LIVEOAT

Farm-Based Organic Cultivar Trials Network

Report 2021

Project name	**LiveOat**
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Report and complete data analysis on the 2021 growing season

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Executive Summary

LiveOat is a supply-chain-led research and development programme that aims to enable informed decision-making for sustainable organic oat production. This can be achieved by assembling a network of farmers, a processor, and researchers, with broad stakeholders' support, able to undertake on-farm experimentation and data collection on oat cultivars. The aim of this report is to highlight and discuss the main results from the 2021 growing season and to inform prioritisation of work for the 2022 growing season and beyond.

In 2021, four cultivars were tested across a network of four farms, all of which are organic certified. A complete block design was adopted using cv. Firth as a reference cultivar (21 years on the Recommended List) and including cultivars Isabel, Lion and Elyann. Data collection has followed a simplified protocol focussing on the crop anthesis stage, with observations on crop morphology and yield components. Grain yield was measured by farmers at harvest and grain samples were analysed for standard commodity quality metrics. Data exploration and analysis addressed the two key components of variation: the environments and the genetics.

- *Environments*

Variation of main performance indicators across farms is presented and descriptively discussed in light of known farm characteristics. In addition, the season was characterised by an unusually cold and dry early spring, which might have altered crop development during the foundation phase. Environments higher in nitrogen supply appear to support enhanced agroecological performance of the oat crop.

- *Genetics*

The analysis of cultivar effects investigates to what extent the available genetic diversity can improve crop performance. Two major 'highlights' from the 'genetics' analysis were

(i) All cultivars performed equally in terms of yield with no outstanding performer, suggesting cv. Isabel, cv. Elyann and cv. Lion may all off suitable alternatives to longstanding benchmark cv. Firth under organic production.

(ii) Grain quality parameters were not significantly different amongst cultivars although cv Isabel had the highest average bushel weight and kernel content and very similar dehullability and 2mm screenings suggesting it may be a suitable milling replacement for the now delisted cv Firth.

In subsequent growing seasons it is recommended a minimum for five, preferably seven farms take part to enable robust data analysis using mixed effects modelling with farm as random effect. It may also be possible to include management factors within the experiment if enough farmers take part, for example by splitting farms into two management groups depending on rotational position to compare the performance of crops as a first or second cereal. Data collection must also be expanded in subsequent years to include early crop vigour, weed cover and disease scoring in order to draw further conclusions about overall agroecological crop performance.

The 2021 growing season provided a preliminary set of results, that need to be interpreted considering the specific climatic pattern and the small number of farms taking part. In addition, cumulative analysis of

subsequent seasons is required to shed light on the stability and resilience potential of the different cultivars tested. A minimum of three seasons is required to draw robust conclusions on cultivar performance

Contents

1 Introduction

In organic oat production, most determinants of crop performance are managed at a rotation level, which leaves cultivar choice as the major decision on a seasonal basis. Winter Oat cultivar Mascani has provided a reliable long term milling oat liked by farmers and processors for its field performance and for its quality and milling attributes linking the supply chain. Spring Oats however, have provided less reliable options, with the most popular cultivar Firth which has been present on the Recommended list (RL) for 20 years but has since been removed. Other high quality options are now sought by processors. Yet, in the absence of a formal organic cultivar testing programme, little information is available to support cultivar choice or to link field performance and environment with milling quality sought by processors. Furthermore, uncertainty about field-scale crop production and quality performance hinders positive development in the supply chain of both grain and seeds. In this context, White's Oats and Organic Arable with support from the Organic Research Centre started an initiative in 2021 to undertake long term field-scale evaluation of spring oat cultivars, integrated with an agronomic survey of oat performance, across a network of organic farms, that has led to the launch of the 'Farm-Based Organic Variety Trials Network 'LiveOat'. The main objective of this overall activity is to raise quantitative evidence on organic oat performance in real-farm, field-scale conditions, as affected by cultivars and farm environment, to help set the foundations and inform supply chain collaboration through more detailed and focused, surveys and experiments.

The first year of farm-based cultivar evaluation allowed a first quantification of spring oat performance on organic farms with an excellent foundation set down for future expansion. In 2021, four varieties have been tested across a network of four farms. As a foundation year, the main outcomes are limited to an establishment of the network and a first step towards learning more about the performance of spring oat cultivars grown organically:

- As a foundation year not enough data is available to draw firm conclusions about genotype performance but despite non-significant differences in yields and quality, the cultivar Isabel tended to be better quality than the other cultivars,

-Extreme weather to start the season (very cold/dry April, cold/wet May) created suboptimal establishment conditions, potentially reducing genotype effects on performance.

- Only four farms took part, with only three providing yield data

The conclusions so far must be cautious given the context above but with Firth now removed from the RL, alternative cultivars are urgently sought for farmers and processors with Isabel showing positive traits that will need substantiating in subsequent seasons. There may exist an opportunity to look at novel lines and even to investigate simple blends to improve field performance, whilst increasing farmer participation and intensifying agroecological data collection from the farms.

2 Materials and Methods

2.1 Cultivars tested

The design for the 2021 growing season comprises four cultivars occurring across all four farms as a randomised complete block design with farms as block. In addition, the farm cultivar grown in the field was included twice to help improve the design and limit the effects of any environmental field gradients. With the selection of cultivars to test and a limited number of farms, we have aimed to balance the following priorities

(i) the inclusion of reference cultivar Firth with 20 years on the Recommended List and a known reliable performer for organic farming

(ii) the opportunity to test entries that have shown promise for organic farming and proved interesting in the plot-scale trials managed by OA and White's- namely cv Isabel

(iii) the opportunity to test new entries in the market – namely cv Lion

The list of cultivars tested is presented in **Table 1**.

2.2 Farms and fields

The 2021 growing season started with no major disruption to crop drilling thanks to dry conditions from late March, with drilling completed by mid-April 2021. Out of five farms originally planned, four were successfully part of the experimental design (**Table 2**). Interviews with the farmers allowed us to ascertain the management of the fields hosting the experimental strips, as presented in **Table 3**. Soil samples were collected from the experimental fields after oat harvest, for determination of texture, pH, available phosphorous, potassium and magnesium and soil organic matter.

