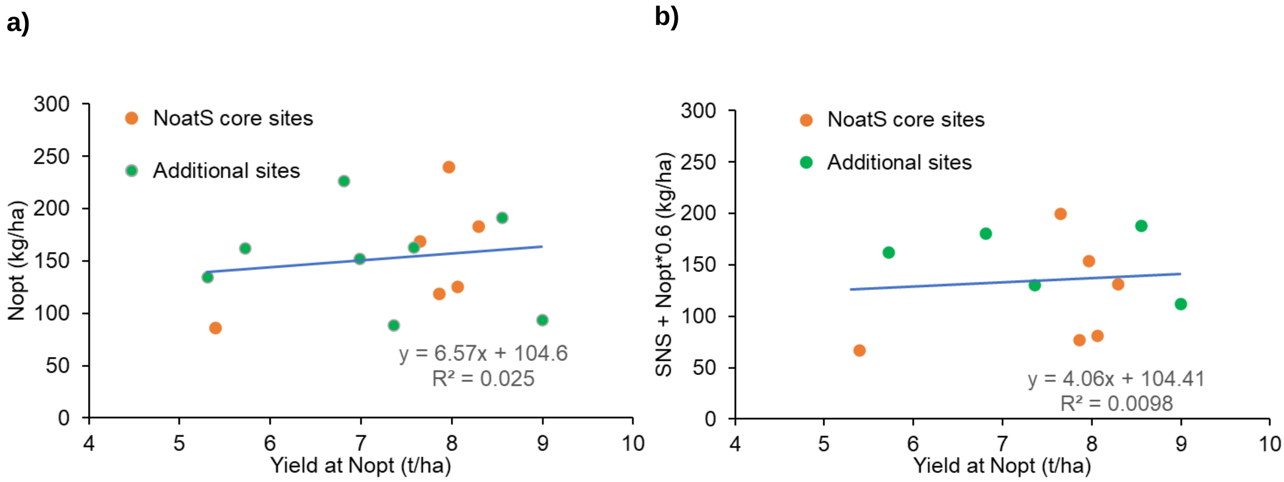


Figure 5.5 Relationship between spring oats yield measured at the optimum N rate (N_{opt}) and a) the N_{opt} and b) the crop N requirement (N_{opt} x fertiliser recovery (0.6) plus the soil N supply estimated by soil measurement). Lines were fitted by regression to combined NoatS core sites and Additional sites data. Each point is the average for an individual site-year.

How should spring oats N recommendations be updated?

It is clear from the analysis of RB209 recommendations vs. actual optimum N rates that the current recommended N rates for spring oats are too low by 25 – 30 kg N/ha, on average. However, there is no clear evidence that N rates should increase with expected yield.

What account should be taken of effects of N on quality of spring oats?

Until this study, little was known about the effect of N application rate on grain quality for modern spring oat varieties. A similar result was found for the spring oat trials to those with winter oats, with low inputs of N resulting in lower kernel contents and hullability, and both increasing in response to N application. The same three varieties used in the trials in Fife, Scotland were also used in additional trials to the same design in Aberystwyth, Wales and Carlow, Ireland and the mean results across trials and varieties are shown in Figure 5.6. Trials in Cambridgeshire replaced Conway for Aspen to reflect local varietal preferences. In these trials, the maximal specific weights and kernel contents were much lower. With no added N, kernel contents were very low in the Cambridgeshire trials and continued to increase until an application rate well above the N_{opt}. This suggests that location and climatic conditions has a strong effect on grain quality but that this does not change the response to N application.

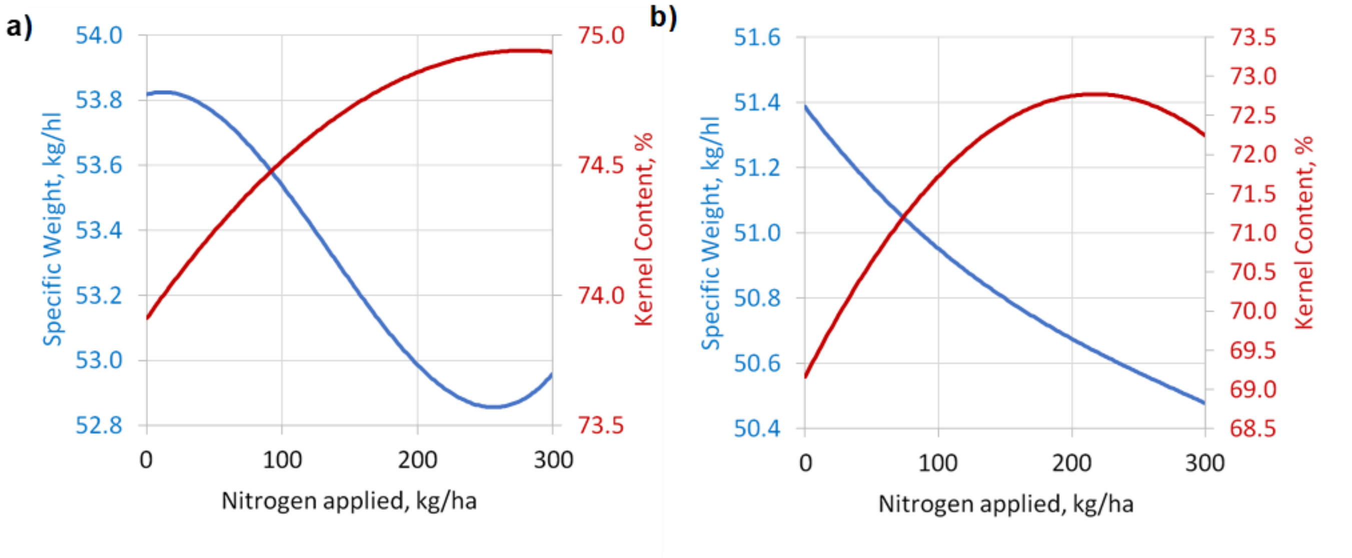


Figure 5.6. Curves fitted to overall means for specific weight and kernel content across trials and varieties for the response to N application for (a) the spring oats Canyon, Conway and WPB Elyann in eight experiments carried out in Fife, Carlow and Aberystwyth in harvest seasons 2019, 2020 and 2021, (b) the spring oats Aspen, Canyon and WPB Elyann in two trials in 2019 and 2021 in Cambridgeshire.

In all locations however, at high N application rates, specific weights are compromised and in some varieties are below milling industry specifications. In spring oats, although screenings also increased at higher N application rates, milling specifications were not exceeded even at the highest N rates used.

Winter oats optimum N timing

The current version of RB209 (2022_220224) advises the following N timings for winter oats:

- Less than 100 kg N/ha: Apply as a single dressing by early stem extension but not before late March
- 100 kg N/ha or more: Split the dressing, with 40 kg N/ha in mid-February/early March
    - If the remaining N is less than 100 kg N/ha, then apply the rest by early stem extension but not before late March
    - If the remaining N is 100 kg N/ha or more, then apply in two dressings, half at early stem extension (not before late March) and half at least two weeks later
- These recommendations assume appropriate measures are taken to control lodging (e.g., choice of variety or use of plant growth regulator). Reduce the recommended rate by 40 kg N/ha if lodging risk is high

The timing experiments on winter oats in this project tested five different timing combinations for application of a total of 180 kg N/ha (Table 3.10) on three different varieties at two sites (Herefordshire and Nottinghamshire) over two seasons. There were significant variety effects (Mascani higher yielding in Herefordshire, Penrose in Nottinghamshire) but there were no interactions with N timing treatments. There was no significant main effect of timing treatment on yield in any of these trials, and this was confirmed when the data were combined and analysed using REML (Figure 4.8). However, the highest mean yields were from treatments where some N had been applied at tillering. When grain quality was analysed, treatments including N at tillering also led to significantly higher specific weights.

Therefore, it appears appropriate to keep winter oats N timings advice for amounts >100 kg N/ha as per current RB209 recommendations. It may be sensible to clarify the phrase '40 kg N/ha in Mid-February/early March' to include 'during tillering'. This project did not examine the most appropriate timings for amounts <100 kg N/ha so it is not possible to update this advice.

Spring oats optimum N timing

There are currently no recommendations for timings of N applications to spring oats in RB209. The timing experiments on spring oats in this project tested five different timing combinations for application of a total of 120 kg N/ha (Table 3.11). The effects of N timing on yield were inconsistent; in three of the six experiments there was no significant effect of the N timing treatments. Where there were significant timing treatment effects, the highest yields resulted from applying all the N in the seedbed, although the increase was not always significantly more than all of the treatments with later applied N. At one site (Suffolk, 2019), there was a significant reduction in yield where no N had been applied in the seedbed. These findings were consistent when all spring oats N timing data were combined and analysed using REML, but are not consistent with the results of the review of previous data which showed that splitting N applications was always advantageous (Table 4.2).

The grain quality analyses of the experiments in this project showed that the greatest impact on quality was variety; the effects of N timing treatments were inconsistent. However, applying all the N in the seedbed resulted in higher specific weights in the Fife trials and higher TGW in the Suffolk experiments.

Whether there were significant treatment effects on yield or quality did not appear to relate to site SMN, sowing date, total rainfall, or whether all N applied in the seedbed resulted in significantly higher yields. Dry springs were a feature of all three experimental seasons, which were particularly marked at the Suffolk site. It is likely that exact timings of rainfall events will have impacted the timing of N uptake.

Overall, for spring oats N timing advice, emphasising the importance of applying a proportion of N in the seedbed for both yield and quality will be key. A minimum of 40 kg N/ha would be sensible; this was the minimum amount applied to the experiments in this project (in treatments where seedbed N was applied) and is consistent with advice for spring barley.

The current spring barley advice states that all N should be applied by GS30, whereas the timing experiments in this project included timings at GS31/32 plus one with an application at GS39. Spring barley growers are trying to maximise yield through increased tiller/grain numbers, and minimise grain N%, hence the emphasis on early applications. For oats, applications up to GS31/32 appear from the results of this project to be appropriate. The treatment in this series of experiments that included a GS39 application did not result in greater yields or quality, but this may be because the application at this timing was included as part of the total N rate rather than being an additional treatment.

Sulphur recommendations

In the current version of RB209 (2022_220224), it is advised for all cereals to assess the likelihood of S deficiency, either through tissue/grain testing or based on soil type and overwinter rainfall, then to apply 25-50 kg SO_3/ha where there is a high chance of S deficiency. The timings for SO_3 are advised as early-March to early-May for wheat and mid-March to mid-April for barley.

The winter and spring oats timing experiments in this project tested the effect of 40 kg SO_3 on yield and quality using treatments where the same amount and timing of N were applied. In the winter oats experiments, the nil-S treatment led to a ~1 t/ha reduction in yield at the sandy Nottinghamshire site, but not at the Herefordshire site on Silty Clay Loam. According to the risk matrix in RB209, both of these sites would have a high risk of S deficiency. There were no consistent significant effects of S on yield in any of the spring oats trials in either Scotland (where the risk of S deficiency would be assessed as high) or East Anglia (where the risk of S deficiency would be assessed as low). However, experiments did not include tissue or grain testing for S deficiency. There were no effects of S on grain quality in winter oats, however, TGW was lower and screenings were higher where no S was applied to the spring oats Suffolk trials.

As well as the trials carried out as part of this project, Jordans Ryvita, one of the project partners, commissioned three years (harvest 2019-21) of S response (rates of 0 to 75 kg SO_3/ha) trials in winter and spring oats. The data were collated and winter and spring oats yield results analysed separately using REML. Even though tissue test results from the trials indicated that the crops were S deficient, there was no significant effect of S in either the winter or spring oats results (Figure 5.7).

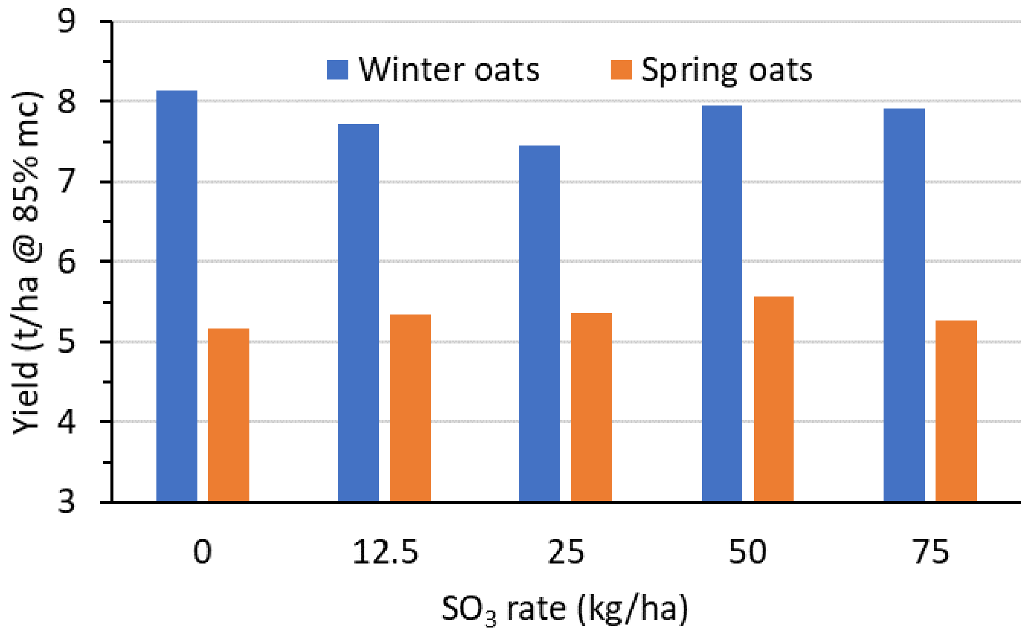


Figure 5.7 The effect of different SO_3 application rates on yields of winter and spring oats. Results displayed are predicted means from REML analyses of 3 years of results from both winter and spring oats trials.

Given the above limited results, it is concluded that there should not be any updates to the S recommendations in RB209 for oats at this time in terms of the circumstances in which applications should be made. It is not appropriate to make any changes to rate recommendations based on the Jordans Ryvita experiments. S timing was not investigated in this project.

6. Key messages and further research requirements

Key messages

Database analysis (up to and including 2018):

- Since the RB209 review in 2016, there was still not enough relevant spring oat N response datasets to analyse, and only two additional N response trials on winter oats, which did not affect the review findings.
- From the database analysis, it appears that current N recommendations are too low
- In both winter and spring oats, splitting N, rather than applying as one dose, boosted yield.
- Understanding timing was more difficult, but winter oats trials indicated that weighting N to more applied at stem extension as opposed to tillering led to higher yields

Current oats farming practice survey (Autumn 2018):

- The most popular varieties were Mascani winter oats and Canyon spring oats, with nearly half of growers reporting an increase in their spring oat area over the previous three years
- Most relied on previous experience when advising on N for oats, with the average total rate advised 138 kg N/ha and 118 kg N/ha for winter and spring oats, respectively.
- For spring oats, the majority recommended applying around half of the total N in the seedbed

- For winter oats half of advisors recommended some N to be applied at tillering, with all recommending some at early stem extension

N response:

- The project winter oats N responses resulted in low N optima, despite the Herefordshire site displaying a good response to N; the low N_{opt} in Herefordshire was due to lodging whereas in Nottinghamshire, few grains/panicle were formed due to a dry spring and sandy soil. Variety differences were evident but there were no interactions.
- The Scottish spring oats trials resulted in high N responses, optima and yields whereas the lack of moisture available to the east Anglian trials generally led to lower optima.
- Overall, it was evident that where there is good moisture availability, yield responses and N_{opts} can be high, although lodging can be an issue
- It is proposed that current winter oats RB209 N rate recommendations are replaced with one using the same format as that found for spring barley i.e., N rate recommendations based on expected yield and SNS index only
- For spring oats it was evident that current RB209 recommended rates are 25 – 30 kg N/ha too low, although there was not clear evidence that higher yielding crops require higher N rates

Sulphur:

- Treatments without S in individual winter and spring oats trials did not impact yield significantly but did result in a ~1 t/ha yield reduction at the Nottinghamshire site. However, when data were combined, a lack of S was found to have a negative effect on yield. It appears that lack of sulphur is most detrimental to yield on sites with light soils.

N timing experiments:

- In most individual timing experiments, there were no significant impacts of N timing on yield. However, when results were combined for winter oats, they indicated that RB209 timings are sensible and that N at tillering is important
- Conclusions for spring oats remain unclear and more research is needed. Applying N to the seedbed is important; currently, it appears that applying at least 40 kg N/ha to the seedbed and the remainder by the start of stem extension leads to good yields and grain quality.

Quality:

- For grain quality, in both winter and spring oats variety choice is more significant than the timing of N application or addition of S
- For the winter oats, Mascani had the most stable grain quality across N timing and rate treatments.
- N application to winter oats at the tillering stage maintains specific weight and TGW
- For spring oats on the lighter soils in East Anglia, a significant effect of sulphur was found with screenings higher when no S was applied. This was not found in the Scottish trials.