2.3 Experimental design

The experimental design comprises four cultivars tested in four locations, including a control variety (Firth). We recorded the farmers' commitment to increasing robustness of the design, with all farms having put in place one within-farm replicate of the farm cultivar. The complete experimental design is shown in **Table 4**.

2.4 Data collection

A first full series of assessments was carried out in correspondence with the onset of stem extension (BBCH GS 32), in the 1st week of June, and a second in correspondence of, or shortly after, anthesis (BBCH GS 65), carried out in the 3rd week of July. The dataset on the spring oat experimental design comprises a series of 195 individual observations, representing 20 individual experimental units ("strips", that will generate yield measurement and grain quality samples) across the four farms. Core variables assessed were:

- Crop cover at GS32 and crop height at GS65;
- Yield components, namely panicle density and spikelet number per panicle;
- Grain yield, measured by farmers at harvest and corrected against admixture weight and moisture content;
- Kernel content, specific weight, hullability, screenings (<2.0mm) measured by White's Oats laboratory.

2.5 Statistical analysis

All analyses were performed by R 4.1.2 (R Core Team, 2021) on a platform x86_64-w64-mingw32/x64 (64-bit). Packages 'lme4', 'lmerTest', 'emmeans' and 'ggpredict' were used for mixed-effect models (Bates et al. 2015). Package 'dplyr' 'ggplot2' were used for data manipulation and visualisation, respectively. All linear and linear-mixed-effect models were checked for homoscedasticity and normality through quantile-quantile plots.

2.5.1 Genetic differences

To investigate cultivar differences, we used a linear mixed model assuming cultivar as a fixed term and farm as random term. The model was formulated as follows:

$$Y_{iyf} = \mu_0 + \alpha_i + b_f + e_{if}$$

where Yi is the value of the response variable for i^{th} cultivar, μ0 is the grand mean, α_i is the effect of cultivar i, b_f is the random effect of the f^{th} farm (random intercept), e_{if} is the error. Significance of cultivar effect was assessed by comparing the likelihood ratio test against a null model only containing the random terms. From the REML-fit model, estimated marginal means of cultivars, related standard errors, and p-values of pairwise comparisons were calculated with Tukey adjustment and Kenward–Roger method for degrees of freedom.

Table 1. Cultivars tested in the 2021 growing season, their parentage, breeder and year/country of release (NL = National List, RL = Recommended List), end-use classification and year of first inclusion in the LiveOat project

Cultivar	Parentage	Breeder (UK contact) / Year of Listing	End-use classification	Year of first inclusion	Notes
WPB Elyann	(Ivory x LW 00W035-01) x LW 97W020-01	Wier (KWS)/2017	Husked/Milling	2021	Outstanding kernel content, high yielding, early to mature
Firth	CR3/418 x Flamingsvita	KWS (KWS)/2000	Husked/Milling	2021	Reference (benchmark) cultivar for known organic performance in field and mill. Dropped from RL in 2022.
Isabel	(LW 03W0383-06 x Husky)	Wier (KWS)/2020	Husked/Milling	2021	Potential Firth replacement showing positive traits and performance for organic farming and milling, high specific weight and kernel content
Lion	Poseidon x Max	Nord (SU)/Year 4 candidate (2021)	Husked/Milling	2021	Yellow oat, high kernel content, good dehullability. Added to RL in 2022

Table 2 Farms participating in the LiveOat experimental design 2021, their description, spring oat production orientation, typical soil texture, typical spring oat position in rotation.

Farm	Farm description	Spring Oat production orientation	Organic certified	Year joined the LiveOat network	Typical farm soil type, texture	Typical Preceding crop
GL_04	Organic arable/pigs/cattle rotation including leys	Milling	Yes	2021	Silty Clay	?
MK_01	Organic arable/beef, rotation including leys	Milling	Yes	2021	Silty Clay	Winter Oats
SN_02	Organic arable rotation including leys	Milling	Yes	2021	Clay	Grass-clover ley
TF_02	Organic arable/vegetable/rotation including leys	Milling	Yes	2021	Loamy Sand	Spring Beans

Table 3 Management descriptors of the fields hosting the LiveOat spring oat cultivars 2021

Farm	Preceding crop	Soil preparation	Sowing scheme/ seed rate	Sowing time	Fertilisation	Weed management	Management system class
GL_04	?	?	? / ?	?	?	?	?
MK_01	2 years red clover-grass ley	Ploughed, cultivated	Narrow rows, 500 seeds/m2	6th April	28t/ha FYM to ley	False seed beds	Narrow row, no in crop weeding
SN_02	Spring oats	Cultivated 3 times	Narrow rows/ 500 seeds/m2	29th March	n/a	False seed beds	Narrow row, no in crop weeding
TF_02	Spring beans	Plough, harrow	Narrow rows, 500 seeds/m2	7th April	18m3/ha Slurry under plough	Einbock harrow	Narrow row, spring tine harrow

Table 4. Experimental design of the 2021 growing season.

	GL_04	**MK_01**	**SN_02**	**TF_02**	**N**
Elyann	X	X	X	X	4
Firth	X	X	X	X	4
Isabel	2X	2X	2X	2X	8
Lion	X	X	X	X	4

3 Results and discussion

3.1 Environments

The climatic pattern was characterised by a rainier than average winter season and a cooler than average spring. Whilst not showing exceptional constraints to crop establishment and growth, the climatic season was characterised by interesting extremes: namely the unusually dry and cold April with a record of air frost days (UK's fourth driest April in a series from 1862). This has affected crops mostly in terms of slowing down the phenological cycle, with delayed onset of stem extension.

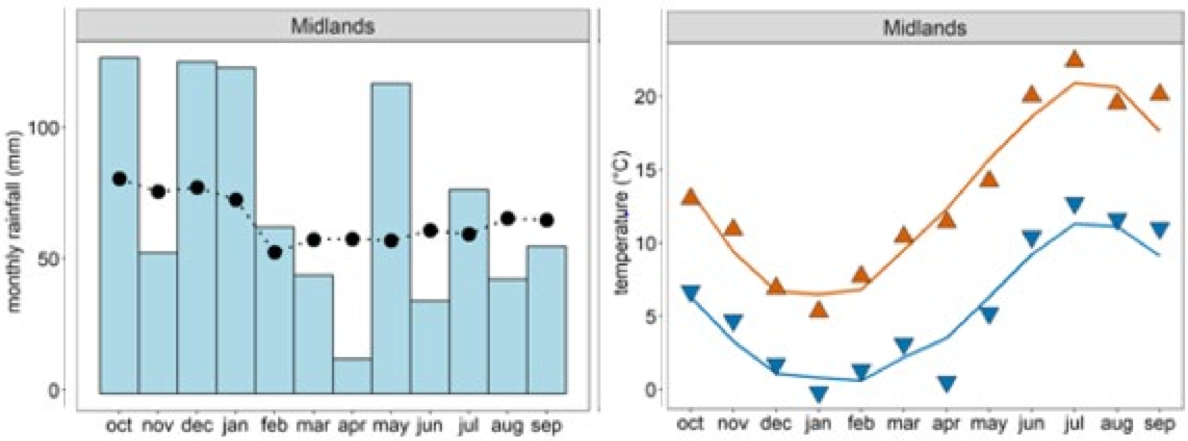

Figure 1. Climatic pattern of the 2020/21 growing season: Monthly cumulative rainfall (bars) as compared to the 1980-2010 average (dots) and monthly average minimum and maximum temperatures (triangles) as compared to the 1980-2010 average (lines) in the Midlands region. Data: MetOffice.

A wide range of performance was observed across farms in 2021. Considering the common control cultivar cv. Firth, the average yield was 4.59 ± 0.86 t/ha, with a range between the lowest values of 3.00 t/ha at SN_02, and maximum values of 5.99 t/ha at TF_02. Grain quality in cv. Firth averaged 45.9kg/hl for bushel weight, 64.6% for Kernel content, 2.0% for 2mm screenings and 93.4% dehullability, with TF_02 having the highest quality in all quality parameters except hullability which was highest at SN_02. Panicle density averaged 419.9 ± 44.3 panicles.m^2 for cv Firth with farms ranging between 327 (SN_02) and 494 (GL_04) panicles.m^2. The highest number of spikelets per panicle was found in MK_01 (42.9), and the lowest in GL_04 (20.1). Benchmark figures from the Opti-Oat growth guide for a yield of 7.0 t/ha are 370 panicles/m2, 44 grains per panicle and an average grain weight of 43mg/grain (Thousand grain weight of 43g).

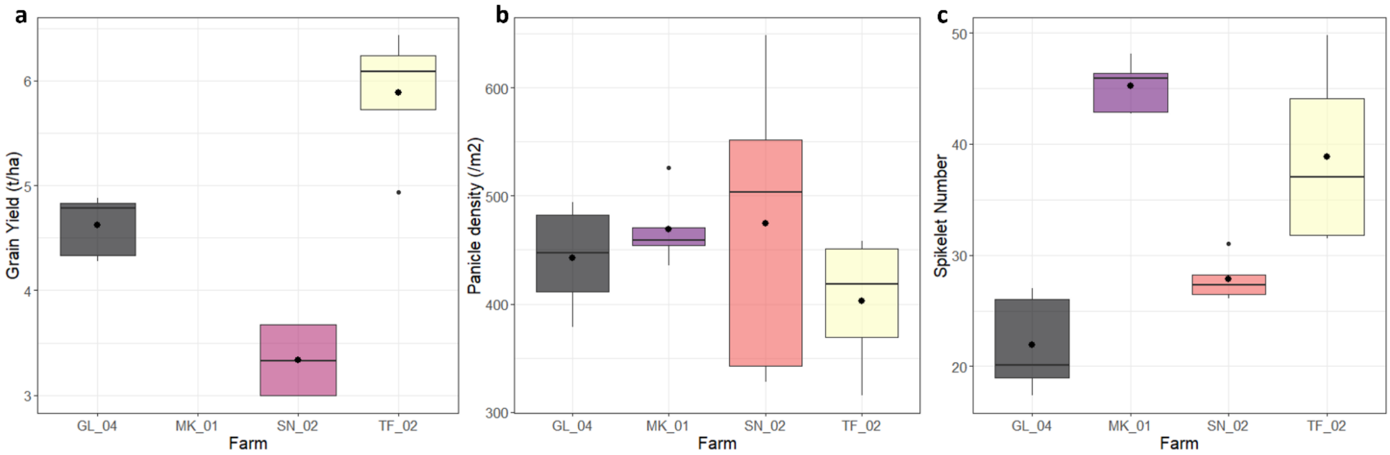

Figure 2. Grain yield (a), panicle density (b) and number of spikelets per panicle (c) by farm in the 2021 growing season.