- For spring oats, grain quality was lower in the trials in East Anglia than in Scotland indicating a strong effect of environment. However, the effect of increasing N on grain quality was similar in both locations.
- Low inputs of nitrogen result in lower kernel contents and hullability
- Specific weights decrease in response to increasing nitrogen application and in some varieties are below milling industry specifications at nitrogen applications above current RB209 recommendations
- Levels of N above the N_{opt} can result in a greater proportion of smaller grain in some varieties with the consequence of an increase in screenings

Further research requirements

Although this project had made significant progress in updating current RB209 recommendations, it was not possible to comprehensively answer a number of oats nutrition questions within the scope of the project. There are a number of areas the authors consider important to investigate further:

1. **Spring oats N recommendations; rates and timings –** the project ran and collated data from as many N response experiments as possible. However, because there was no previous data from the 2016 RB209 review available to build on, the ability to derive robust recommendations was limited. It is clear that current spring oats N recommendations are generally too low, but more research is required to confidently say what these should be, and how they are affected by yield and why there was no relationship found between yield at the optimum N rate and either the optimum N rate or the estimate of crop N demand. Further research is also required on spring oats N timings to elucidate what proportion of N should be applied to the seedbed, and the most appropriate timings for different growing conditions.
2. **N rates-** Winter oats in particular were very responsive to the application of N. Lowering the N opt whilst maintaining yield is a useful approach in developing varieties with a lower nitrogen requirement and further investigation of a wide range of varieties across environments would be very useful.
3. **S rates and timings –** The NoatS experiments investigated whether S affected yield and quality, and for winter oats the indication was that it was important on sandy soils. However, the Jordans Ryvita trials showed that there was no impact of S even when the crop would have been classified as N deficient. Further investigation of the optimal S rates plus timings would be valuable.
4. **Phosphorous and potassium** – it was beyond the scope of this project to investigate these nutrients. However, work is needed on P and K in oats to understand whether requirements are similar to other cereals. Since oats are generally taller than other cereals, and most K is held in the straw, does this mean that oats need more potassium?

5. **Additional N for grain filling –** The NoatS trials included one treatment where a proportion of the N was applied at GS39 with the hypothesis that this may prolong grain filling. The results from this treatment didn't indicate that this was the case. Further work should test whether it is beneficial to apply the total amount of N by early stem extension and then apply extra at GS39. On-farm trials in spring oats have indicated this may be beneficial to both yield and quality, so it would be valuable to investigate further.
6. **Quality-** clear genetic components to grain quality traits were observed across treatments in both winter and spring oats and understanding the basis for this would enhance the breeding of improved varieties maximising stability of grain quality and yields.
7. **Environmental effects-** different responses to N timing and rates for both yield and quality traits were found across different climatic regions and the ability to predict these from early season data would be very helpful.

7. Acknowledgments

The wide scope of this project would not have been possible without the tremendous support of the whole oats supply chain, for which the authors are extremely grateful. We would like to sincerely thank: PepsiCo for their cash, data and grain quality analyses; Saaten Union for carrying out spring oats N timing trials over three seasons; RAGT Seeds, Senova, KWS and Saaten Union for providing seed for trials, CF Fertilisers for providing fertiliser and lab analyses of soil and crops; OMEX for providing fertiliser and hosting trials; Richardsons Milling for providing grain lab tests and trial data; Jordans for carrying out S response trials and providing data; Gordon Gowlett for hosting a trial; and the Chadacre & Felix Thornley Cobbold Agricultural Trusts for funding trials whose data was used in the project. Thanks also to the whole consortium for their contributions to project direction.

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9. Appendices

Objective 2: Evaluate optimal nitrogen rates and timings and sulphur applications on winter oats yield

Effects of N rate on winter oats yield (t/ha at 85% dry matter)

Table 9.1. Yield (t/ha) and N_{opt} (kg/ha) for the Nottinghamshire 2019 rate trial on winter oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	80	130	180	230	300			
Mascani	2.72	5.41	4.91	5.10	4.77	4.80	4.62	20.18	6.11
Penrose	3.03	6.09	5.53	5.97	5.71	5.33	5.28	19.58	5.37
RGT Southwark	2.72	5.87	5.21	5.59	5.23	4.92	4.92	19.82	5.90
Grand mean	2.82	5.79	5.22	5.55	5.24	5.02	4.94	19.86	5.79

	P	SED	LSD
N rate	0.004	0.55	1.2327
Variety	<0.001	0.11	0.2344
N rate x Variety	0.91	0.60	1.2872

Table 9.2. Yield (t/ha) and N_{opt} (kg/ha) for the Herefordshire 2019 rate trial on winter oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	80	130	180	230	300			
Mascani	5.23	8.04	8.06	7.75	5.36	4.78	6.54	59.93	8.50
Penrose	5.30	6.79	7.09	5.69	5.36	4.27	5.75	52.09	7.12
RGT Southwark	3.89	7.08	5.06	5.38	4.38	4.40	5.03	60.16	6.17
Grand mean	4.80	7.30	6.73	6.27	5.03	4.48	5.77	57.39	7.26

	P	SED	LSD
N rate	0.001	0.528	1.175
Variety	<0.001	0.219	0.454
N rate x Variety	0.018	0.686	1.417

Table 9.3. Yield (t/ha) and N_{opt} (kg/ha) for the Nottinghamshire 2021 rate trial on winter oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	80	130	180	230	300			
Mascani	2.46	5.03	5.33	4.52	4.58	4.64	4.43	34.53	5.56
Penrose	2.26	5.79	5.86	5.06	4.75	4.91	4.77	34.53	5.56
RGT Southwark	2.54	5.53	5.50	4.36	4.54	4.54	4.50	34.53	5.56
Grand mean	2.42	5.45	5.56	4.65	4.62	4.70	4.57	34.53	5.56
	P	SED	LSD						
N rate	0.004	0.587	1.307						
Variety	0.007	0.103	0.213						
N rate x Variety	0.216	0.622	1.348						

Table 9.4. Yield (t/ha) and N_{opt} (kg/ha) for the Herefordshire 2021 rate trial on winter oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	80	130	180	230	300			
Mascani	4.74	9.10	9.50	9.61	10.03	8.87	8.64	118.07	9.89
Penrose	5.10	9.98	10.39	9.79	9.52	8.71	8.91	118.07	9.89
RGT Southwark	5.05	9.39	9.99	8.58	9.97	7.27	8.38	118.07	9.89
Grand mean	4.97	9.49	9.96	9.33	9.84	8.29	8.64	118.07	9.89
	P	SED	LSD						
N rate	<0.001	0.539	1.202						
Variety	0.097	0.238	0.491						
N rate x Variety	0.201	0.719	1.481						

Effects of N rate on winter oats yield parameters

Table 9.5. Yield parameters for the Nottinghamshire 2019 rate trial on winter oats.

Variety	N rate (kg N/ha)	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Mascani		43.1	77.59	537.29	46.39	12.71
Penrose		47.04	71.66	623.2	46.35	12.79
RGT Southwark		52.02	72.39	501.23	37.42	19.21
	0	47.92	70.54	283.02	44.94	15.19
	80	53.05	76.79	553.91	44.04	15.17
	130	46.83	77.03	674.69	44.65	18.15
	180	45.25	75.66	553.91	42.82	14.06
	230	46.38	70.18	704.01	41.39	13.03
	300	44.9	73.07	553.91	42.5	13.82
Mascani	0	48.12	72.36	270.37	45.82	14.53
	80	50.32	79.49	538.17	47.29	12.92
	130	42.05	82.44	661.11	47.61	14.27
	180	38.77	80.03	538.17	46.4	12.04
	230	40.41	75.43	677.78	45.4	11.62
	300	38.96	75.81	538.17	45.85	10.88
Penrose	0	48	67.66	331.48	49.58	13.34
	80	51.77	72.36	619.56	46.73	13.48
	130	46.24	71.88	775.93	48.02	14.03
	180	44.91	75.75	619.56	44.78	12.64
	230	44.73	70.36	773.15	43.29	10.93
	300	46.58	71.92	619.56	45.71	12.31
RGT Southwark	0	47.63	71.59	247.22	39.41	17.69
	80	57.06	78.52	504	38.12	19.12
	130	52.19	76.76	587.04	38.31	26.13
	180	52.08	71.19	504	37.29	17.49
	230	54.01	64.76	661.11	35.47	16.55
	300	49.15	71.49	504	35.95	18.27
N rate	P-value	0.323	0.227	<.001	<.001	<.001
	S.E.D.	3.64	3.349	31.745	0.36	0.757
	L.S.D.	8.111	7.462	88.13	0.737	1.551
Variety	P-value	<.001	0.001	<.001	<.001	0.001
	S.E.D.	1.024	1.516	16.157	0.509	1.071
	L.S.D.	2.114	3.128	35.2	1.042	2.194
N rate. Variety	P-value	0.031	0.362	0.429	0.008	0.122
	S.E.D.	4.177	4.517	45.299	0.881	1.855
	L.S.D.	8.827	9.288	98.51	1.805	3.8

Table 9.6. Yield parameters for the Nottinghamshire 2021 rate trial on winter oats.

Variety	**N rate (kg N/ha)**	**DMHI**	**Height (cm)**	**Panicles/ m2**	**TGW**	**Grains/ panicle**
Mascani		53.3	63.8	453.83	40.37	19.68
Penrose		56.88	60.75	435.94	41.86	21.97
RGT Southwark		58.76	62.15	413.39	33.66	25.02
	0	58.43	55.58	319.15	43.74	19.73
	80				41.09	
	130				38.66	
	180	54.19	68.89	549.63	36.77	24.72
	230				36.01	
	300				35.51	
Mascani	0	55.64	56.23	340.67	44.86	17.68
	80				44.2	
	130				40.29	
	180	50.97	71.37	567	38.15	21.67
	230				37.63	
	300				37.11	
Penrose	0	58.74	54.4	323.56	46.93	20.63
	80				44.73	
	130				41.96	
	180	55.02	67.1	548.33	40.27	23.32
	230				38.87	
	300				38.42	
RGT Southwark	0	60.92	56.1	293.22	39.44	20.87
	80				34.34	
	130				33.75	
	180	56.59	68.2	533.56	31.9	29.16
	230				31.53	
	300				30.99	
N rate	P-value	<.001	0.139	<.001	<.001	0.03
	S.E.D.	0.119	5.552	6.13	0.928	0.884
	L.S.D.	0.514	23.887	26.4	2.069	3.805
Variety	P-value	<.001	0.056	0.647	<.001	0.009
	S.E.D.	0.893	1.051	42.223	0.328	1.261
	L.S.D.	2.06	2.423	97.4	0.678	2.908
N rate. Variety	P-value	0.869	0.359	0.98	0.06	0.127
	S.E.D.	1.038	5.683	49.139	1.137	1.704
	L.S.D.	2.384	22.488	112.7	2.369	3.811

Table 9.7. Yield parameters for the Herefordshire 2019 rate trial on winter oats.

Variety	N rate (kg N/ha)	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Mascani		60.49	148.43	729.45	42.78	33.1
Penrose		58.24	140.07	777.6	42.45	30.2
RGT Southwark		62.19	150.09	682.56	33.09	49.2
	0	58.9	98.74	512.96	40.03	30.9
	80	63.9	146.26	719.44	40.98	37.9
	130	63.17	153.37	770.37	38.85	38.8
	180	61.26	159.44	763.43	38.23	44.5
	230	54.84	161.44	802.08	38.15	31
	300	59.78	157.93	810.93	40.41	41.9
Mascani	0	57.19	101.56	505.56	40.48	28.6
	80	67.38	146.67	675.93	43.65	34.8
	130	66.76	154.44	754.63	42.7	35.1
	180	64.22	163.33	795.37	43.25	37
	230	52.58	165.33	822.22	42.9	32
	300	54.83	159.22	822.97	43.72	31
Penrose	0	62.26	96.44	567.59	45.22	24.1
	80	52.59	134.89	758.33	44.74	28.7
	130	64.82	146.89	820.37	42.07	33.8
	180	64.98	154.22	787.96	39.57	35.6
	230	51.34	156	852.78	39.72	25
	300	53.45	152	878.55	43.38	34
RGT Southwark	0	57.27	98.22	465.74	34.38	40
	80	71.73	157.22	724.07	34.53	50.3
	130	57.92	158.78	736.11	31.79	47.5
	180	54.57	160.78	706.94	31.85	60.8
	230	60.59	163	731.25	31.84	35.9
	300	71.05	162.56	731.26	34.14	60.7
N rate	P-value	0.224	<.001	<.001	0.028	0.055
	S.E.D.	3.576	3.081	38.459	0.838	4.41
	L.S.D.	7.97	6.864	87	1.868	9.83
Variety	P-value	0.457	<.001	<.001	<.001	<.001
	S.E.D.	3.113	1.178	19.529	0.406	3.72
	L.S.D.	6.42	2.432	40.61	0.839	7.67
N rate. Variety	P-value	0.115	0.007	0.613	<.001	0.822
	S.E.D.	7.18	3.879	54.815	1.168	8.64
	L.S.D.	14.6	8.044	112.78	2.394	17.57

Table 9.8. Yield parameters for the Herefordshire 2021 rate trial on winter oats.

Variety	N rate (kg N/ha)	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Mascani		54.11	82.45	327.98	40.84	40.1
Penrose		54.61	82.8	358.44	40.49	40.7
RGT Southwark		58.17	92	323.86	36.09	53.3
	0	58.28	61.64	305.62	42.14	34.1
	80				41.82	
	130				38.99	
	180	52.98	109.86	367.9	38.24	55.4
	230				37.69	
	300				35.97	
Mascani	0	56.48	57.53	310.29	43.39	28
	80				43.39	
	130				40.7	
	180	51.75	107.37	345.68	40.38	52.3
	230				230	
	300				300	
Penrose	0	57.4	59.7	339.92	45.4	29.1
	80				44.15	
	130				40.54	
	180	51.82	105.9	376.95	39.12	52.3
	230				37.58	
	300				36.16	
RGT Southwark	0	60.95	67.7	266.66	37.63	45.1
	80				37.91	
	130				35.72	
	180	55.39	116.3	381.07	35.2	61.6
	230				35.38	
	300				34.69	
N rate	P-value	0.018	0.005	0.103	<.001	0.027
	S.E.D.	0.722	3.586	21.676	0.337	3.6
	L.S.D.	3.105	15.428	93.26	0.686	15.49
Variety	P-value	0.005	0.004	0.191	<.001	0.002
	S.E.D.	0.948	2.231	18.667	0.477	2.62
	L.S.D.	2.186	5.146	43.05	0.97	6.03
N rate. Variety	P-value	0.881	0.72	0.111	<.001	0.32
	S.E.D.	1.311	4.415	30.569	0.826	4.7
	L.S.D.	2.947	11.918	73.79	1.679	11.96

Effects of N rate on winter oats N uptake and partitioning

Table 9.9. Nitrogen uptake and partitioning for the Nottinghamshire 2019 rate trial on winter oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Mascani		119.70	1.68	0.96	0.56
Penrose		120.40	1.81	0.76	0.67
RGT Southwark		108.20	1.75	0.81	0.69
	0	43.40	1.28	0.49	0.71
	180	146.20	1.95	0.93	0.63
	300	158.60	2.01	1.11	0.58
Mascani	0	40.10	1.14	0.55	0.66
	180	156.40	1.91	1.10	0.53
	300	162.40	1.99	1.25	0.50
Penrose	0	45.80	1.32	0.43	0.74
	180	152.60	2.00	0.83	0.67
	300	162.70	2.10	1.02	0.62
RGT Southwark	0	44.30	1.38	0.49	0.73
	180	129.70	1.94	0.87	0.71
	300	150.50	1.94	1.07	0.63
N rate	P-value	0.002	<.001	0.004	0.035
	S.E.D.	13.350	0.056	0.082	0.030
	L.S.D.	37.050	0.154	0.228	0.084
Variety	P-value	0.008	0.060	0.005	0.003
	S.E.D.	3.140	0.048	0.045	0.027
	L.S.D.	7.240	0.105	0.104	0.062
N rate. Variety	P-value	0.011	0.209	0.280	0.254
	S.E.D.	14.070	0.088	0.104	0.049
	L.S.D.	36.370	0.188	0.236	0.106

Table 9.10. Nitrogen uptake and partitioning for the Herefordshire 2019 rate trial on winter oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Mascani		111.10	1.89	0.47	0.85
Penrose		94.50	1.79	0.64	0.81
RGT Southwark		76.60	1.69	0.49	0.84
	0	61.30	1.29	0.31	0.86
	180	121.40	1.89	0.63	0.83
	300	99.50	2.20	0.66	0.82
Mascani	0	70.10	1.32	0.34	0.84
	180	149.10	1.97	0.53	0.87
	300	114.20	2.37	0.54	0.84
Penrose	0	65.00	1.24	0.33	0.86
	180	114.70	1.97	0.73	0.83
	300	103.60	2.16	0.86	0.74
RGT Southwark	0	48.80	1.30	0.28	0.86
	180	100.30	1.71	0.62	0.77
	300	80.60	2.07	0.58	0.88
N rate	P-value	0.006	<.001	0.057	0.637
	S.E.D.	8.800	0.074	0.107	0.038
	L.S.D.	24.430	0.207	0.298	0.104
Variety	P-value	<.001	0.042	0.062	0.397
	S.E.D.	6.140	0.066	0.070	0.027
	L.S.D.	13.510	0.145	0.152	0.060
N rate. Variety	P-value	0.316	0.276	0.388	0.072
	S.E.D.	12.360	0.120	0.146	0.054
	L.S.D.	27.040	0.256	0.321	0.117

Table 9.11. Nitrogen uptake and partitioning for the Nottinghamshire 2021 rate trial on winter oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Mascani		90.60	1.91	0.95	0.71
Penrose		86.80	1.89	0.84	0.76
RGT Southwark		85.50	1.86	1.13	0.73
	0	35.70	1.42	0.49	0.80
	180	139.60	2.35	1.46	0.66
Mascani	0	37.20	1.39	0.56	0.76
	180	144.10	2.43	1.33	0.66
Penrose	0	33.30	1.42	0.51	0.80
	180	140.30	2.36	1.18	0.71
RGT Southwark	0	36.50	1.45	0.40	0.85
	180	134.60	2.27	1.86	0.61
N rate	P-value	0.026	0.001	0.022	0.054
	S.E.D.	17.240	0.032	0.145	0.035
	L.S.D.	74.180	0.138	0.622	0.149
Variety	P-value	0.675	0.494	0.100	0.126
	S.E.D.	5.870	0.046	0.116	0.020
	L.S.D.	13.540	0.107	0.267	0.046
N rate. Variety	P-value	0.698	0.109	0.018	0.011
	S.E.D.	18.530	0.062	0.197	0.042
	L.S.D.	63.610	0.140	0.485	0.116

Table 9.12. Nitrogen uptake and partitioning for the Herefordshire 2021 rate trial on winter oats

Variety	**N rate (kg N/ha)**	**Total N uptake**	**Grain N%**	**straw + chaff N%**	**NHI**
Mascani		139.70	1.71	0.47	0.81
Penrose		131.70	1.64	0.38	0.84
RGT Southwark		117.70	1.68	0.38	0.86
	0	68.10	1.39	0.31	0.86
	180	191.30	1.96	0.50	0.82
Mascani	0	64.00	1.33	0.34	0.84
	180	215.30	2.09	0.59	0.79
Penrose	0	68.30	1.38	0.27	0.88
	180	195.10	1.90	0.49	0.81
RGT Southwark	0	72.00	1.47	0.33	0.88
	180	163.40	1.90	0.43	0.85
N rate	P-value	<.001	0.006	0.063	0.056
	S.E.D.	3.340	0.046	0.051	0.011
	L.S.D.	14.380	0.198	0.219	0.049
Variety	P-value	0.017	0.584	0.434	0.245
	S.E.D.	5.910	0.068	0.074	0.026
	L.S.D.	13.630	0.157	0.170	0.060
N rate. Variety	P-value	0.003	0.101	0.601	0.742
	S.E.D.	7.600	0.091	0.099	0.032
	L.S.D.	16.940	0.203	0.221	0.072

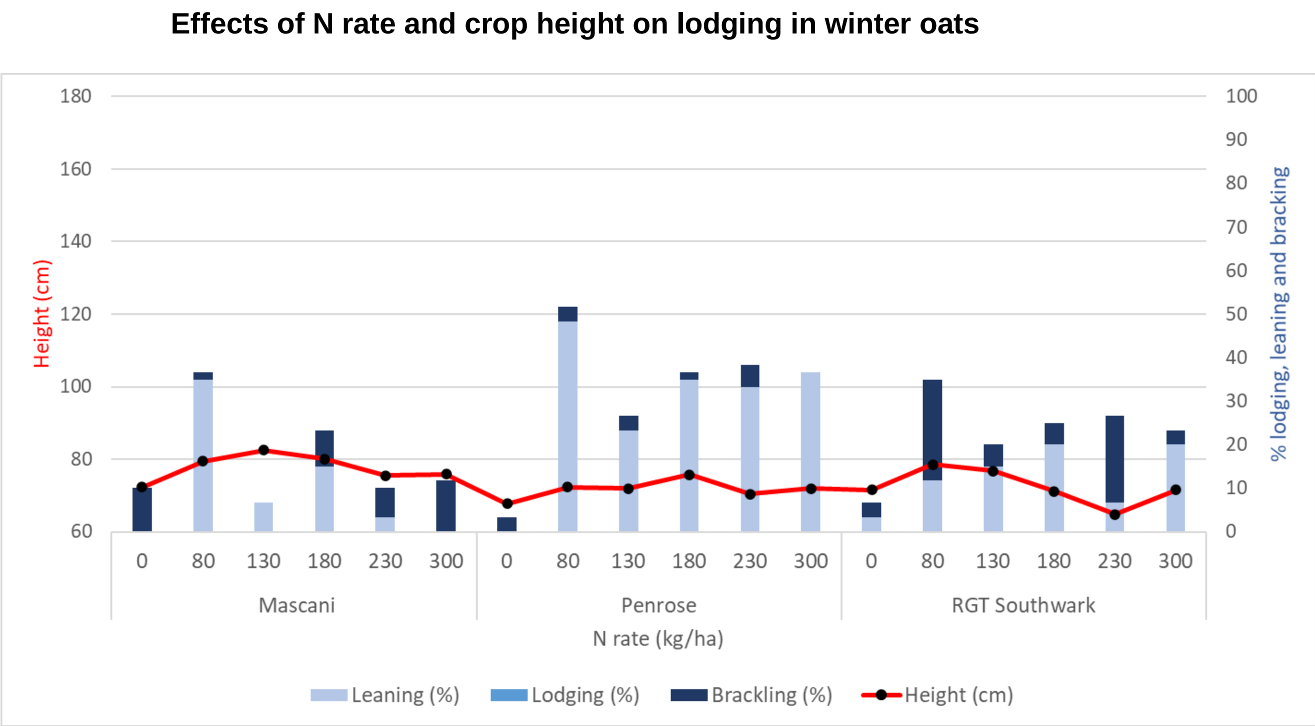

Figure 9.1. Impacts of N rate and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Nottinghamshire 2019 N rate trial on winter oats.

Effects of N timing on winter oats yield (t/ha at 85% dry matter)

Table 9.13. Yield (t/ha) for the Nottinghamshire 2019 timing trial on winter oats.

	Yield (t/ha) at N timing treatments						
Variety	1	2	3	4	5	6	Grand mean
Mascani	6.45	6.04	6.23	5.98	6.27	5.59	6.09
Penrose	7.02	6.57	6.00	6.63	6.56	5.89	6.45
RGT Southwark	6.43	5.52	5.11	5.95	5.98	5.20	5.70
Grand mean	6.63	6.04	5.78	6.19	6.27	5.56	6.08
	P	SED	LSD				
N timing	0.107	0.342	0.762				
Variety	<0.001	0.151	0.312				
N rate x Variety	0.681	0.456	0.939				

Table 9.14. Yield (t/ha) for the Herefordshire 2019 timing trial on winter oats.

	Yield (t/ha) at N timing treatments						
Variety	1	2	3	4	5	6	Grand mean
Mascani	9.67	8.95	8.91	8.98	8.94	8.89	9.06
Penrose	6.79	7.89	5.88	6.92	6.55	7.67	6.95
RGT Southwark	6.99	6.99	6.12	6.22	6.63	7.31	6.71
Grand mean	7.82	7.94	6.97	7.37	7.37	7.96	7.57
	P	SED	LSD				
N timing	0.067	0.325	0.725				
Variety	<0.001	0.305	0.636				
N rate x Variety	0.716	0.691	1.415				

Table 9.15. Yield (t/ha) for the Nottinghamshire 2021 timing trial on winter oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Mascani	7.19	7.07	7.13	7.24	6.47	6.19	6.88
Penrose	7.28	7.69	7.14	8.07	7.03	6.41	7.27
RGT Southwark	6.55	6.47	6.62	6.67	6.06	5.72	6.35
Grand mean	7.01	7.08	6.96	7.32	6.52	6.11	6.83
	P	SED	LSD				
N timing	0.101	0.394	0.878				
Variety	<0.001	0.125	0.257				
N rate x Variety	0.612	0.466	0.978				

Table 9.16. Yield (t/ha) for the Herefordshire 2021 timing trial on winter oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Mascani	10.81	10.70	11.11	10.26	9.92	10.38	10.53
Penrose	10.36	10.37	10.22	11.10	10.47	10.69	10.54
RGT Southwark	10.62	11.04	9.79	11.26	11.14	11.53	10.90
Grand mean	10.60	10.71	10.37	10.87	10.51	10.87	10.65
	P	SED	LSD				
N timing	0.628	0.334	0.744				
Variety	0.203	0.229	0.472				
N rate x Variety	0.131	0.566	1.151				

Effects of N timing + S on winter oats yield parameters

Table 9.17. Yield parameters for the Nottinghamshire 2019 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Mascani		48.01	81.26	752	45.56	15.23
Penrose		50.57	74.07	911	43.75	14.16
RGT Southwark		55.24	71.92	694	35.88	21.73
	1	52.17	79.25	791	41.86	18.93
	2	50.24	77.74	743	42.13	18.43
	3	52.01	78.31	796	41.77	16.09
	4	48.12	73.19	814	40.44	15.41
	5	53.38	74.81	905	41.31	15.05
	6	51.72	71.2	664	42.86	18.33
Mascani	1	48.68	86.69	766	45.29	15.97
	2	46.84	83.2	737	46.17	16.41
	3	50.04	84.81	719	46.18	14.34
	4	43.86	76.52	763	43.69	13.53
	5	50.18	78.47	841	45.88	14.54
	6	48.45	77.86	684	46.15	16.6
Penrose	1	49.91	78.99	943	44.65	14.28
	2	47.84	75.4	895	44.45	15.15
	3	53.49	73.82	883	42.98	14.05
	4	48.95	73.17	894	42.71	12.43
	5	53.08	74.58	1071	42.16	12.95
	6	50.14	68.48	779	45.55	16.11
RGT Southwark	1	57.92	72.06	665	35.65	26.54
	2	56.06	74.62	595	35.76	23.72
	3	52.51	76.31	785	36.14	19.88
	4	51.54	69.87	784	34.94	20.28
	5	56.87	71.39	804	35.89	17.67
	6	56.56	67.27	530	36.88	22.28
Timing	P-value	0.123	0.488	0.013	0.287	0.07
	S.E.D.	1.719	4.616	49.3	0.951	1.416
	L.S.D.	3.83	10.285	109.8	2.12	3.155
Variety	P-value	<.001	<.001	<.001	<.001	<.001
	S.E.D.	1.209	1.815	26.5	0.287	1.006
	L.S.D.	2.495	3.746	54.7	0.592	2.076
Timing.Variety	P-value	0.612	0.896	0.225	0.045	0.675
	S.E.D.	2.967	5.872	72.3	1.111	2.46
	L.S.D.	6.031	12.16	147.8	2.337	5.001

Table 9.18. Yield parameters for the Nottinghamshire 2021 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	TGW	Grains/ panicle
Mascani		47.7	40	21.2
Penrose		53.5	40.51	29.1
RGT Southwark		52.9	31.36	39.6
	1	51.4	36.17	29.9
	2		36.6	
	3		38.42	
	4		35.99	
	5		39.47	
	6		37.11	
Mascani	1	47.7	38.81	21.2
	2		38.39	
	3		42.23	
	4		37.81	
	5		42.79	
	6		39.98	
Penrose	1	53.5	38.84	29.1
	2		40.98	
	3		41.24	
	4		39.67	
	5		42.37	
	6		39.99	
RGT Southwark	1	52.9	30.86	39.6
	2		30.43	
	3		31.8	
	4		30.48	
	5		33.24	
	6		31.36	
Timing	P-value		<.001	
	S.E.D.		0.337	
	L.S.D.		0.75	
Variety	P-value	0.155	<.001	0.094
	S.E.D.	2.6	0.279	6.13
	L.S.D.	7.23	0.576	17.02
Timing.Variety	P-value		0.017	
	S.E.D.		0.652	
	L.S.D.		1.325	

Table 9.19. Yield parameters for the Herefordshire 2019 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Mascani		61.05	145.1	513.4	42.99	37.8
Penrose		58.85	125	504.2	41.27	33.4
RGT Southwark		57.05	145.6	489.7	34.24	50.6
	1	60.46	129.2	508	39.35	36.5
	2	55.32	153	514.5	39.18	42.4
	3	58.16	133.3	508.3	39.62	41
	4	60.7	136.6	486.1	39.52	41.4
	5	60.1	142.2	503.1	39.51	41.8
	6	59.15	137.1	494.4	39.81	40.5
Mascani	1	60.87	147	524.1	43.73	17.1
	2	61.23	145.8	521.3	42.85	50.5
	3	64.36	142.3	510.2	44.21	44.6
	4	60.32	148.5	497.2	43.11	34.8
	5	60.66	138.2	532.4	43.69	37.6
	6	58.88	148.5	495.4	40.35	42.3
Penrose	1	57.91	125.5	494.4	41.29	31.8
	2	59.73	132.2	510.2	42.7	32.4
	3	57.87	110.3	533.3	41.2	32.1
	4	59.24	117	488	41.32	40.9
	5	57.9	141.2	506.5	39.08	32
	6	60.45	123.7	492.6	42.04	31.4
RGT Southwark	1	62.61	115	505.6	33.05	60.8
	2	45	181	512	31.99	44.3
	3	52.25	147.2	481.5	33.45	46.3
	4	62.55	144.3	473.1	34.14	48.5
	5	61.74	147.2	470.4	35.76	55.8
	6	58.13	139	495.4	37.03	47.8
Timing	P-value	0.44	0.518	0.428	0.953	0.739
	S.E.D.	2.793	12.37	14.19	0.676	4.02
	L.S.D.	6.224	27.57	31.62	1.506	8.95
Variety	P-value	0.051	0.052	0.18	<.001	<.001
	S.E.D.	1.542	9.08	12.48	0.887	3.29
	L.S.D.	3.182	18.74	25.77	1.845	6.88
Timing.Variety	P-value	0.013	0.662	0.866	0.24	0.031
	S.E.D.	4.16	21.97	28.72	1.899	7.71
	L.S.D.	8.492	44.66	58.39	3.9	15.78

Table 9.20. Yield parameters for the Herefordshire 2021 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	TGW	Grains/ panicle
Mascani		49.21	41.53	46.8
Penrose		54.6	40.13	48.7
RGT Southwark		55.39	37.26	53.5
	1	53.07	39.37	49.6
	2		39.19	
	3		40.04	
	4		38.39	
	5		40.08	
	6		40.78	
Mascani	1	49.21	41.35	46.8
	2		40.97	
	3		42.22	
	4		40.28	
	5		42.53	
	6		41.85	
Penrose	1	54.6	39.73	48.7
	2		39.23	
	3		39.95	
	4		39.62	
	5		40.13	
	6		42.12	
RGT Southwark	1	55.39	37.03	53.5
	2		37.36	
	3		37.96	
	4		35.27	
	5		37.58	
	6		38.37	
Timing	P-value		0.002	
	S.E.D.		0.392	
	L.S.D.		0.873	
Variety	P-value	0.007	<.001	0.157
	S.E.D.	0.419	0.315	2.81
	L.S.D.	1.164	0.651	7.8
Timing.Variety	P-value		0.255	
	S.E.D.		0.743	
	L.S.D.		1.509	

Effects of N timing + S on winter oats N uptake and partitioning

Table 9.21. Nitrogen uptake and partitioning for the Nottinghamshire 2019 timing + sulphur trial on winter oats. "NA" indicates where data is not available.

Variety	N timing treatment	Total N uptake	Grain N%	straw + chaff N%	NHI
Mascani		151.50	1.72	1.10	0.59
Penrose		133.00	1.61	0.83	0.66
RGT Southwark		111.80	1.60	0.87	0.69
	1	137.60	1.57	NA	0.65
	2	132.00	1.61	NA	0.64
	3	127.50	1.71	NA	0.66
	4	141.10	1.65	NA	0.62
	5	137.70	1.74	NA	0.68
	6	116.90	1.57	NA	0.64
Mascani	1	151.90	1.61	NA	0.58
	2	152.00	1.71	NA	0.58
	3	156.50	1.86	NA	0.63
	4	158.20	1.70	NA	0.55
	5	157.90	1.84	NA	0.63
	6	132.60	1.59	NA	0.58
Penrose	1	138.30	1.48	NA	0.64
	2	138.00	1.56	NA	0.63
	3	120.00	1.62	NA	0.69
	4	144.10	1.67	NA	0.66
	5	138.50	1.76	NA	0.70
	6	118.90	1.55	NA	0.65
RGT Southwark	1	122.50	1.61	NA	0.72
	2	106.00	1.58	NA	0.70
	3	105.90	1.64	NA	0.67
	4	120.90	1.58	NA	0.66
	5	116.70	1.63	NA	0.71
	6	99.10	1.58	NA	0.70
N rate	P-value	0.031	0.339	NA	0.014
	S.E.D.	6.350	0.089	NA	0.013
	L.S.D.	14.140	0.197	NA	0.029
Variety	P-value	<.001	0.007	NA	<.001
	S.E.D.	4.050	0.038	NA	0.012
	L.S.D.	8.360	0.079	NA	0.024
N rate. Variety	P-value	0.779	0.563	NA	0.312
	S.E.D.	10.290	0.117	NA	0.027
	L.S.D.	20.940	0.241	NA	0.054

Table 9.22. Nitrogen uptake and partitioning for the Herefordshire 2019 timing + S trial on winter oats. "NA" indicates where data is not available.