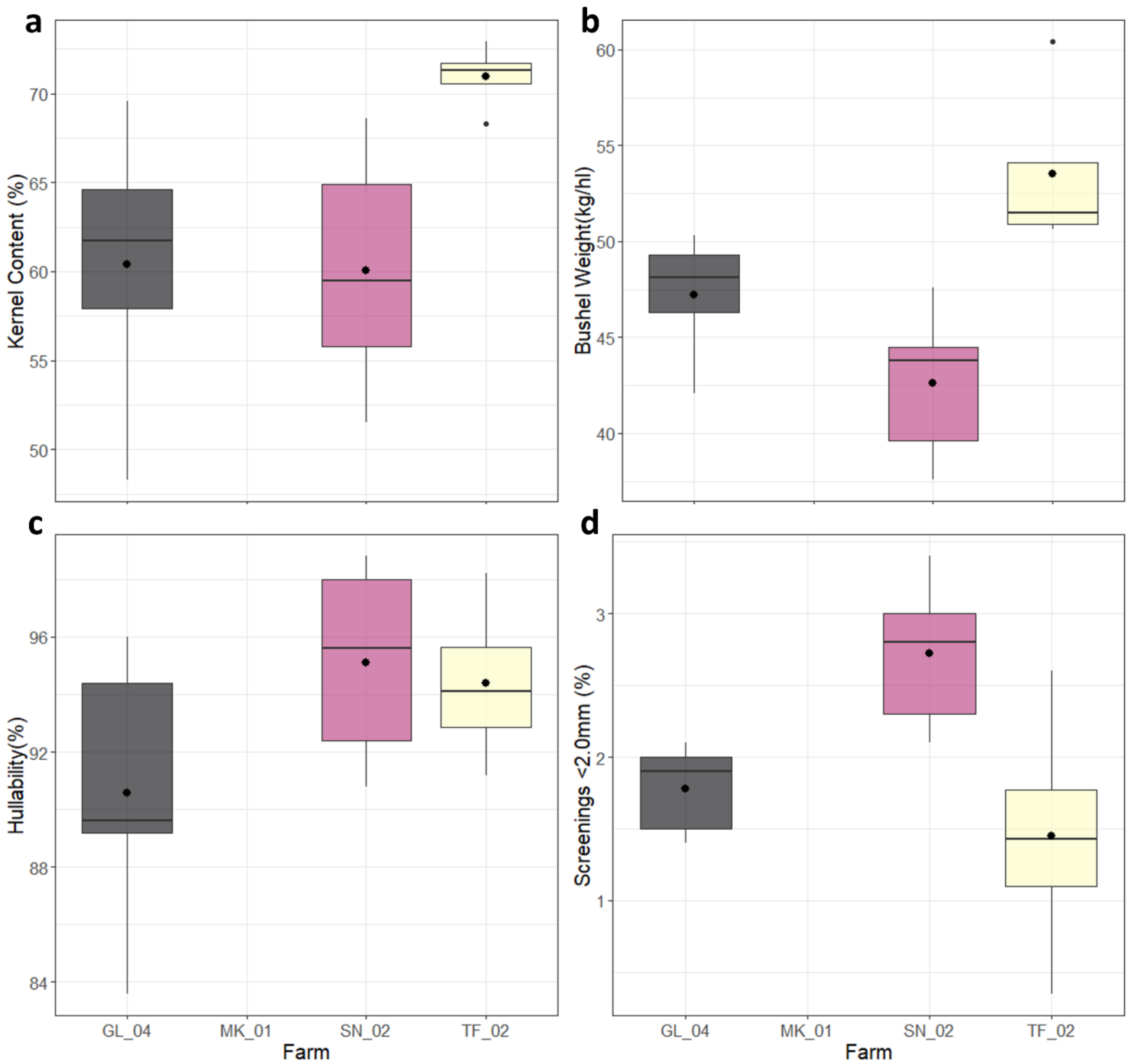

Figure 3. Kernel content (a), bushel weight (b) hullability (c) and 2mm screenings (d) by farm in the 2021 growing season.

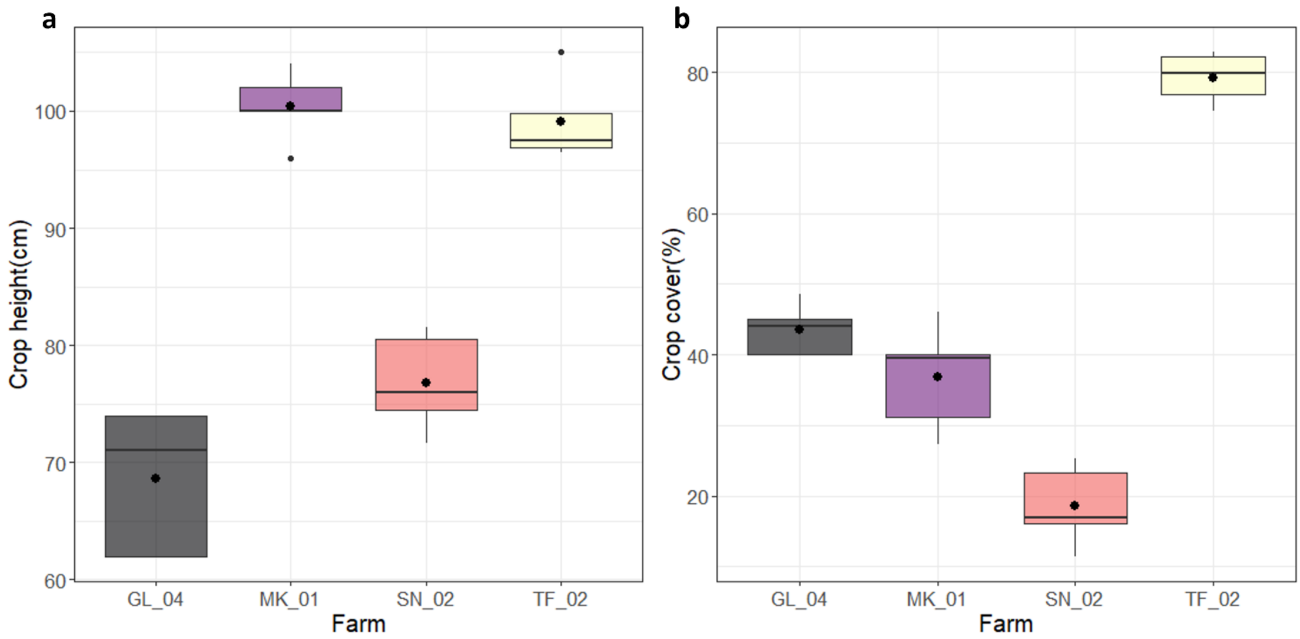

Figure 4. Crop height (a) and crop cover (b) at anthesis by farm in the 2021 growing season.

Farm and field characteristics may explain these differences. Farm TF_02, the highest in yield and bushel weight, has high fertility soils due to regular additions of organic manures, with field vegetables in the rotation and with an application of slurry ahead of the spring oat crop. Farm MK_02, with the highest spikelets per panicle and the tallest crops, Site MK_02 sits in the most naturally fertile soils with the highest levels of P and K of the four farms and good organic matter content, with farmyard manure regularly added from the beef cattle enterprise. The spring oats were grown in the first cereal position not typical for this crop or farm, following difficult autumn conditions that prevented the drilling of a winter oat crop. The lowest yields and bushel weight recorded in farm SN_02 might be explained by the low fertility and high pH, limiting crop nutrient availability. Crop cover was highest in farm TF_02 (79.2±2,7 %) and lowest in farm SN_02 (18.9±2.5%). Crop height was highest at MK_02 and TF_02 and lowest at GL_04, with crop height often a good proxy for nitrogen availability, and given the manure additions to both rotations, the taller crops at MK_02 and TF_02 would be expected.

Principle component analysis (Figure A6) revealed a link between kernel content, bushel weight, height, yield and groundcover, suggesting that environments higher in nitrogen are likely to support these traits and enhance agroecological performance of the crop. Using environment and management practices to help increase nitrogen availability may help to improve not just yield but grain quality as well.