Variety	N timing treatment	Total N uptake	Grain N%	straw + chaff N%	NHI
Mascani		161.70	1.85	0.31	0.89
Penrose		117.00	1.73	0.40	0.88
RGT Southwark		106.70	1.64	0.41	0.87
	1	141.10	1.68	0.37	0.88
	2	125.40	1.65	NA	NA
	3	124.70	1.90	NA	NA
	4	121.00	1.71	NA	NA
	5	127.30	1.80	NA	NA
	6	131.10	1.72	NA	NA
Mascani	1	172.80	1.70	0.31	0.89
	2	142.00	1.64	NA	NA
	3	175.00	2.02	NA	NA
	4	156.70	1.83	NA	NA
	5	176.50	2.09	NA	NA
	6	147.30	1.83	NA	NA
Penrose	1	127.50	1.76	0.40	0.88
	2	121.30	1.61	NA	NA
	3	99.00	1.76	NA	NA
	4	117.30	1.78	NA	NA
	5	105.20	1.70	NA	NA
	6	131.50	1.77	NA	NA
RGT Southwark	1	123.00	1.58	0.41	0.87
	2	113.00	1.70	NA	NA
	3	100.20	1.91	NA	NA
	4	89.00	1.53	NA	NA
	5	100.30	1.59	NA	NA
	6	114.40	1.56	NA	NA
N rate	P-value	0.311	0.262	NA	NA
	S.E.D.	8.470	0.102	NA	NA
	L.S.D.	18.870	0.228	NA	NA
Variety	P-value	<.001	0.008	0.526	0.413
	S.E.D.	5.950	0.061	0.037	0.004
	L.S.D.	12.410	0.125	0.102	0.007
N rate. Variety	P-value	0.116	0.236	NA	NA
	S.E.D.	14.600	0.159	NA	NA
	L.S.D.	29.820	0.323	NA	NA

Effects of N timing + S and crop height on lodging in winter oats

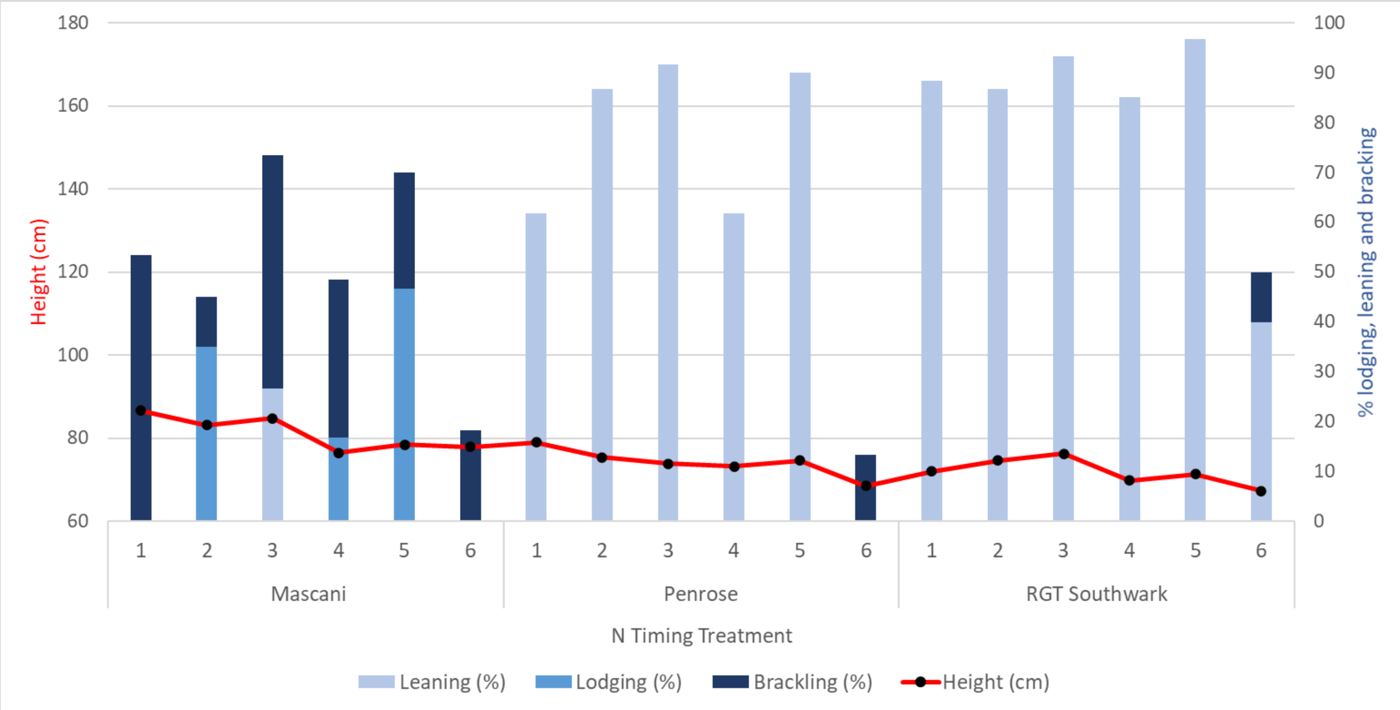

Figure 9.2. Impacts of N timing + S and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Nottinghamshire 2019 N timing + S trial on winter oats.

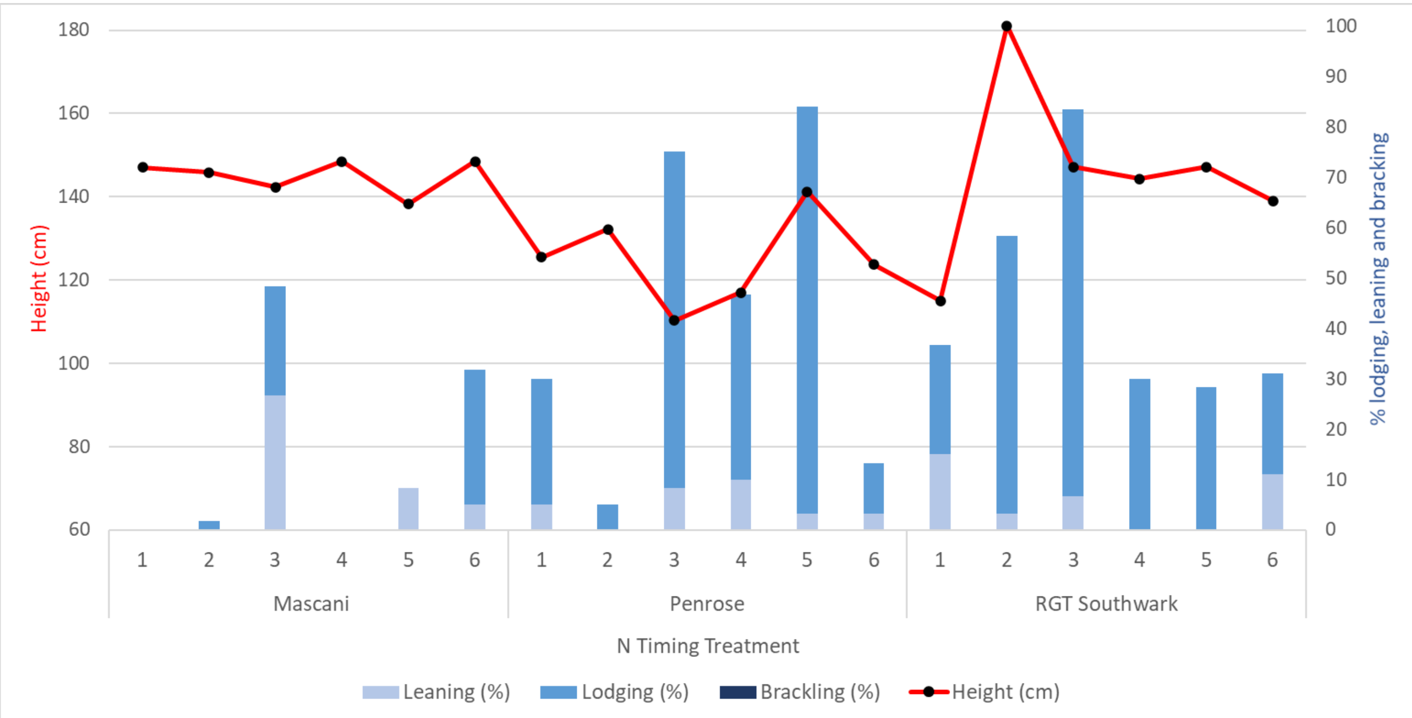

Figure 9.3. Impacts of N timing + S and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Herefordshire 2019 N timing + S trial on winter oats.

Objective 3: Evaluate optimal nitrogen rates and timings and sulphur applications on spring oats yield

Effects of N rate on spring oats yield (t/ha at 85% dry matter)

Table 9.23. Yield (t/ha) and N_{opt} (kg/ha) for the Fife 2019 rate trial on spring oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	50	100	140	180	220			
Canyon	3.62	5.01	4.39	4.62	3.97	7.38	4.83	N/A	N/A
Conway	4.73	5.85	7.27	7.70	7.00	7.23	6.63	173.44	7.70
WBP Elyann	5.15	6.43	7.10	7.24	7.40	6.65	6.66	164.74	7.60
Grand mean	4.50	5.76	6.25	6.52	6.12	7.09	6.04	169.09	7.65
	P	SED	LSD						
N rate	<.001	0.288	0.589						
Variety	<.001	0.204	0.416						
N rate x Variety	<.001	0.499	1.020						

Table 9.24. Yield (t/ha) and N_{opt} (kg/ha) for the Cambridgeshire 2019 rate trial on spring oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	60	120	160	220	280			
Aspen	4.46	5.56	5.70	5.83	5.07	5.77	5.40	86.44	5.56
Canyon	3.79	5.18	5.72	5.74	5.62	5.25	5.22	86.44	5.38
WBP Elyann	3.91	5.27	5.22	5.20	5.48	5.36	5.07	86.44	5.23
Grand mean	4.05	5.33	5.54	5.59	5.39	5.46	5.23	86.44	5.39
	P	SED	LSD						
N rate	<0.001	0.191	0.388						
Variety	0.068	0.135	0.274						
N rate x Variety	0.252	0.331	0.672						

Table 9.25. Yield (t/ha) and N_{opt} (kg/ha) for the Fife 2020 rate trial on spring oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	50	100	140	180	220			
Canyon	4.99	8.12	8.63	9.63	9.6	9.95	8.49	N/A	N/A
Conway	4.76	7.79	7.78	8.47	8.91	9.28	7.83	N/A	N/A
WBP Elyann	4.49	7.36	8.19	8.36	8.31	8.07	7.46	110.79	8.29
Grand mean	4.75	7.76	8.20	8.82	8.94	9.10	7.93	110.79	8.29
	P	SED	LSD						
N rate	<0.001	0.342	0.329						
Variety	0.001	0.342	0.233						
N rate x Variety	0.050	0.342	0.570						

Table 9.26. Yield (t/ha) and N_{opt} (kg/ha) for the Fife 2021 rate trial on spring oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	70	120	180	220	300			
Canyon	2.78	5.28	6.04	7.03	7.52	8.21	6.14	265.72	8.04
Conway	1.97	5.22	5.9	7.99	7.8	8.17	6.18	237.66	8.26
WBP Elyann	4.37	5.16	6.2	7.54	7.98	7.26	6.42	217.30	7.56
Grand mean	3.04	5.22	6.05	7.52	7.77	7.88	6.25	240.23	7.96
	P	SED	LSD						
N rate	<0.001	0.303	0.290						
Variety	0.082	0.303	0.205						
N rate x Variety	<0.001	0.303	0.503						

Table 9.27. Yield (t/ha) and N_{opt} (kg/ha) for the Cambridgeshire 2021 rate trial on spring oats.

Variety	Yield (t/ha) at N rates (kg/ha)						Grand mean	N_{opt}	Yield at N_{opt}
	0	70	120	180	220	300			
Aspen	6.52	5.53	4.34	5.21	3.78	4.04	4.90	N/A	N/A
Canyon	6.85	5.65	6.35	5.04	4.97	5.41	5.71	N/A	N/A
WBP Elyann	5.48	4.91	4.77	4.28	3.75	4.49	4.61	N/A	N/A
Grand mean	6.28	5.36	5.16	4.84	4.17	4.65	5.08	N/A	N/A

	P	SED	LSD
N rate	0.003	0.364	0.81
Variety	0.003	0.248	0.512
N rate x Variety	0.145	0.615	1.251

Effects of N rate on spring oats yield parameters

Table 9.28. Yield parameters for the Cambridgeshire 2019 rate trial on spring oats.

Variety	N rate (kg N/ha)	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Aspen		46.29	103.84	421	39.22	33.98
Canyon		42.47	108.95	366	41.263	31.69
WPB Elyann		48.3	104.4	484	40.376	33.75
	0	46.94	97.61	437	40.872	29.72
	80	47.66	104.78	424	40.502	36.48
	130	45.93	108.38	422	40.055	32.85
	180	45.19	107.99	424	40.043	34.31
	230	43.96	110.46	412	40.086	31.86
	300	44.43	105.17	424	40.161	33.63
Aspen	0	46.85	95.83	456	40.383	30.59
	80	47.55	99.57	422	39.49	35.05
	130	47.35	107.27	402	38.789	34.58
	180	46.71	107.03	422	38.463	35.9
	230	44.22	110.33	406	39.025	34.66
	300	45.08	103	422	39.169	33.08
Canyon	0	45.82	102.23	323	41.453	28.79
	80	44.53	110.85	369	41.804	34.32
	130	41.36	109.93	375	40.899	30.94
	180	41.63	111.57	369	41.531	33.23
	230	39.49	114.2	390	40.958	28.27
	300	41.99	104.93	369	40.934	34.58
WPB Elyann	0	48.16	94.77	532	40.78	29.76
	80	50.89	103.93	481	40.21	40.07
	130	49.1	107.93	489	40.476	33.02
	180	47.23	105.37	481	40.135	33.8
	230	48.18	106.83	442	40.276	32.65
	300	46.23	107.57	481	40.38	33.23
N rate	P-value	0.346	0.056	0.841	0.039	0.327
	S.E.D.	1.798	3.569	42	0.2473	2.809
	L.S.D.	4.007	7.953	116.6	0.551	6.258
Variety	P-value	<.001	0.088	<.001	<.001	0.359
	S.E.D.	1.1	2.418	17.9	0.2238	1.725
	L.S.D.	2.271	4.991	39	0.462	3.561
N rate. Variety	P-value	0.888	0.948	0.162	0.446	0.935
	S.E.D.	2.842	6.011	55.2	0.5114	4.449
	L.S.D.	5.787	12.223	122.7	1.04	9.059

Table 9.29. Yield parameters for the Cambridgeshire 2021 rate trial on spring oats.

Variety	N rate (kg N/ha)	DMHI	Grains/ panicle	TGW
Aspen		58.9	54.4	43.4
Canyon		53.6	57.6	43.52
WPB Elyann		57.5	52.7	40.26
	0	56.7	54.9	43.76
	80			42.66
	130			42.22
	180			41.98
	230			41.91
	300			41.82
Aspen	0	58.9	54.4	44.62
	80			43.08
	130			43.87
	180			43.11
	230			42.01
	300			43.74
Canyon	0	53.6	57.6	44.49
	80			44.44
	130			42.77
	180			43.36
	230			43.69
	300			42.35
WPB Elyann	0	57.5	52.7	42.16
	80			40.46
	130			40.02
	180			39.48
	230			40.04
	300			39.37
N rate	P-value			0.224
	S.E.D.			0.797
	L.S.D.			1.776
Variety	P-value	0.599	0.871	<.001
	S.E.D.	5.11	9.29	0.394
	L.S.D.	14.19	25.78	0.812
N rate. Variety	P-value			0.446
	S.E.D.			1.12
	L.S.D.			2.295

Table 9.30. Yield parameters for the Fife 2019 rate trial on spring oats.

Variety	**N rate (kg N/ha)**	**DMHI**	**Height (cm)**	**Panicles/ m2**	**TGW**	**Grains/ panicle**
Canyon		52.34	111.58	428.2	40.67	45.97
Conway		48.92	92.94	420.4	38.67	38.74
WBP Elyann		54.2	98.48	411.3	41.41	42.9
	0	53.28	85.19	318.8	42.93	36.51
	50	53.1	92.9	420	42.78	40.38
	100	51.63	104.74	427.8	40.69	46.48
	140	51.73	103.33	420	39.12	41.46
	180	50.86	111.43	513.3	37.76	47.44
	220	50.33	108.39	420	38.23	42.95
Canyon	0	54.48	96.63	300.9	43.41	40.28
	50	52.87	102.8	428	43.2	39.48
	100	52.46	119	440.7	41.64	55.36
	140	51.21	114.47	428	39.47	43.18
	180	52.23	123.03	543.5	37.27	49.28
	220	50.78	113.53	428	39.05	48.2
Conway	0	49.75	75.9	363.9	40.93	33.85
	50	50.19	86.17	420.3	40.96	38.14
	100	49.24	97.77	391.7	38.71	40.28
	140	48.97	93.07	420.3	37.93	38.93
	180	48.41	102.57	505.6	36.83	45.01
	220	46.96	102.17	420.3	36.66	36.21
WBP Elyann	0	55.6	83.03	291.7	44.46	35.38
	50	56.24	89.73	411.6	44.18	43.51
	100	53.19	97.47	450.9	41.71	43.79
	140	55.01	102.47	411.6	39.98	42.26
	180	51.93	108.7	490.7	39.19	48.05
	220	53.25	109.47	411.6	38.97	44.43
N rate	P-value	0.066	<.001	0.012	<.001	0.01
	S.E.D.	0.962	3.122	34.52	0.82	2.414
	L.S.D.	2.144	6.957	95.84	1.827	5.378
Variety	P-value	<.001	<.001	0.708	<.001	0.003
	S.E.D.	0.56	1.73	20.01	0.397	1.857
	L.S.D.	1.157	3.571	43.59	0.819	3.832
N rate. Variety	P-value	0.58	0.408	0.333	0.802	0.498
	S.E.D.	1.477	4.661	52.85	1.142	4.429
	L.S.D.	3.011	9.513	113.56	2.34	9.001

Table 9.31. Yield parameters for the Fife 2021 rate trial on spring oats.

Variety	N rate (kg N/ha)	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Canyon		55.51	75.06	391.3	44.14	34.4
Conway		54.75	63.97	406.9	40.23	30.5
WBP Elyann		60.29	70.7	423.3	41.6	33.4
	0	54.48	53	308.6	43.27	23
	70	54.24	65.01	392.7	42.87	28.9
	120	56.86	68.28	419.3	42.43	34.1
	180	58.54	76.5	426.3	41.94	37.6
	220	58.9	76.83	444.6	41.06	35.1
	300	58.07	79.83	451.8	40.36	37.7
Canyon	0	50.72	57.33	285.7	46.29	21.6
	70	52.58	71.5	383.3	44.66	27.1
	120	55.07	74.83	398.7	44.45	35
	180	57.03	82.67	412.3	43.85	43.2
	220	55.81	81	429	43.49	33.3
	300	61.83	83	439	42.09	46
Conway	0	53.04	46	292.3	40.99	22.6
	70	50.71	59	375.7	41.56	27.7
	120	54.53	61.67	440.3	41.17	32.8
	180	55.76	71.33	436.7	40.16	32.5
	220	57.28	70.17	449	39.3	35.1
	300	57.2	75.67	447.7	38.16	32.4
WBP Elyann	0	59.68	55.67	347.7	42.54	24.7
	70	59.44	64.53	419	42.39	31.9
	120	60.99	68.33	419	41.65	34.6
	180	62.84	75.5	430	41.81	37.2
	220	63.6	79.33	455.7	40.37	37
	300	55.17	80.83	468.7	40.83	34.7
N rate	P-value	0.17	<.001	<.001	<.001	0.02
	S.E.D.	2.066	1.196	17.32	0.329	3.82
	L.S.D.	4.603	2.666	38.59	0.733	8.51
Variety	P-value	0.002	<.001	0.084	<.001	0.31
	S.E.D.	1.489	1.432	13.66	0.308	2.55
	L.S.D.	3.073	2.955	28.2	0.636	5.27
N rate. Variety	P-value	0.266	0.902	0.923	0.366	0.687
	S.E.D.	3.624	3.103	32.35	0.699	6.38
	L.S.D.	7.367	6.33	65.75	1.421	12.97

Table 9.32. Yield parameters for the Lincolnshire 2021 rate trial on spring oats.

Variety	**N rate (kg N/ha)**	**DMHI**	**Height (cm)**	**Panicles/ m2**	**TGW**	**Grains/ panicle**
Aspen		51.43	99.41	554.8	46.37	34.18
Canyon		51.27	106.71	478.7	46.99	39.6
	0	49.22	95.18	458.1	45.43	32.13
	70	53.48	110.93	575.4	47.93	41.64
	120	51.78	103.42	501.8	46.76	37.2
	180	50.92	102.7	531.8	46.6	36.58
	220	52.12	101.76	520.1	46.6	38.83
	300	50.58	104.36	513.4	46.76	34.94
Aspen	0	51.33	92.93	486.5	47.09	32.49
	70	54.81	108.53	578.7	46.96	44.49
	120	51.01	99.46	537.3	45.95	34.44
	180	51.1	97.92	562.9	45.91	32.53
	220	51.16	98.18	601.8	46.14	32.69
	300	49.18	99.41	561.8	46.16	28.43
Canyon	0	47.11	97.43	429.8	43.77	31.77
	70	52.15	113.33	572	48.9	38.8
	120	52.54	107.39	466.2	47.57	39.96
	180	50.74	107.47	500.6	47.29	40.63
	220	53.08	105.34	438.4	47.05	44.97
	300	51.97	109.31	465.1	47.36	41.45
N rate	P-value					
	S.E.D.					
	L.S.D.					
Variety	P-value	0.819	<.001	<.001	0.176	<.001
	S.E.D.	0.715	1.48	15.96	0.445	1.172
	L.S.D.	1.475	3.054	32.94	0.919	2.42
N rate. Variety	P-value	0.058	0.843	0.159	0.023	<.001
	S.E.D.					
	L.S.D.					

Effects of N rate on spring oats N uptake and partitioning

Table 9.33. Nitrogen uptake and partitioning for the Fife 2019 rate trial on spring oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Canyon		92.40	1.68	0.56	0.77
Conway		118.00	1.69	0.38	0.82
WBP Elyann		100.40	1.43	0.40	0.83
	0	60.80	1.35	0.28	0.85
	50	83.10	1.43	0.30	0.84
	100	101.80	1.55	0.43	0.80
	140	110.40	1.59	0.46	0.80
	180	119.60	1.80	0.54	0.77
	220	146.00	1.86	0.67	0.78
Canyon	0	52.90	1.39	0.36	0.83
	50	78.10	1.52	0.35	0.83
	100	80.50	1.73	0.48	0.80
	140	95.30	1.75	0.70	0.73
	180	82.50	1.82	0.64	0.74
	220	165.30	1.86	0.80	0.71
Conway	0	64.40	1.36	0.23	0.85
	50	84.90	1.44	0.24	0.86
	100	119.10	1.55	0.37	0.80
	140	134.80	1.70	0.34	0.83
	180	150.90	1.98	0.52	0.78
	220	154.10	2.08	0.58	0.81
WBP Elyann	0	65.20	1.29	0.25	0.86
	50	86.30	1.33	0.31	0.85
	100	105.70	1.37	0.43	0.79
	140	101.10	1.33	0.33	0.84
	180	125.50	1.59	0.45	0.80
	220	118.50	1.65	0.64	0.82
N rate	P-value	<.001	<.001	0.001	0.01
	S.E.D.	5.720	0.063	0.066	0.017
	L.S.D.	12.740	0.140	0.148	0.039
Variety	P-value	<.001	<.001	<.001	<.001
	S.E.D.	4.610	0.047	0.040	0.012
	L.S.D.	9.660	0.096	0.082	0.025
N rate. Variety	P-value	<.001	0.17	0.46	0.11
	S.E.D.	10.860	0.112	0.104	0.029
	L.S.D.	22.220	0.228	0.212	0.060

Table 9.34. Nitrogen uptake and partitioning for the Cambridgeshire 2019 rate trial on spring oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Aspen		121.90	2.00	0.55	0.76
Canyon		124.40	2.03	0.62	0.72
WPB Elyann		111.00	1.88	0.69	0.72
	0	74.90	1.68	0.43	0.78
	180	133.60	2.04	0.63	0.73
	300	148.80	2.20	0.80	0.69
Aspen	0	83.80	1.76	0.39	0.80
	180	129.90	2.00	0.54	0.76
	300	152.00	2.25	0.71	0.72
Canyon	0	70.50	1.66	0.44	0.76
	180	149.40	2.11	0.65	0.70
	300	153.30	2.33	0.77	0.69
WPB Elyann	0	70.30	1.61	0.45	0.77
	180	121.60	2.01	0.68	0.73
	300	141.10	2.03	0.92	0.65
N rate	P-value	<.001	0.001	0.006	0.015
	S.E.D.	5.260	0.050	0.054	0.017
	L.S.D.	14.590	0.140	0.150	0.046
Variety	P-value	0.126	0.027	0.180	0.199
	S.E.D.	6.400	0.051	0.068	0.028
	L.S.D.	13.940	0.111	0.148	0.061
N rate. Variety	P-value	0.335	0.188	0.874	0.915
	S.E.D.	10.470	0.088	0.110	0.043
	L.S.D.	22.190	0.187	0.233	0.091

Table 9.35. Nitrogen uptake and partitioning for the Fife 2020 rate trial on spring oats

Variety	N rate (kg N/ha)	Total N uptake	Grain N%	straw + chaff N%	NHI
Canyon		118.50	1.51	0.31	0.92
Conway		123.60	1.66	0.32	0.90
WBP Elyann		97.80	1.38	0.37	0.90
	0	58.30	1.31	0.28	0.91
	50	100.60	1.40	0.29	0.92
	100	115.70	1.51	0.33	0.91
	140	122.80	1.49	0.37	0.90
	180	137.30	1.66	0.33	0.92
	220	145.30	1.70	0.40	0.91
Canyon	0	60.40	1.32	0.26	0.92
	50	100.40	1.35	0.27	0.93
	100	121.20	1.53	0.29	0.93
	140	128.10	1.49	0.32	0.91
	180	146.80	1.67	0.34	0.93
	220	154.20	1.68	0.37	0.92
Conway	0	62.80	1.39	0.26	0.90
	50	111.10	1.53	0.28	0.91
	100	121.90	1.63	0.39	0.89
	140	138.40	1.70	0.42	0.89
	180	145.00	1.79	0.24	0.93
	220	162.70	1.89	0.33	0.92
WBP Elyann	0	51.60	1.22	0.32	0.91
	50	90.40	1.31	0.31	0.91
	100	104.00	1.37	0.32	0.92
	140	101.90	1.26	0.37	0.90
	180	120.10	1.54	0.43	0.90
	220	119.00	1.54	0.48	0.89
N rate	P-value	<.001	<.001	0.082	0.480
	S.E.D.	3.580	0.051	0.039	0.011
	L.S.D.	7.980	0.113	0.087	0.025
Variety	P-value	<.001	<.001	0.064	0.029
	S.E.D.	2.800	0.034	0.027	0.007
	L.S.D.	5.800	0.070	0.056	0.015
N rate. Variety	P-value	0.080	0.579	0.267	0.463
	S.E.D.	6.650	0.085	0.067	0.018
	L.S.D.	13.540	0.172	0.136	0.038

Table 9.36. Nitrogen uptake and partitioning for the Fife 2021 rate trial on spring oats

Variety	**N rate (kg N/ha)**	**Total N uptake**	**Grain N%**	**straw + chaff N%**	**NHI**
Canyon		72.60	1.69	0.30	0.86
Conway		63.30	1.70	0.23	0.90
WBP Elyann		75.60	1.48	0.29	0.88
	0	46.40	1.63	0.26	0.88
	120	94.60	1.62	0.29	0.88
Mascani	0	47.40	1.73	0.31	0.85
	120	97.80	1.66	0.29	0.87
Conway	0	32.00	1.75	0.19	0.91
	120	94.50	1.66	0.28	0.88
WBP Elyann	0	59.80	1.41	0.30	0.88
	120	91.50	1.55	0.29	0.89
N rate	P-value	0.002	0.936	0.312	0.934
	S.E.D.	2.330	0.073	0.017	0.015
	L.S.D.	10.040	0.314	0.073	0.066
Variety	P-value	0.031	<.001	0.173	0.074
	S.E.D.	3.870	0.036	0.035	0.012
	L.S.D.	8.930	0.082	0.081	0.027
N rate. Variety	P-value	0.012	0.022	0.276	0.077
	S.E.D.	5.040	0.084	0.044	0.020
	L.S.D.	11.240	0.250	0.098	0.051

Effects of N rate and crop height on lodging in spring oats

Figure 9.4. Impacts of N rate and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Cambridgeshire 2019 N rate trial on spring oats.

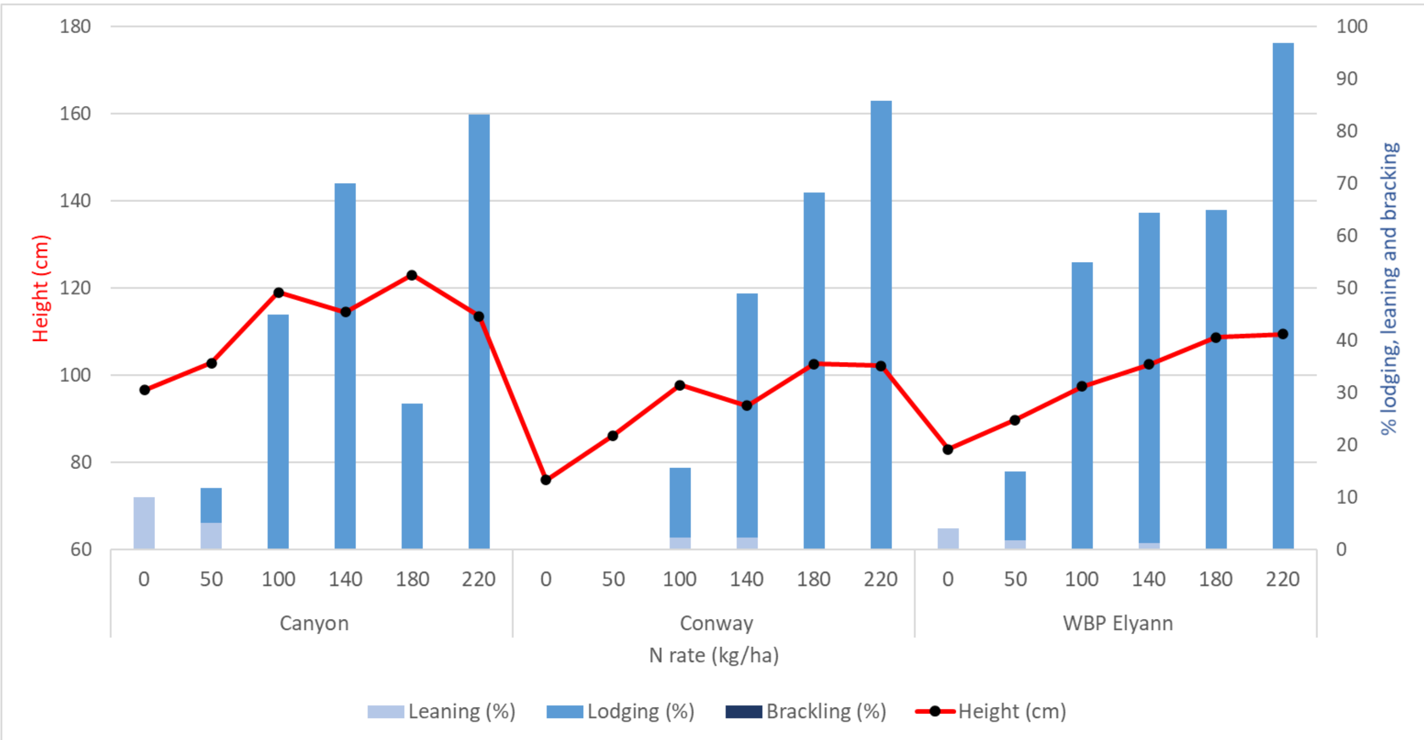

Figure 9.5. Impacts of N rate and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Fife 2019 N rate trial on spring oats.

Effects of N timing on spring oats yield (t/ha at 85% dry matter)

Table 9.37. Yield (t/ha) for the Fife 2019 timing trial on spring oats.

	Yield (t/ha) at N timing treatments						
Variety	1	2	3	4	5	6	Grand mean
Canyon	8.68	8.36	8.44	8.7	9.82	8.96	8.83
Conway	9.11	9.11	9.2	8.7	9.36	9.08	9.09
WBP Elyann	8.72	9.24	8.51	8.07	8.56	7.9	8.50
Grand mean	8.84	8.90	8.72	8.49	9.25	8.65	8.81
	P	SED	LSD				
N timing	0.024	0.474	0.390				
Variety	0.086	0.474	0.530				
N timing x Variety	0.069	0.474	0.840				

Table 9.38. Yield (t/ha) for the Suffolk 2019 timing trial on spring oats.

	Yield (t/ha) at N timing treatments						
Variety	1	2	3	4	5	6	Grand mean
Aspen	7.66	8.08	8.44	7.83	9.05	7.49	8.09
Canyon	8.17	7.52	7.59	7.98	9.93	8.28	8.24
WBP Elyann	8.50	7.51	7.80	8.31	9.25	8.03	8.23
Grand mean	8.11	7.71	7.94	8.04	9.41	7.94	8.19
	P	SED	LSD				
N timing	<0.001	0.188	0.383				
Variety	0.448	0.133	0.271				
N timing x Variety	0.004	0.326	0.663				

Table 9.39. Yield (t/ha) for the Fife 2020 timing trial on spring oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Canyon	8.76	8.58	8.88	8.72	8.92	8.53	8.73
Conway	8.14	8.82	7.87	7.88	8.11	7.89	8.12
WBP Elyann	7.78	8.27	7.86	7.62	8.01	8.1	7.94
Grand mean	8.23	8.56	8.20	8.07	8.35	8.17	8.26
	P	SED	LSD				
N timing	0.135	0.325	0.360				
Variety	0.004	0.325	0.310				
N timing x Variety	0.101	0.325	0.540				

Table 9.40. Yield (t/ha) for the Suffolk 2020 timing trial on spring oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Aspen	4.73	4.90	4.92	4.79	4.97	5.06	4.89
Canyon	4.39	4.29	4.07	4.01	4.42	4.26	4.24
WBP Elyann	4.17	4.18	4.45	3.93	4.16	4.05	4.16
Grand mean	4.43	4.46	4.48	4.24	4.52	4.46	4.43
	P	SED	LSD				
N timing	0.521	0.144	0.320				
Variety	<0.001	0.071	0.147				
N timing x Variety	0.208	0.202	0.414				

Table 9.41. Yield (t/ha) for the Fife 2021 timing trial on spring oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Canyon	6.72	7.18	7	5.77	6.98	6.92	6.76
WBP Elyann	5.79	6.54	6.05	6.66	6.53	6.12	6.28
Conway	6.43	6.28	6.82	5.78	6.83	6.27	6.40
Grand mean	6.31	6.67	6.62	6.07	6.78	6.44	6.48
	P	SED	LSD				
N timing	<0.001	0.208	0.220				
Variety	<0.001	0.208	0.090				
N timing x Variety	<0.001	0.208	0.380				

Table 9.42. Yield (t/ha) for the Suffolk 2021 timing trial on spring oats.