3.2 Genetics

Analysis showed no significant cultivar effects for all the main indicators of productive performance (**Table 5**). Grain yield was highest in cv Lion, with 4.8 ± 0.8 t/ha, and lowest in Isabel, with 4.5 ± 0.8 t/ha. This result includes all yield data collected from three farms but with the Isabel yield result at TF_02 being an outlier **(Figure A2),** removing this result, which may have been the whole field yield rather than the experimental strip, would see Isabel going from lowest yielding to highest at 4.9 ± 0.9 t/ha. Although there was no significant cultivar effect on the yield components, panicle density, spikelet number and spikelet density, the cultivar Isabel had one of the highest spikelet densities, supporting evidence that it may have in fact been one of the highest yielding cultivars, without the unreliable yield data from TF-02. Higher spikelet density was associated with higher yield at two of three farms **(Figure A3).**

Table 5. Estimated marginal means ± standard errors by cultivar of grain yield (t/ha adjusted at 15% moisture), panicle density (panicles/m^2) and spikelet number (spikelets/panicle). Values with the same letter are not significantly different (Kenward-Roger method for degrees-of-freedom and Tukey adjustment for p-value) at a 0.95 confidence level (0.90 if letters are in brackets). Chi-square (X^2) and significance of cultivar effect as compared to a null model are indicated (* p < 0.05, ** p < 0.01, *** p < 0.001)

Cultivar	Grain Yield (t/ha)	Panicle Density (Panicles/m^2)	Spikelet Number (Spikelet/Panicle)	Spikelet Density (Spikelet/ m^2)
Elyann	4.6 ± 0.8 a	450 ± 43 a	34.6 ± 5.7 a	15542 ±2694 a
Firth	4.6 ± 0.8 a	420 ± 43 a	30.3 ± 5.7 a	12513 ±2694 a
Isabel	4.5 ± 0.8 a	471 ± 33 a	34.5 ± 5.5 a	15110 ±2560 a
Lion	4.8 ± 0.8 a	441 ± 43 a	33.6 ± 5.7 a	14959 ±2694 a
	X^2 = 0.60	X^2 = 1.19	X^2 = 2.54	X^2 = 3.74
	p-value 0.90	p-value 0.75	p-value 0.47	p-value 0.29

Analysis of Grain quality parameters showed no effect of cultivar (**Table 6**). Isabel had the highest of all the bushel weights at 50.3 ± 3.6kg/hl and also had the highest kernel content at 65.8 ± 4.5 %. There was a low variation between cultivars for the quality parameters of hullability and screenings <2.0mm. Bushel weight and Kernel content are heritable traits but are also influenced by environment, particularly nitrogen supply.

Table 6. Estimated marginal means ± standard errors by cultivar of grain bushel weight (kg/hl), Kernel content (%), Hullability (%) and 2mm Screenings (%). Values with the same letter are not significantly different (Kenward-Roger method for degrees-of-freedom and Tukey adjustment for p-value) at a 0.95 confidence level (0.90 if letters are in brackets). Chi-square (X^2) and significance of cultivar effect as compared to a null model are indicated (* p < 0.05, ** p < 0.01, *** p < 0.001)

Cultivar	Bushel Weight (kg/hl)	Kernel Content (%)	Hullability (%)	Screenings 2mm (%)
Elyann	45.9 ± 3.8 a	61.5 ± 5.1 a	93.7 ± 2.8 a	1.8 ± 0.5 a
Firth	45.9 ± 3.8 a	64.6 ± 5.1 a	93.4 ± 2.8 a	2.0 ± 0.5 a
Isabel	50.3 ± 3.6 a	65.8 ± 4.5 a	92.9 ± 2.3 a	2.3 ± 0.4 a
Lion	47.3 ± 3.8 a	61.5 ± 5.1 a	93.4 ± 2.8 a	1.7 ± 0.5 a
	X^2 = 4.23	X^2 = 1.29	X^2 = 0.09	X^2 = 2.15
	p-value 0.24	p-value 0.73	p-value 0.99	p-value 0.54

Analysis of canopy traits at GS65 shows no significant effect of cultivar on either groundcover or height. The cultivar with the highest cover was cv Elyann with a groundcover of 48.3 ± 13%, whilst the lowest cover was found for cv Isabel at 41.6 ± 13%. The tallest cultivar was Lion at 87.3± 8.3cm , whilst the shortest cultivar was Isabel at 85.3± 8.1cm. This result is in contradiction of plot trial results in the 2019 and 2020 seasons that found Isabel to be the tallest, highest covering and most vigorous of the cultivars grown compared with Firth and Elyann included in both seasons and Lion included in 2020. In fact, data form the RL shows that Isabel is the tallest of the four cultivars tested, although this is under non-Organic high input conditions. Cultivars, displaying maximised growth rate before stem extension, and hence high early vigour, mediated by an overall faster growth and developmental cycle, can be expected to provide enhanced weed suppression at the onset of stem extension. It can be inferred that traits of high ground cover, height and vigour provide weed competition, although weed cover data was not collected in the 2021 LiveOat season, data on weeds would be beneficial to help complete the picture on agroecological performance of the cultivars.

Table 7. Estimated marginal means ± standard errors by cultivar of crop cover, crop height at anthesis (GS65). Values with the same letter are not significantly different (Kenward-Roger method for degrees-of-freedom and Tukey adjustment for p-value) at a 0.95 confidence level. Chi-square (X^2) and significance of cultivar effect as compared to a null model are indicated (* p < 0.05, ** p < 0.01, *** p < 0.001)

Cultivar	Crop Cover GS65			Crop Height GS65			Weed Cover
Elyann	48.3	± 13	a	87.1	± 8.3	a	na
Firth	44.3	± 13	a	85.8	± 8.3	a	na
Isabel	41.6	± 13	a	85.3	± 8.1	a	na
Lion	46.0	± 13	a	87.3	± 8.3	a	na
	X^2 = 4.92			X^2 = 0.78			
	p-value = 0.18			p-value = 0.85			

The other set of important data missing from the 2021 growing season is that of foliar disease, with Mildew and crown rust expected to affect both yield and quality performance. Overall disease severity may have been low during the 2021 growing season due to the very cold and dry April, and the continued cold weather in May but foliar disease data would help in overall cultivar comparisons and should be considered a key trait for judging overall agroecological performance.