Variety	Yield (t/ha) at N timing treatments						Grand mean
	1	2	3	4	5	6	
Aspen	5.27	5.06	4.94	5.04	4.72	4.67	4.95
Canyon	6.34	6.33	6.20	5.85	6.47	6.35	6.26
WBP Elyann	5.17	5.37	5.70	5.32	5.18	5.22	5.32
Grand mean	5.59	5.59	5.61	5.40	5.46	5.41	5.51
	P	SED	LSD				
N timing	0.800	0.202	0.451				
Variety	<0.001	0.106	0.219				
N timing x Variety	0.163	0.293	0.600				

Effects of N timing + S on spring oats yield parameters

Table 9.43. Yield parameters for the Suffolk 2019 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	Panicles/ m2	TGW
Aspen		53.96	89.42	537.3	41.81
Canyon		55.5	99.3	458.8	42.17
WPB Elyann		54.91	90.77	518.5	40.05
	1	54.28	91.02	500.6	41.93
	2	54.91	93.36	522.5	40.55
	3	55.64	92.92	490.7	41.63
	4	54.63	91.19	521	41.09
	5	54.49	95.09	497.2	41.93
	6	54.78	95.4	497.2	40.93
Aspen	1	54.3	90.33	512	42.2
	2	53.64	88.33	542.6	41.19
	3	53.99	85.43	517.6	41.73
	4	52.99	90.37	545.4	40.76
	5	54.41	88.7	558.3	43.28
	6	54.45	93.37	548.1	41.67
Canyon	1	55.3	96.63	438.9	41.63
	2	55.01	100.3	477.8	43.62
	3	58.59	100.9	448.1	42.37
	4	57.1	92.93	466.7	41.93
	5	53.27	104.33	460.2	41.71
	6	53.72	100.7	461.1	41.78
WPB Elyann	1	53.24	86.1	550.9	41.95
	2	56.09	91.43	547.2	36.83
	3	54.34	92.43	506.5	40.8
	4	53.8	90.27	550.9	40.56
	5	55.78	92.23	473.1	40.8
	6	56.18	92.13	482.4	39.34
Timing	P-value	0.796	0.628	0.156	0.011
	S.E.D.	0.981	3.114	13.29	0.347
	L.S.D.	2.185	6.939	29.61	0.774
Variety	P-value	0.226	<.001	<.001	<.001
	S.E.D.	0.87	1.929	11.9	0.473
	L.S.D.	1.795	3.982	24.56	0.977
Timing.Variety	P-value	0.349	0.619	0.203	0.026
	S.E.D.	1.997	4.958	27.26	1.008
	L.S.D.	4.06	10.095	55.42	2.061

Table 9.44. Yield parameters for the Suffolk 2019 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	TGW
Aspen		47.39	93.89	35.583
Canyon		49.83	104.17	37.876
WPB Elyann		50.27	95.28	34.04
	1	48.83	95.56	35.77
	2	49.33	97.22	35.785
	3	50.24	99.44	36.206
	4	50.58	97.78	35.857
	5	48.53	96.11	36.379
	6	47.46	100.56	34.998
Aspen	1	50.88	91.67	35.768
	2	46.84	95	35.747
	3	48.74	95	35.958
	4	46.45	93.33	35.925
	5	46.14	90	35.826
	6	45.33	98.33	34.271
Canyon	1	48.21	101.67	37.563
	2	50.31	100	37.647
	3	51.8	106.67	37.994
	4	53.4	103.33	38.18
	5	47.15	105	38.351
	6	48.08	108.33	37.517
WPB Elyann	1	47.39	93.33	33.979
	2	50.85	96.67	33.959
	3	50.19	96.67	34.667
	4	51.88	96.67	33.467
	5	52.31	93.33	34.961
	6	48.98	95	33.205
Timing	P-value	0.174	0.23	0.04
	S.E.D.	1.166	2.108	0.3556
	L.S.D.	2.597	4.697	0.7922
Variety	P-value	0.106	<.001	<.001
	S.E.D.	1.392	1.389	0.2443
	L.S.D.	2.873	2.867	0.5042
Timing.Variety	P-value	0.608	0.59	0.571
	S.E.D.	3.018	3.487	0.6043
	L.S.D.	6.156	7.093	1.2287

Table 9.45. Yield parameters for the Fife 2019 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Canyon		53.72	104.41	608.3	43.07	33.04
Conway		51.77	95.07	520.4	41.11	37.63
WPB Elyann		53.96	97.52	548	39.93	36.2
	1	53.15	99.48	570.1	41.2	36.65
	2	54.16	97.8	562.3	41.73	35.76
	3	53.86	100.38	558	41.42	35
	4	52.51	100.31	575.9	41.5	34.68
	5	53.23	97.69	546.9	41.02	35.68
	6	51.98	98.34	540.1	41.34	35.95
Canyon	1	53.25	101.1	662	42.98	33.76
	2	53.52	100.4	585.2	43.73	30.37
	3	54.48	104.57	604.6	42.9	34.55
	4	55.15	108.9	625	43.34	33.29
	5	50.98	107.97	601.9	42.4	31.07
	6	54.95	103.53	571.3	43.07	35.17
Conway	1	51.78	97.2	508.3	40.82	40.89
	2	53.47	97.93	525.9	40.87	39.19
	3	51.06	95.87	540.7	41.08	35.84
	4	51.38	96.3	520.4	41.72	35.06
	5	53.68	91.07	484.3	40.9	39.31
	6	49.23	92.07	542.6	41.25	35.48
WPB Elyann	1	54.43	100.13	539.8	39.81	35.31
	2	55.48	95.07	575.9	40.6	37.71
	3	56.03	100.7	528.7	40.28	34.61
	4	50.99	95.73	582.4	39.43	35.69
	5	55.04	94.03	554.6	39.76	36.65
	6	51.77	99.43	506.5	39.68	37.21
Timing	P-value	0.42	0.453	0.744	0.457	0.759
	S.E.D.	1.096	1.704	26.2	0.344	1.384
	L.S.D.	2.443	3.797	58.38	0.766	3.084
Variety	P-value	0.117	<.001	<.001	<.001	<.001
	S.E.D.	1.109	1.365	19.7	0.326	1.036
	L.S.D.	2.289	2.816	40.67	0.674	2.138
Timing.Variety	P-value	0.463	0.06	0.66	0.873	0.198
	S.E.D.	2.474	3.217	47.32	0.738	2.492
	L.S.D.	5.037	6.539	96.17	1.501	5.064

Table 9.46. Yield parameters for the Fife 2021 timing + S trial on winter oats.

Variety	N timing treatment	DMHI	Height (cm)	Panicles/ m2	TGW	Grains/ panicle
Canyon		56.88	80.03	458.8	43.772	28.14
Conway		56.07	67.53	437.9	40.12	29.62
WPB Elyann		62.6	71.78	469.6	41.148	27.19
	1	57.37	68.61	447	41.739	26.08
	2	58.46	75	456.1	41.699	27.59
	3	58.9	74.17	474.1	41.111	31.04
	4	59.08	72.06	446.9	42.011	26.79
	5	59.12	75.94	456.2	41.295	30.5
	6	58.19	72.89	452.3	42.225	27.9
Canyon	1	54.78	76.5	453.3	43.891	23.62
	2	54.83	82	464.3	44.145	24.49
	3	60.73	80	464.3	43.106	38.74
	4	58.42	78	495.3	44.006	24.66
	5	57.96	82.17	437.7	43.455	33.41
	6	54.56	81.5	437.7	44.027	23.89
Conway	1	54.66	65.67	414.3	39.901	27.68
	2	56.61	69	437.7	40.053	30.32
	3	56.07	70	505.7	39.205	31.1
	4	57.28	65.67	401	40.666	28.7
	5	56.66	69.17	434.3	39.865	29.24
	6	55.18	65.67	434.7	41.028	30.71
WPB Elyann	1	62.65	63.67	473.3	41.424	26.93
	2	63.95	74	466.3	40.9	27.95
	3	59.91	72.5	452.3	41.021	23.29
	4	61.53	72.5	444.3	41.36	27.01
	5	62.74	76.5	496.7	40.566	28.86
	6	64.83	71.5	484.7	41.62	29.09
Timing	P-value	0.855	0.017	0.692	0.41	0.38
	S.E.D.	1.554	1.687	18.1	0.5619	2.611
	L.S.D.	3.462	3.758	40.32	1.252	5.818
Variety	P-value	<.001	<.001	0.335	<.001	0.339
	S.E.D.	1.11	1.069	21.27	0.2341	1.631
	L.S.D.	2.291	2.206	43.89	0.4843	3.373
Timing.Variety	P-value	0.321	0.353	0.73	0.787	0.059
	S.E.D.	2.71	2.723	46.22	0.7314	4.178
	L.S.D.	5.508	5.542	94.27	1.5105	8.512

Effects of N timing + S on spring oats N uptake and partitioning

Table 9.47. Nitrogen uptake and partitioning for the Fife 2019 timing + sulphur trial on spring oats

Variety	N timing treatment	Total N uptake	Grain N%	straw + chaff N%	NHI
Canyon		151.60	1.62	0.43	0.81
Conway		166.10	1.84	0.28	0.88
WPB Elyann		139.60	1.55	0.43	0.81
	1	146.90	1.63	0.34	0.85
	2	155.60	1.69	0.38	0.84
	3	154.60	1.74	0.38	0.84
	4	146.40	1.62	0.41	0.82
	5	159.30	1.68	0.35	0.84
	6	151.80	1.64	0.42	0.81
Canyon	1	140.40	1.60	0.31	0.86
	2	148.30	1.66	0.46	0.81
	3	145.70	1.64	0.43	0.82
	4	146.60	1.61	0.42	0.83
	5	171.20	1.57	0.46	0.78
	6	157.40	1.61	0.51	0.79
Conway	1	155.10	1.77	0.21	0.90
	2	169.00	1.86	0.30	0.88
	3	177.10	1.94	0.29	0.87
	4	158.30	1.78	0.33	0.85
	5	170.80	1.89	0.24	0.90
	6	166.10	1.80	0.29	0.86
WPB Elyann	1	145.00	1.52	0.49	0.79
	2	149.60	1.56	0.40	0.83
	3	141.00	1.63	0.42	0.83
	4	134.20	1.48	0.47	0.77
	5	136.00	1.58	0.34	0.85
	6	132.00	1.51	0.47	0.77
N rate	P-value	0.160	0.203	0.462	0.219
	S.E.D.	5.070	0.047	0.046	0.018
	L.S.D.	11.310	0.104	0.104	0.040
Variety	P-value	<.001	<.001	<.001	<.001
	S.E.D.	3.750	0.028	0.035	0.015
	L.S.D.	7.730	0.058	0.073	0.031
N rate. Variety	P-value	0.102	0.821	0.547	0.368
	S.E.D.	9.050	0.073	0.085	0.035
	L.S.D.	18.390	0.150	0.172	0.071

Table 9.48. Nitrogen uptake and partitioning for the Suffolk 2019 timing + sulphur trial on spring oats

Variety	**N timing treatment**	**Total N uptake**	**Grain N%**	**straw + chaff N%**	**NHI**
Aspen		149.30	1.93	0.51	0.82
Canyon		151.30	1.92	0.51	0.82
WPB Elyann		146.90	1.84	0.54	0.81
	1	149.70	1.91	0.46	0.83
	2	134.70	1.85	0.47	0.83
	3	141.90	1.86	0.47	0.83
	4	141.20	1.88	0.46	0.83
	5	173.20	1.95	0.64	0.79
	6	154.30	1.92	0.61	0.79
Aspen	1	131.90	1.80	0.44	0.83
	2	141.40	1.83	0.46	0.82
	3	165.60	2.06	0.47	0.84
	4	139.30	1.91	0.47	0.82
	5	170.50	2.04	0.58	0.81
	6	146.80	1.94	0.61	0.79
Canyon	1	158.80	2.04	0.45	0.85
	2	129.30	1.86	0.42	0.85
	3	135.20	1.83	0.56	0.82
	4	136.50	1.86	0.45	0.84
	5	183.00	1.94	0.63	0.78
	6	165.30	1.96	0.57	0.80
WPB Elyann	1	158.30	1.91	0.48	0.82
	2	133.40	1.85	0.53	0.82
	3	124.90	1.69	0.38	0.84
	4	147.90	1.89	0.47	0.83
	5	166.10	1.87	0.72	0.77
	6	150.80	1.85	0.64	0.79
N rate	P-value	0.011	0.915	0.070	0.148
	S.E.D.	8.280	0.099	0.069	0.021
	L.S.D.	18.450	0.220	0.153	0.046
Variety	P-value	0.707	0.275	0.790	0.695
	S.E.D.	5.270	0.057	0.049	0.014
	L.S.D.	10.870	0.117	0.101	0.028
N rate. Variety	P-value	0.059	0.478	0.912	0.953
	S.E.D.	13.400	0.150	0.119	0.034
	L.S.D.	27.260	0.307	0.242	0.070

Table 9.49. Nitrogen uptake and partitioning for the Fife 2020 timing + sulphur trial on spring oats

Variety	N timing treatment	Total N uptake	Grain N%	straw + chaff N%	NHI
Canyon		125.90	1.53	0.35	0.90
Conway		131.90	1.73	0.31	0.90
WPB Elyann		111.20	1.44	0.44	0.87
	1	122.00	1.55	0.37	0.89
	2	130.70	1.60	0.37	0.89
	3	117.20	1.52	0.34	0.90
	4	119.20	1.57	0.36	0.90
	5	123.40	1.53	0.40	0.88
	6	125.70	1.62	0.35	0.89
Canyon	1	131.80	1.59	0.40	0.89
	2	117.80	1.46	0.32	0.91
	3	118.70	1.42	0.33	0.90
	4	132.10	1.60	0.35	0.90
	5	122.00	1.43	0.37	0.89
	6	133.30	1.69	0.31	0.92
Conway	1	131.80	1.75	0.26	0.92
	2	154.40	1.82	0.38	0.89
	3	121.50	1.66	0.27	0.91
	4	120.90	1.69	0.29	0.91
	5	134.60	1.74	0.33	0.89
	6	128.30	1.72	0.32	0.90
WPB Elyann	1	102.20	1.32	0.46	0.86
	2	119.80	1.51	0.41	0.89
	3	111.50	1.47	0.43	0.88
	4	104.60	1.42	0.42	0.88
	5	113.70	1.43	0.50	0.86
	6	115.60	1.46	0.44	0.87
N rate	P-value	0.208	0.376	0.359	0.230
	S.E.D.	5.100	0.052	0.025	0.007
	L.S.D.	11.370	0.115	0.055	0.016
Variety	P-value	<.001	<.001	<.001	<.001
	S.E.D.	2.890	0.036	0.020	0.006
	L.S.D.	5.980	0.074	0.042	0.013
N rate. Variety	P-value	0.006	0.098	0.329	0.419
	S.E.D.	7.710	0.088	0.047	0.015
	L.S.D.	15.740	0.179	0.096	0.030

Effects of N timing + S and crop height on lodging in spring oats

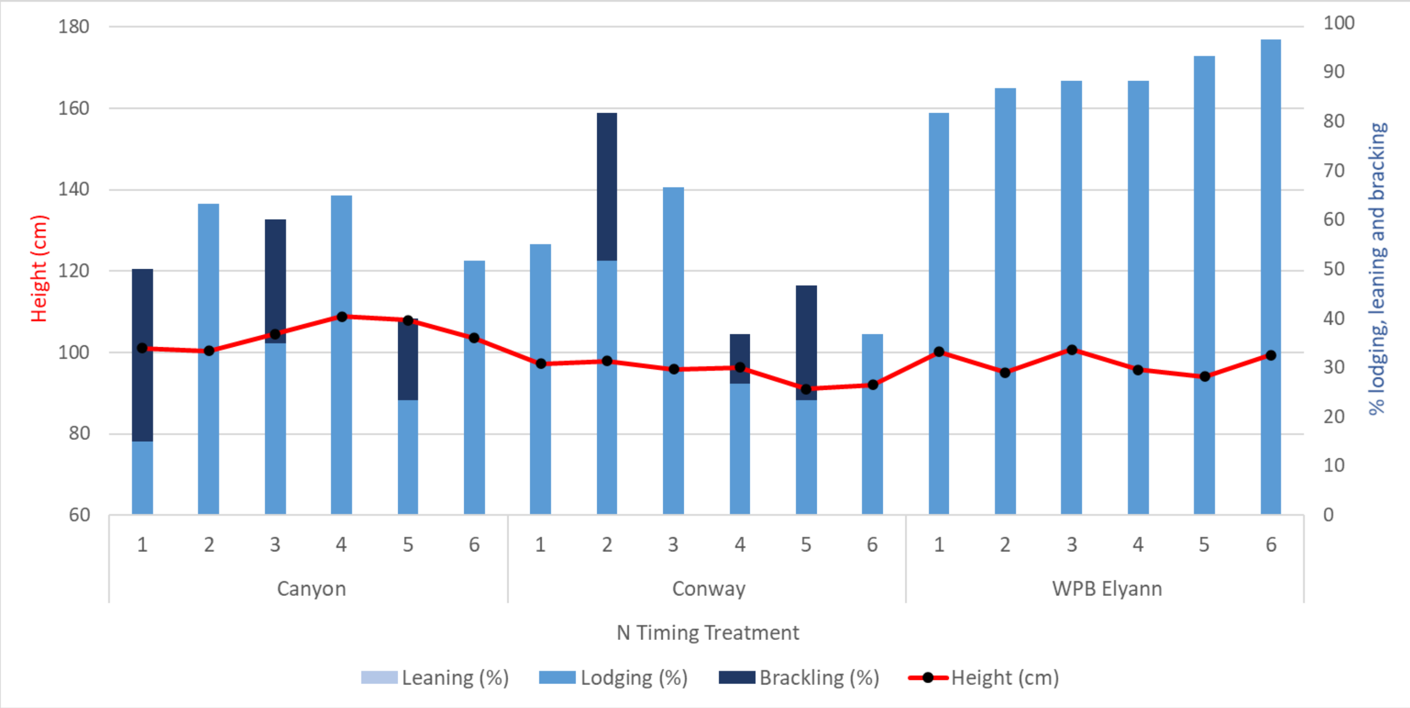

Figure 9.6. Impacts of N timing + S and crop heights on leaning (9-45°), lodging (46-85°) and brackling (>85°) % at the Fife 2019 N timing + S trial on spring oats.

Objective 4: Evaluate the impact of nitrogen and sulphur on the milling quality of oats

Effect of N rate on milling quality of winter oats

Table 9.50. Specific Weight (kg/hl) means for each variety and nitrogen (N) treatment at each location (Nottinghamshire (Notts), and Herefordshire (Here)) in 2019 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

SPWT, kg hl^{-1}		**Notts19**	**Notts21**	**Here19**	**Here21**
Site mean		51.8	50.3	52.2	50.0
N TRT kg N ha^{-1}					
1	0	51.8	51.8 c	52.8 bc	52.7 e
2	80	51.8	51.7 c	53.7 c	51.1 d
3	130	51.3	51.4 c	52.7 bc	50.1 c
4	180	52.3	50.0 b	51.5 ab	48.9 b
5	230	52.0	48.5 a	51.0 a	48.2 ab
6	300	51.7	48.3 a	51.3 ab	48.0 a
VAR					
Mascani		52.4 b	50.6 b	53.7 c	50.2 b
Penrose		50.9 a	49.7 a	50.5 a	47.4 a
RGT Southwark		52.2 b	50.5 ab	52.3 b	52.2 c
Mascani					
	0	51.7	51.3	53.4	52.5
	80	52.4	51.9	54.6	50.6
	130	51.9	51.5	54.4	50.0
	180	52.5	50.4	54.2	49.6
	230	52.8	49.3	53.1	48.9
	300	52.7	49.1	52.2	48.0
Penrose					
	0	51.5	51.7	53.4	52.8
	80	50.8	51.4	52.1	50.2
	130	50.2	51.1	51.2	47.9
	180	51.3	49.6	48.3	45.1
	230	51.2	47.3	48.1	43.9
	300	50.3	47.3	50.0	43.0
RGT Southwark					
	0	52.1	52.3	51.5	52.9
	80	52.2	51.9	54.4	52.4
	130	51.8	51.7	52.5	52.5
	180	53.2	49.8	52.0	52.0
	230	52.0	48.9	51.8	51.8
	300	52.1	48.5	51.7	51.3
P-value					
TRT		0.562	<0.001	<0.001	<0.001
VAR		<0.001	<0.05	<0.001	<0.001
TRT*VAR		0.925	0.662	<0.001	<0.001
LSD					
TRT		1.11	0.96	1.00	0.45
VAR		0.79	0.68	0.71	0.32
TRT*VAR		1.93	1.66	1.74	0.79

Table 9.51. Screenings (%) means for each variety and nitrogen (N) treatment at each location (Nottinghamshire (Notts), and Herefordshire (Here)) in 2019 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

Screenings, %					
		Notts19	**Notts21**	**Here19**	**Here21**
Site mean		0.91	2.37	3.25	3.88
N TRT	kg N ha^{-1}				
1	0	0.32 a	0.48 a	1.93 a	1.04 a
2	80	1.06 b	1.38 ab	2.06 b	2.64 b
3	130	0.92 b	1.94 b	3.80 b	4.07 c
4	180	1.01 b	3.07 c	3.95 b	4.86 d
5	230	1.15 b	3.46 c	4.30 b	5.18 d
6	300	1.01 b	3.77 c	3.47 b	6.27 e
VAR					
Mascani		0.27 a	1.51 a	1.24 a	2.08 a
Penrose		0.61 b	1.43 a	2.57 b	3.32 b
RGT Southwark		1.84 c	4.27 b	5.94 c	6.00 c
Mascani					
	0	0.22	0.46	1.35	1.03
	80	0.24	0.66	0.68	1.60
	130	0.25	1.13	0.91	2.37
	180	0.27	2.01	1.05	2.49
	230	0.32	2.16	1.48	2.75
	300	0.31	2.65	1.95	2.51
Penrose					
	0	0.20	0.36	0.74	0.55
	80	0.81	1.11	1.29	1.63
	130	0.57	1.12	2.40	3.35
	180	0.80	1.82	3.96	4.43
	230	0.65	1.84	4.20	5.15
	300	0.67	2.31	2.86	5.54
RGT Southwark					
	0	0.55	0.61	3.69	1.53
	80	2.14	2.87	4.22	4.69
	130	1.96	3.55	8.10	6.48
	180	1.96	5.36	6.85	7.68
	230	2.47	6.39	7.20	7.64
	300	2.06	6.36	5.60	8.01
P-value					
TRT		<0.001	<0.001	<0.001	<0.001
VAR		<0.001	<0.001	<0.001	<0.001
TRT*VAR		<0.01	<0.001	<0.001	<0.001
LSD					
TRT		0.29	0.66	0.81	0.42
VAR		0.21	0.47	0.57	0.30
TRT*VAR		0.51	1.14	1.40	0.73

Table 9.52. Thousand Grain Weight (TGW, g) means for each variety and nitrogen (N) treatment at each location (Nottinghamshire (Notts), and Herefordshire (Here)) in 2019 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

TGW, g					
		Notts19	**Notts21**	**Here19**	**Here21**
Site mean		43.3	38.6	39.4	39.4
N TRT	kg N ha^{-1}				
1	0	44.9 c	43.7 d	40.0 ab	42.1 d
2	80	44.0 bc	41.1 c	41.0 b	41.8 d
3	130	44.3 bc	38.7 b	38.9 ab	39.0 c
4	180	42.5 ab	36.8 ab	38.2 a	38.2 bc
5	230	41.4 a	36.0 a	38.2 a	37.7 b
6	300	42.5 ab	35.5 a	40.4 ab	36.3 a
VAR					
Mascani		46.2 b	40.4 b	42.8 b	41.5 c
Penrose		46.3 b	41.9 c	42.5 b	40.8 b
RGT Southwark		37.3 a	33.7 a	33.1 a	36.1 a
Mascani					
	0	45.8	44.9	40.5	43.4
	80	47.3	44.2	43.7	43.4
	130	47.3	40.3	42.7	40.7
	180	46.1	38.2	43.3	40.4
	230	45.4	37.6	42.9	40.1
	300	45.9	37.1	43.7	40.4
Penrose					
	0	49.6	46.9	45.2	45.4
	80	46.7	44.7	44.7	44.1
	130	47.7	42.0	42.1	40.5
	180	44.5	40.3	39.6	39.1
	230	43.3	38.9	39.7	37.6
	300	45.7	38.4	43.4	36.6
RGT Southwark					
	0	39.4	39.4	34.4	37.6
	80	38.1	34.3	34.5	37.9
	130	38.0	33.8	31.8	35.7
	180	37.0	31.9	31.9	35.2
	230	35.5	31.5	31.8	35.4
	300	35.9	31.0	34.1	34.7
P-value					
TRT		<0.001	<0.001	<0.001	<0.001
VAR		<0.001	<0.001	<0.001	<0.001
TRT*VAR		<0.05	0.542	<0.01	<0.001
LSD					
TRT		1.17	1.46	1.53	0.63
VAR		0.82	1.03	1.08	0.45
TRT*VAR		2.02	2.52	2.65	1.10

Table 9.53. Kernel Content (%) means for each variety and nitrogen (N) treatment at each location (Nottinghamshire (NOTTS), and Herefordshire - (HERE)) in 2019 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

KC, %					
		NOTTS19	**NOTTS21**	**HERE19**	**HERE21**
Site mean		74.4	74.2	74.6	74.0
N TRT	kg N ha^{-1}				
1	0	73.8	74.3 bc	73.0 a	72.7 a
2	80	74.3	75.2 c	75.1 b	73.8 b
3	130	73.9	74.9 bc	74.8 b	73.9 bc
4	180	75.4	74.1 ab	74.7 b	74.4 cd
5	230	74.3	73.2 a	75.0 b	74.7 d
6	300	74.7	73.2 a	75.1 b	74.6 d
VAR					
Mascani		75.2 b	75.2 c	75.8 c	74.9 b
Penrose		74.5 ab	74.5 b	75.1 b	73.4 a
RGT Southwark		73.4 a	72.7 a	73.0 a	73.7 a
Mascani					
	0	73.7	74.6	73.7	73.3
	80	75.0	76.1	75.8	74.4
	130	75.1	75.9	76.1	74.6
	180	76.5	75.6	76.4	75.5
	230	75.6	74.4	76.8	76.1
	300	75.8	74.8	75.7	76.5
Penrose					
	0	74.2	74.7	74.6	72.9
	80	74.5	75.7	75.5	73.7
	130	74.3	75.3	75.1	73.1
	180	75.0	74.5	74.5	73.7
	230	74.2	73.3	74.8	73.4
	300	74.8	73.5	76.2	74.1
RGT Southwark					
	0	73.6	73.6	70.7	71.8
	80	73.4	74.0	74.0	73.2
	130	72.4	73.5	73.1	74.1
	180	74.6	72.2	73.0	74.0
	230	73.0	71.8	73.5	74.5
	300	73.5	71.3	73.4	74.4
P-value					
TRT		0.167	<0.001	<0.001	<0.001
VAR		<0.001	<0.001	<0.001	<0.001
TRT*VAR		0.862	0.250	<0.01	<0.001
LSD					
TRT		1.24	0.67	0.67	0.41
VAR		0.88	0.48	0.48	0.29
TRT*VAR		2.16	1.17	1.16	0.70

Table 9.54. Hullability (%) means for each variety and nitrogen (N) treatment at each location (Nottinghamshire (Notts), and Herefordshire (Here)) in 2019 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

Hullability, %					
		NOTTS19	**NOTTS21**	**HERE19**	**HERE21**
Site mean		99.5	98.8	99.6	98.8
N TRT	kg N ha^{-1}				
1	0	98.5 a	97.7 a	98.8 a	96.4 a
2	80	99.5 b	99.2 b	99.8 b	98.5 b
3	130	99.7 b	99.3 b	99.7 b	99.3 c
4	180	99.8 b	99.2 b	99.9 b	99.6 c
5	230	99.9 b	98.8 b	99.8 b	99.6 c
6	300	99.9 b	98.8 b	99.9 b	99.6 c
VAR					
Mascani		99.6 b	99.0	99.8 b	99.3 b
Penrose		99.8 b	98.9	99.8 b	99.0 b
RGT Southwark		99.3 a	98.6	99.2 a	98.1 a
Mascani					
	0	98.6	97.3	99.5	97.9
	80	99.7	99.3	99.8	99.4
	130	99.8	99.6	100.0	99.6
	180	99.9	99.5	100.0	99.7
	230	99.9	98.9	99.8	99.7
	300	100.0	99.3	99.9	99.9
Penrose					
	0	99.3	97.4	99.5	97.3
	80	99.8	99.5	99.9	98.4
	130	99.8	99.5	99.9	99.2
	180	99.8	99.3	100.0	99.6
	230	99.9	98.8	99.7	99.7
	300	99.9	99.0	99.9	99.8
RGT Southwark					
	0	97.7	98.3	97.3	94.0
	80	99.1	98.8	99.7	97.5
	130	99.5	98.7	99.2	99.0
	180	99.8	98.7	99.8	99.4
	230	99.9	98.7	99.8	99.5
	300	99.8	98.1	99.8	99.3
P-value					
TRT		<0.001	<0.001	<0.001	<0.001
VAR		<0.001	0.185	<0.001	<0.001
TRT*VAR		<0.001	0.480	<0.001	<0.001
LSD					
TRT		0.23	0.69	0.24	0.45
VAR		0.16	0.48	0.17	0.32
TRT*VAR		0.39	1.19	0.42	0.78

Effect of N rate on milling quality of spring oats

Table 9.55. Specific Weight (kg/hl) means for each variety and nitrogen (N) treatment at each location (Cambridgeshire (EA), Fife (SAG) and Lincolnshire (OMEX)) in 2019, 2020 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at $p < 0.05$.

SPWT, kg hl^{-1}		**EA19**			**EA21**		**OMEX 21**			**SAG19**	**SAG20**		**SAG21**
Site mean		53.74			48.51		46.68			51.3	55.3		54.8
N TRT	**kg N ha^{-1}**			**kg N ha^{-1}**					**kg N ha^{-1}**			**kg N ha^{-1}**	
1	**0**	53.74	ab	**0**	49.47	b	49.68		**0**	52.6 b	56.0 c	**0**	55.2 b
2	**80**	53.92	b	**70**	48.67	ab	50.65		**50**	52.4 b	56.3 c	**70**	55.2 b
3	**130**	54.13	b	**120**	48.13	a	50.44		**100**	51.7 ab	55.4 bc	**120**	55.0 b
4	**180**	53.7	ab	**180**	47.71	a	50.5		**140**	50.7 ab	55.1 ab	**180**	54.6 ab
5	**230**	53.73	ab	**220**	48.14	a	50.34		**180**	50.6 ab	54.9 ab	**220**	54.6 ab
6	**300**	53.21	a	**300**	48.03	a	49.83		**220**	50.0 a	54.3 a	**300**	54.1 a
VAR								**VAR**					
Aspen		54.01	a		48.62	b	49.90	a	**Canyon**	50.8	56.1 c		55.6 b
Canyon		54.93	a		49.06	b	50.58	b	**Conway**	51.8	55.3 b		54.5 a
WPB Elyann		52.28	b		47.4	a			**WPB Elyann**	51.5	54.5 a		54.4 a
Canyon									**Canyon**				
	0	55.07			50.68		50.77		**0**	51.8	56.7	**0**	55.8
	80	55.36			49.46		50.99		**50**	52.0	57.3	**70**	55.8
	130	54.87			48.64		50.63		**100**	51.5	55.5	**120**	55.8
	180	55.17			49.14		50.79		**140**	51.0	55.8	**180**	55.4
	230	54.95			48.89		50.41		**180**	49.4	55.9	**220**	55.5
	300	54.14			48.41		49.86		**220**	49.1	55.3	**300**	55.1
Aspen									**Conway**				
	0	53.70			49.23		48.59		**0**	52.7	55.2	**0**	54.3
	80	54.11			48.64		50.32		**50**	52.5	56.2	**70**	54.8
	130	54.86			48.60		50.24		**100**	51.4	55.5	**120**	54.5
	180	54.03			47.94		50.21		**140**	51.5	55.0	**180**	54.5
	230	54.02			48.57		50.27		**180**	51.6	54.9	**220**	54.6
	300	53.33			48.78		49.80		**220**	51.0	54.9	**300**	54.1
WPB Elyann									**WPB Elyann**				
	0	52.45			48.88				**0**	53.2	56.1	**0**	55.4
	80	52.30			47.96				**50**	52.7	55.3	**70**	55.0
	130	52.66			47.48				**100**	52.4	55.2	**120**	54.9
	180	51.89			47.01				**140**	49.8	54.3	**180**	53.9
	230	52.22			47.11				**180**	50.8	53.7	**220**	53.6
	300	52.16			47.74				**220**	49.9	52.7	**300**	53.2
P-value													
TRT		<0.05			<0.001		0.066			<0.01	<0.001		<0.001
VAR		<0.001			<0.001		0.003			0.130	<0.001		<0.001
TRT* VAR		0.822			0.156		0.071			0.735	<0.05		<0.05

Table 9.56. Hullability (%) means for each variety and nitrogen (N) treatment at each location (Cambridgeshire (EA), Fife (SAG) and Lincolnshire (OMEX)) in 2019, 2020 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at $p < 0.05$.

Hullability, %													
		EA19			**EA21**		**OMEX 21**			**SAG19**	**SAG20**		**SAG21**
Site mean		98.05			95.50		98.09			97.7	99.4		97.2
N TRT	**kg N ha^{-1}**			**kg N ha^{-1}**					**kg N ha^{-1}**			**kg N ha^{-1}**	
1	**0**	96.99	a	**0**	94.78		94.98	a	**0**	96.5 a	99.1 a	**0**	95.5 a
2	**80**	98.15	b	**70**	96.29		97.96	b	**50**	96.6 ab	99.3 ab	**70**	97.3 bc
3	**130**	98.21	b	**120**	95.35		98.49	b	**100**	97.9 bc	99.5 bc	**120**	96.8 b
4	**180**	98.41	b	**180**	95.4		98.72	b	**140**	98.1 c	99.5 bc	**180**	97.5 bc
5	**230**	98.12	b	**220**	96.03		99.03	b	**180**	98.7 c	99.3 ab	**220**	97.6 bc
6	**300**	98.39	b	**300**	95.15		99.35	b	**220**	98.5 c	99.7 c	**300**	98.4 c
VAR									**VAR**				
Aspen		98.7	b		97.46	b	99.13	a	**Conway**	95.4 a	99.1 a		94.3 a
Canyon		96.73	a		92.4	a	97.05	b	**Canyon**	99.4 c	99.9 b		99.2 c
WPB Elyann		98.71	b		96.63	b			**WPB Elyann**	98.3 b	99.3 a		98.1 b
Canyon									**Canyon**				
	0	96.08			92.12		92.72		**0**	93.7	98.8	**0**	91.4
	80	96.83			93.52		96.83		**50**	93.3	98.9	**70**	94.7
	130	96.75			91.80		97.47		**100**	95.2	99.3	**120**	93.8
	180	97.09			92.20		97.87		**140**	96.7	99.4	**180**	94.7
	230	96.71			93.10		98.44		**180**	97.3	99.0	**220**	94.5
	300	96.92			91.69		98.95		**220**	96.5	99.3	**300**	96.6
Aspen									**Conway**				
	0	97.00			96.31		97.24		**0**	99.3	99.4	**0**	98.2
	80	98.87			97.81		99.10		**50**	98.9	100.0	**70**	99.3
	130	98.83			97.57		99.50		**100**	99.8	100.0	**120**	99.3
	180	99.40			97.54		99.57		**140**	99.0	100.0	**180**	99.5
	230	98.86			98.01		99.62		**180**	99.6	100.0	**220**	99.4
	300	99.22			97.54		99.74		**220**	99.7	99.8	**300**	99.7
WPB Elyann									**WPB Elyann**				
	0	97.89			95.91				**0**	96.5	99.2	**0**	96.9
	80	98.73			97.55				**50**	97.5	99.0	**70**	97.7
	130	99.05			96.67				**100**	98.6	99.0	**120**	98.1
	180	98.75			96.46				**140**	99.0	99.2	**180**	98.3
	230	98.80			96.97				**180**	99.1	99.0	**220**	99.0
	300	99.03			96.24				**220**	99.2	100.0	**300**	98.8
P-value													
TRT		<0.05			0.138		<0.001			<0.01	<0.05		<0.001
VAR		<0.001			<0.001		<0.001			<0.05	<0.001		<0.001
TRT* VAR		0.822			0.650		0.035			0.474	0.296		<0.05

Table 9.57. Kernel Content (KC, %) means for each variety and nitrogen (N) treatment at each location (Cambridgeshire (EA), Fife (SAG) and Lincolnshire (OMEX)) in 2019, 2020 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at $p < 0.05$.