3.2.1 Drivers of crop performance

A quantitative understanding of the traits that can be predictors of productive performance is strategic to generate management recommendations and suggest prioritisation of management goals. Considering the three farms that provided yield data, and offsetting against the random effect of both farms and cultivars, significant effects of grain yield (p= 1.56e-05***) were found for crop groundcover at anthesis (**Figure 5)** in the 2021 growing season.

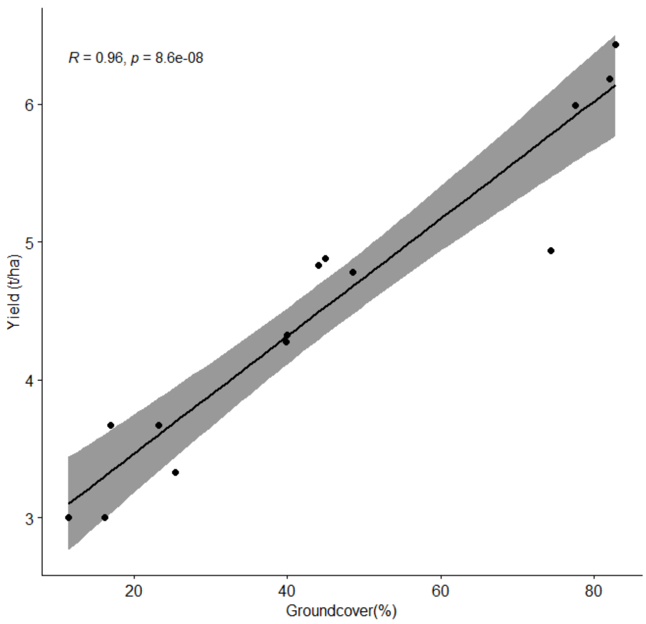

Figure 5 Relationship between crop groundcover and Yield

Crop cover at anthesis was a significant predictor of grain yield, with a positive relationship. Among yield components (panicle density, number of spikelets per panicle, panicle density per m^2) panicle density was a significant predictor of yield (p=0.0008 ***) with a positive relationship to grain yield **(Figure A5).** The record low minimum temperatures in April coupled with a cold May might have limited the crop's capacity to buffer differences in fertile tiller density through a compensation effect of increasing spikelet number, therefore strongly linking the final yield with the earliest set yield component (Slafer et al. 2014). The slow development during the foundation phase in 2021 allowed for tiller production but lower temperatures may have reduced overall tiller numbers, whilst shortening the late construction and production phases. In oats grain number has a greater effect on yield than final grain size. The number of grins per panicle is a heritable trait but grains per panicle and panicles (tillers) per m2 are affected by management and environment.

4 Conclusion

The 2021 growing season provided a dataset that needs to be carefully interpreted considering the fact that this is a first season of the experiment that needs to be continued for further years to provide a robust set of results. The project is now at a stage where some hypotheses need to be defined and challenged, by analysing the data of the current growing season and thinking of the priorities for future years. The expanded collective experiment LiveOat can allow cultivars to be tested in diverse rotational and agronomic, but commercially relevant, contexts, particularly regarding the assumed temporal distribution of nitrogen availability and associated effects on yield and grain quality, and competition from weeds, the following recommendations are made:

1. Build a larger network of farms to increase the power of detecting cultivar effects on the key metrics of agroecosystem performance with at least seven farms taking part in 2022.
2. Continue to assess current alternatives to long standing organic spring oat benchmark Firth, particularly given its removal after 21 years from the RL, with cvs Isabel and Lion showing good potential as organic options. Simple blends (e.g., Isabel and Lion) may also be investigated to provide complementarity and increase resource capture efficiency compared to monocultures.
3. Increase data collection to allow for a more in-depth study of agroecosystem performance and the drivers of performance, including data collected at both stem extension and anthesis, disease data and weed community data.
4. Use a larger network of farms to consider investigating management effects, for instance rotational position and subsequent effect of different nitrogen availability on yield and quality performance.
5. Engage in more farmer training to help empower them to make their own assessments and collect their own data to feed into the collective experiment
6. Measure additional grain quality traits of protein and beta-glucan, which are affected by genetics, environment and management, to further distinguish the cultivars.

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Annexes

Table A1. AHDB Recommended List, Spring Oats 2021, including candidate varieties, showing characteristics of all four LiveOat 2021 cultivars, with specific traits of interest highlighted.

AHDB Recommended List

Spring oats 2021

AHDB RECOMMENDED

	Delfin	WPB Isabel	Elison	Yukon	Canyon	Aspen	WPB Elyann	Conway	Firth	Average LSD (5%)	Oliver	Madison	Kamil	Merlin	Lion
											Described varieties			Year 4 Candidates	
Variety type	Husked varieties										Naked varieties			Husked varieties	
Scope of recommendation	UK	UK	UK	UK	UK C	UK C	UK C	UK	UK *		UK	UK	UK	-	-
UK yield (% treated control)															
Fungicide-treated (6.9 t/ha)	106	105	105	104	102	100	98	98	94	5.4	75	70	64	104	98
Untreated (% of treated control)	101	88	97	99	96	86	88	88	79	6.5	62	59	57	[98]	[83]
Grain quality															
Kernel content (%)	73.0	75.9	72.5	73.2	73.2	73.8	77.0	74.4	74.3	1.1	-	-	-	[73.4]	[77.6]
Specific weight (kg/hl)	50.9	54.5	51.0	50.3	51.7	51.7	50.9	50.5	49.3	1.1	62.2	57.0	64.6	[51.5]	[52.4]
Screenings (% through 2.0 mm)	2.8	2.0	2.7	2.8	2.4	2.1	2.5	2.5	2.9	1.6	[5.7]	[10.3]	[3.0]	1.6	1.9
Agronomic features															
Resistance to lodging (1–9)	8	[9]	8	8	7	7	7	9	7	1.0	8	[7]	9	[9]	[9]
Straw length (cm)	111	[109]	110	106	110	98	100	105	98	2.5	104	[101]	106	[106]	[104]
Ripening (days +/- Firth, -ve = earlier)	0	0	0	0	0	0	-1	-1	0	1.3	0	-1	+1	-1	-1
Disease resistance															
Mildew (1–9) - **see note below**	8	5	8	7	8	4	4	5	4	1.0	3	3	4	8	3
Crown rust (1–9)	4	5	3	5	4	5	5	4	5	1.1	4	4	5	-	-
Annual treated yield (% control)															
2016 (8.3 t/ha)	[104]	[103]	[104]	[102]	[101]	[100]	[99]	[97]	[95]	4.7	[72]	[72]	[61]	-	-
2017 (7.2 t/ha)	[112]	[111]	[102]	[106]	[103]	[101]	[96]	[98]	[101]	6.7	[77]	[70]	[62]	-	-
2018 (6.0 t/ha)	[106]	[101]	[103]	[100]	[96]	[102]	[102]	[96]	[95]	8.5	[70]	[69]	[65]	[104]	[101]
2019 (7.1 t/ha)	[104]	[106]	[110]	[106]	[105]	[100]	[95]	[98]	[86]	11.4	[78]	[64]	[70]	[109]	[101]
2020 (6.1 t/ha)	[106]	[103]	[104]	[105]	[104]	[96]	[100]	[102]	[90]	7.6	[76]	[72]	[65]	[101]	[95]
Breeder/ UK contact															
Breeder	Nord	Wier	SE	Nord	Nord	Bau	Wier	IBERS	KWS		Selg	IBERS	Selg	Selg	Nord
UK contact	SU	KWS	Sen	SU	SU	Sen	KWS	Sen	KWS		Cope	Sen	Cope	Cope	SU
Status in RL system															
Year first listed	18	20	19	17	11	15	17	14	00		18	20	18	-	-
RL status	-	P2	-	-	-	-	-	-	*		-	P2	-	-	-

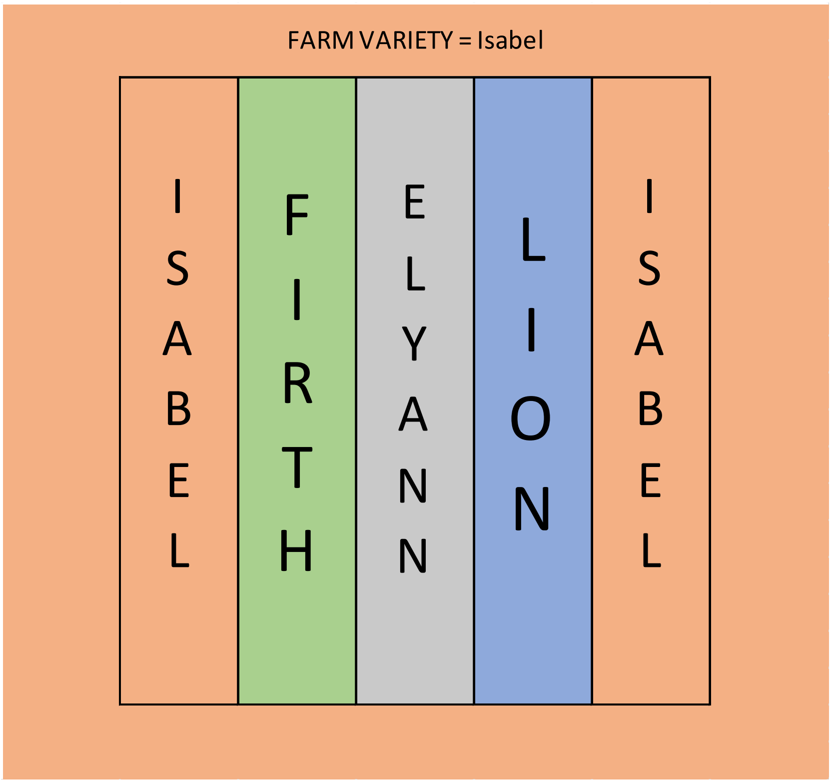

Figure A1. Example of generalised trial design layout showing use of farm crop as a control and in field replicate, helping to mitigate the effect of any environmental gradient.

Table A2. Soil characteristics in nine of the 2020/21 organic fields. P = Available Phosphorus (mg/l P2O5); K = Available Potassium (mg/L K2O); Mg = Available Magnesium (mg/l); SOM = Soil Organic Matter (loss on ignition); Resp. = Respiration ; SHI = Soil Health Index; Na = NH4NO3 extractable Sodium (mg/l); Ca = NH4NO3 extractable Calcium (mg/l); CEC = Cation Exchange Capacity (meq/100g)

Farm	P (mg/l)	K (mg/l)	Mg (mg/l)	SOM (%)	pH	Resp.	SHI	Na (mg/l)	Ca (mg/l)	CEC (meq/100g)	Clay (%)
GL_04	6.8	204	44.7	6.8	8.0	26	2.8	13	3370	23.2	45
MK_01	13.2	213	58.8	5.0	7.5	93	4.5	14.7	2149	15.5	40
SN_02	6.8	129	38.1	4.2	8.3	64	3.2	9.3	2590	17.8	59
TF_02	20	106	85.3	2.8	6.9	59	3.4	6.8	1198	11.4	11

Table A3. Dominant weed species in the 2021 farms at the onset of stem extension and at crop anthesis

Farm	Dominant weed species at stem extension	Dominant weed species at crop anthesis
GL_04	Data not collected	Data not collected
MK_01	Data not collected	Data not collected
SN_02	Data not collected	Data not collected
TF_02	Data not collected	Data not collected