KC, %													
		EA19			**EA21**		**OMEX 21**			**SAG19**	**SAG20**		**SAG21**
Site mean		73.60			70.04		70.70			73.0	76.8		75.2
N TRT	**kg N ha^{-1}**			**kg N ha^{-1}**					**kg N ha^{-1}**			**kg N ha^{-1}**	
1	**0**	71.31	a	**0**	73.02		67.07	a	**0**	72.9	75.9 a	**0**	74.5 a
2	**80**	73.28	b	**70**	73.53		71.95	b	**50**	73.0	76.8 bc	**70**	75.2 b
3	**130**	74.21	bc	**120**	72.9		72.4	bc	**100**	73.2	76.7 b	**120**	75.1 ab
4	**180**	74.18	bc	**180**	73.08		73.53	bc	**140**	72.6	77.1 bc	**180**	75.3 b
5	**230**	74.14	bc	**220**	73.72		73.95	c	**180**	73.0	77.3 c	**220**	75.3 b
6	**300**	74.48	c	**300**	72.64		73.35	bc	**220**	73.1	77.1 bc	**300**	75.6 b
VAR								**VAR**					
Aspen		72.97	a		73.13	b	72.42	b	**Canyon**	70.1 a	75.6 a		73.7 a
Canyon		72.46	a		71.79	a	71.66	a	**Conway**	73.0 b	76.8 b		74.4 b
WPB Elyann		75.37	b		74.52	c			**WPB Elyann**	75.9 c	78.2 c		77.4 c
Canyon									**Canyon**				
	0	70.92			66.81		68.53		**0**	70.5	74.8	**0**	73.5
	80	72.32			67.58		71.81		**50**	70.6	75.4	**70**	73.7
	130	72.99			65.68		72.29		**100**	70.2	75.9	**120**	73.4
	180	72.54			66.03		72.54		**140**	69.5	75.8	**180**	73.7
	230	72.75			67.34		73.24		**180**	69.9	76.0	**220**	73.9
	300	73.27			67.58		71.57		**220**	69.7	75.5	**300**	74.2
Aspen									**Conway**				
	0	70.91			69.61		65.6		**0**	72.5	75.6	**0**	73.4
	80	72.38			71.89		72.08		**50**	72.4	76.7	**70**	74.5
	130	73.33			71.46		72.52		**100**	73.1	76.5	**120**	74.4
	180	73.80			71.30		74.52		**140**	72.8	76.7	**180**	74.6
	230	73.81			72.04		74.66		**180**	73.4	77.7	**220**	74.6
	300	73.56			71.37		75.14		**220**	73.7	77.3	**300**	74.9
WPB Elyann									**WPB Elyann**				
	0	72.11			71.23				**0**	75.8	77.2	**0**	76.8
	80	75.15			72.99				**50**	76.1	78.3	**70**	77.3
	130	76.30			71.45				**100**	76.2	78.1	**120**	77.4
	180	76.20			71.88				**140**	75.6	78.9	**180**	77.6
	230	75.87			73.04				**180**	75.8	78.2	**220**	77.5
	300	76.60			71.50				**220**	75.9	78.6	**300**	77.8
P-value													
TRT		<0.001			0.066		<.001			0.875	<0.001		<0.001
VAR		<0.001			<.001		0.024			<0.001	<0.001		<0.001
TRT* VAR		.298			0.273		<.001			<0.05	<0.05		<0.05

Table 9.58. Thousand grain weight (TGW, g) means for each variety and nitrogen (N) treatment at each location (Cambridgeshire (EA), Fife (SAG) and Lincolnshire (OMEX)) in 2019, 2020 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

TGW, g													
		EA19			**EA21**		**OMEX 21**			**SAG19**	**SAG20**		**SAG21**
Site mean		40.29			48.51		50.24			40.3	44.5		42.0
N TRT	**kg N ha^{-1}**			**kg N ha^{-1}**					**kg N ha^{-1}**			**kg N ha^{-1}**	
1	**0**	40.87		**0**	43.76		43.59	a	**0**	42.9 c	45.5 d	**0**	43.3 c
2	**80**	40.5		**70**	42.66		46.09	ab	**50**	42.8 c	45.4 cd	**70**	42.9 c
3	**130**	40.05		**120**	42.22		47.86	b	**100**	40.7 b	44.6 bc	**120**	42.4 bc
4	**180**	40.04		**180**	41.98		47.7	b	**140**	39.1 ab	44.2 ab	**180**	41.9 bc
5	**230**	40.09		**220**	41.91		47.34	b	**180**	37.8 a	44.1 ab	**220**	41.1 ab
6	**300**	40.16		**300**	41.82		47.5	b	**220**	38.2 a	43.6 a	**300**	40.4 a
VAR								**VAR**					
Aspen		39.22	a		43.4	b			**Canyon**	40.7 b	47.0 c		44.1 c
Canyon		41.26	c		43.52	b			**Conway**	38.7 a	43.8 b		40.2 a
WPB Elyann		40.38	b		40.26	a			**WPB Elyann**	51.5	41.4 b		42.8 a
Canyon									**Canyon**				
	0	41.45			44.49		41.93		**0**	43.4	47.7	**0**	46.3
	80	41.80			44.44		47.06		**50**	43.2	48.1	**70**	44.7
	130	40.90			42.77		48.67		**100**	41.6	46.3	**120**	44.5
	180	41.53			43.36		48.39		**140**	39.5	46.6	**180**	43.8
	230	40.96			43.69		47.79		**180**	37.3	46.7	**220**	43.5
	300	40.93			42.35		48.10		**220**	39.1	46.7	**300**	42.1
Aspen									**Conway**				
	0	40.38			44.62		45.25		**0**	40.9	44.3	**0**	41.0
	80	39.49			43.08		45.12		**50**	41.0	44.8	**70**	41.6
	130	38.79			43.87		47.05		**100**	38.7	43.9	**120**	41.2
	180	38.46			43.11		47.01		**140**	37.9	43.4	**180**	40.2
	230	39.03			42.01		46.88		**180**	36.8	43.1	**220**	39.3
	300	39.17			43.74		46.90		**220**	36.7	43.2	**300**	38.2
WPB Elyann									**WPB Elyann**				
	0	40.78			42.16				**0**	44.5	44.4	**0**	42.5
	80	40.21			40.46				**50**	44.2	43.2	**70**	42.4
	130	40.48			40.02				**100**	41.7	42.9	**120**	41.7
	180	40.14			39.48				**140**	40.0	42.8	**180**	41.8
	230	40.28			40.04				**180**	39.2	42.5	**220**	40.4
	300	40.38			39.37				**220**	39.0	40.9	**300**	40.8
P-value													
TRT		<0.05			<0.05		<0.001			<0.01	<0.001		<0.001
VAR		<0.001			<0.001		<0.05			<0.001	<0.001		<0.001
TRT*VAR		0.822			<0.001		0.442			0.919	<0.05		<0.05

Table 9.59. Screenings (%) means for each variety and nitrogen (N) treatment at each location (Cambridgeshire (EA), Fife (SAG) and Lincolnshire (OMEX)) in 2019, 2020 and 2021. N Treatment (TRT), variety (VAR), and location (LOC) means are shown. Two-way ANOVA p-value results and the least significant difference for TRT, VAR and treatment x variety (TRT x VAR) interaction are displayed. Letters next to the TRT and VAR mean values indicate significant differences between mean values at p < 0.05.

Screenings, %													
		EA19			**EA21**		**OMEX 21**			**SAG19**	**SAG20**		**SAG21**
Site mean		1.58			1.84		0.48			2.85	2.22		1.28
N TRT ha^{-1}	**kg N**			**kg N ha^{-}**					**kg N ha^{-}**			**kg N ha^{-}**	
1	**0**	1.55		**0**	1.29	a			**0**	2.02 a	2.15	**0**	1.17 ab
2	**80**	1.547		**70**	1.624	ab			**50**	2.18 ab		**70**	0.95 a
3	**130**	1.509		**120**	1.838	bc			**100**	2.75 bc		**120**	1.16 ab
4	**180**	1.66		**180**	1.975	bc			**140**	3.12 cd	2.21	**180**	1.29 abc
5	**230**	1.619		**220**	2.015	bc			**180**	3.35 cd		**220**	1.46 bc
6	**300**	1.585		**300**	2.279	c			**220**	3.67 d	2.29	**300**	1.62 c
VAR								**VAR**					
Aspen		1.46	b		1.291	a	0.43	a	**Canyon**	2.98 b	2.28 ab		1.56 c
Canyon		1.254	a		1.362	a	0.53	b	**Conway**	2.58 a	1.83 a		0.98 a
WPB Elyann		2.022	c		2.858	b			**WPB Elyann**	2.99 b	2.55 b		
Canyon									**Canyon**				
	0	1.43			1.04		0.70		**0**	2.41	2.14	**0**	1.11
	80	1.24			1.02		0.39		**50**	2.50		**70**	0.99
	130	1.18			1.52		0.49		**100**	2.96		**120**	1.19
	180	1.20			1.42		0.48		**140**	3.18	2.47	**180**	1.83
	230	1.31			1.36		0.54		**180**	3.35		**220**	1.92
	300	1.17			1.81		0.58		**220**	3.46	2.23	**300**	2.30
Aspen									**Conway**				
	0	1.36			1.10		0.41		**0**	1.65	2.22	**0**	1.39
	80	1.38			1.24		0.34		**50**	1.97		**70**	0.87
	130	1.41			1.27		0.54		**100**	2.67		**120**	1.07
	180	1.69			1.16		0.42		**140**	2.78	1.57	**180**	0.70
	230	1.47			1.45		0.41		**180**	2.83		**220**	0.90
	300	1.45			1.53		0.48		**220**	3.58	1.70	**300**	0.96
WPB Elyann									**WPB Elyann**				
	0	1.86			1.73				**0**	2.01	2.10	**0**	1.01
	80	2.02			2.61				**50**	2.06		**70**	0.99
	130	1.95			2.73				**100**	2.62		**120**	1.22
	180	2.09			3.35				**140**	3.42	2.60	**180**	1.34
	230	2.08			3.24				**180**	3.86		**220**	1.56
	300	2.14			3.50				**220**	3.97	2.94	**300**	1.59
P-value													
TRT		0.685			<0.001		0.080			<0.001	0.797		<0.001
VAR		<0.001			<0.001		<0.05			<0.05	<0.001		<0.001
TRT*VAR		0.516			0.004		0.251			0.474	.075		<0.001

Effect of N timing on milling quality of winter oats

Table 9.60. Variety and treatment mean values across sites, treatments and years for winter oat N timing experiments carried out in Nottinghamshire and Herefordshire in 2019 and 2021 as predicted by REML analysis.

		SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Variety						
Mascani		52.4	75.7	99.2	1.4	42.4
Penrose		50.0	74.5	99.3	2.4	41.4
RGT Southwark		52.6	73.5	99.1	6.0	34.8
Treatment						
	1	52.0	74.5	99.2	3.3	39.2
	2	52.2	74.6	99.2	3.3	39.2
	3	51.1	74.7	99.2	3.4	40.0
	4	51.9	74.4	99.2	3.4	38.4
	5	51.0	74.8	99.1	3.5	40.2
	6	52.0	74.3	99.2	2.7	40.3
Mascani		52.8	75.7	99.2	1.3	42.1
		52.7	75.9	99.3	1.4	41.8
		51.9	76.0	99.2	1.3	43.5
		52.5	75.4	99.3	1.5	41.0
		51.9	76.2	99.2	1.3	43.7
		52.6	75.3	99.3	1.3	42.5
Penrose		50.2	74.6	99.3	2.3	41.0
		50.8	74.5	99.3	2.6	41.3
		49.1	74.8	99.3	2.6	41.3
		50.3	74.3	99.3	2.4	40.7
		49.1	74.6	99.2	2.5	41.3
		50.7	74.2	99.2	1.8	42.7
RGT Southwark		52.9	73.4	99.1	6.3	34.4
		53.1	73.5	99.1	5.8	34.5
		52.2	73.3	99.1	6.4	35.3
		52.9	73.6	99.1	6.1	33.4
		52.1	73.7	99.0	6.5	35.5
		52.5	73.5	99.2	5.1	35.7
Variety p value		<0.001	<0.001	<0.001	<0.001	<0.001
Treatment p value		<0.001	0.142	0.277	0.005	<0.001
variety x treatment p value		0.32	0.612	0.448	0.157	0.025

Effect of N timing on milling quality of spring oats

Table 9.61. Variety and treatment mean values across sites, treatments and years for spring oat N timing experiments in Fife in 2019, 2020 and 2021 as predicted by REML analysis.

	SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Variety					
Canyon	53.85	73.42	96.26	1.53	44.51
Conway	53.36	74.93	98.98	0.89	41.55
WPB Elyann	52.58	77.21	97.99	1.75	41.19
Treatment					
1	53.30	75.17	97.61	1.42	42.34
2	53.18	75.24	97.44	1.37	42.61
3	53.32	75.22	98.06	1.33	42.28
4	53.02	75.06	97.58	1.46	42.45
5	53.44	75.15	97.97	1.37	42.28
6	53.32	75.27	97.81	1.39	42.56
Canyon					
1	53.92	73.43	95.75	1.51	44.46
2	53.66	73.49	95.55	1.57	44.87
3	53.95	73.45	97.18	1.45	44.18
4	53.66	73.17	95.91	1.54	44.49
5	54.19	73.48	96.78	1.52	44.55
6	53.74	73.52	96.36	1.59	44.50
Conway					
1	53.34	74.81	99.00	0.92	41.38
2	53.41	74.98	99.00	0.91	41.44
3	53.26	75.06	98.97	0.85	41.36
4	53.19	74.85	98.96	0.92	41.74
5	53.49	74.86	99.02	0.86	41.46
6	53.48	75.03	98.95	0.87	41.96
WPB Elyann					
1	52.63	77.28	98.08	1.83	41.18
2	52.47	77.25	97.76	1.64	41.51
3	52.76	77.15	98.04	1.68	41.30
4	52.22	77.16	97.86	1.91	41.13
5	52.65	77.13	98.10	1.74	40.84
6	52.74	77.27	98.12	1.71	41.21
Variety p value	<.001	<.001	<.001	<.001	<.001
Treatment p value	0.04	0.67	0.01	0.28	0.63
variety x treatment p value	0.71	0.99	0.03	0.66	0.84

Table 9.62. Variety and treatment mean values across sites, treatments and years for spring oat N timing experiments conducted in Suffolk in 2019, 2020 and 2021 as predicted by REML analysis.

	SPWT, kg/hl	Kernel Content, %	Hullability, %	Screening, %	TGW, g
Variety					
Aspen	48.38	69.61	98.92	1.48	38.78
Canyon	49.41	69.33	97.09	1.56	40.45
WPB Elyann	47.29	71.38	98.93	3.15	37.35
Treatment					
1	48.29	70.21	98.40	1.92	38.93
2	48.51	69.77	98.29	2.10	38.79
3	48.38	69.99	98.26	2.02	39.20
4	48.26	70.05	98.37	1.94	38.65
5	48.59	70.34	98.26	2.02	39.43
6	48.12	70.28	98.30	2.39	38.17
Aspen					
1	48.33	69.55	98.94	1.29	39.03
2	48.41	69.19	98.98	1.45	39.03
3	48.34	69.39	98.83	1.49	39.03
4	48.83	69.85	98.93	1.25	39.03
5	48.44	69.90	98.86	1.38	39.03
6	47.93	69.76	99.00	2.03	39.03
Canyon					
1	49.37	69.66	97.27	1.57	40.14
2	49.82	69.22	96.97	1.48	40.55
3	49.35	69.10	97.06	1.50	40.72
4	48.81	69.32	97.36	1.51	40.42
5	49.73	69.21	96.93	1.55	40.72
6	49.38	69.47	96.95	1.78	40.15
WPB Elyann					
1	47.17	71.41	98.98	2.89	37.61
2	47.29	70.90	98.93	3.37	36.90
3	47.46	71.47	98.89	3.09	37.90
4	47.14	70.97	98.83	3.07	36.89
5	47.60	71.91	98.99	3.14	38.18
6	47.06	71.60	98.95	3.37	36.65
Variety p value	<.001	0.032	<.001	<.001	<.001
Treatment p value	0.124	0.39	0.585	0.046	0.002
variety x treatment p value	0.103	0.825	0.36	0.878	0.63