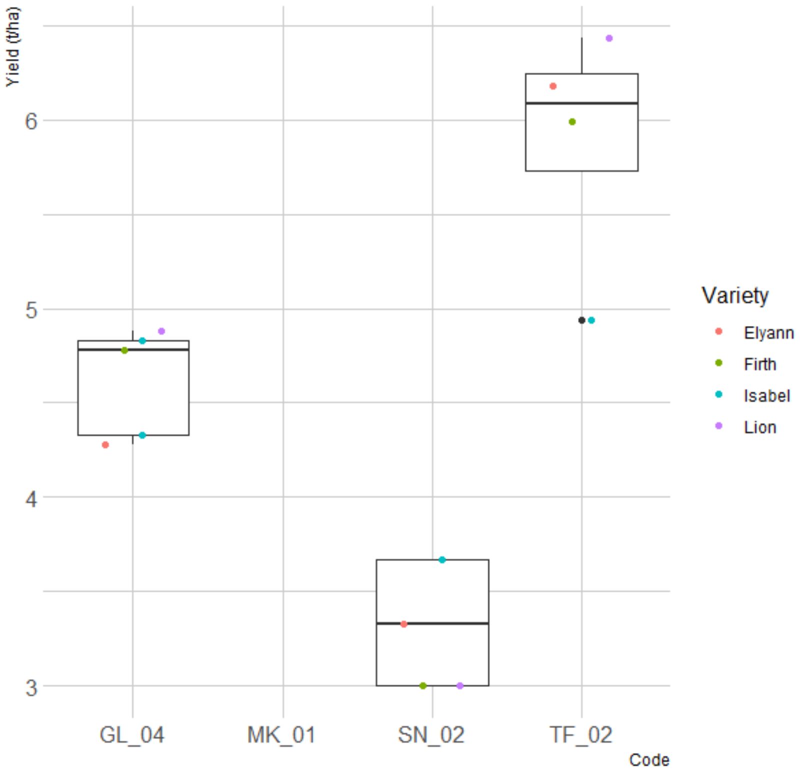

Figure A2 Crop yield by farm and Cultivar showing the Isabel outlier at TF_02

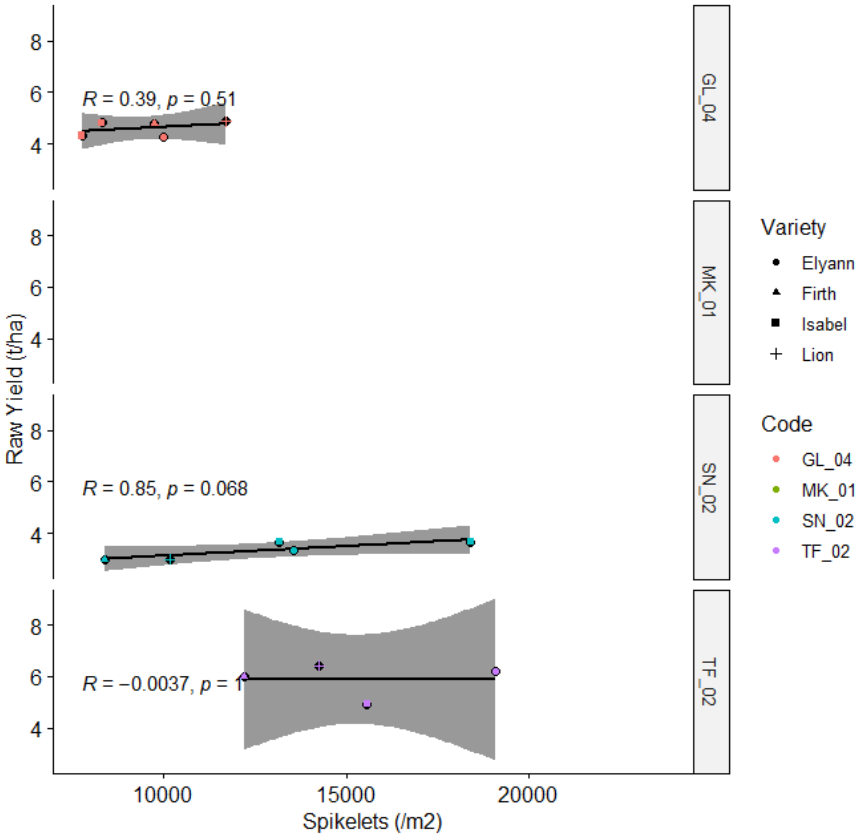

Figure A3. Relationship between spikelet density and yield by Farm, showing the inconsistent result for cv. Isabel at TF_02.

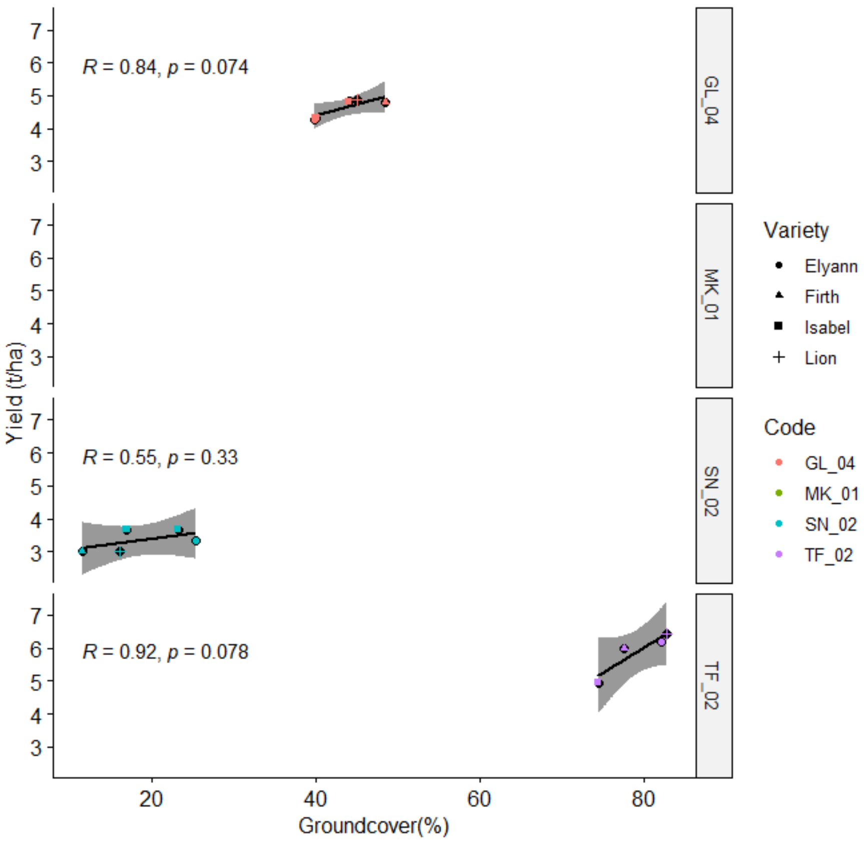

Figure A4. Relationship between crop groundcover and yield by Farm

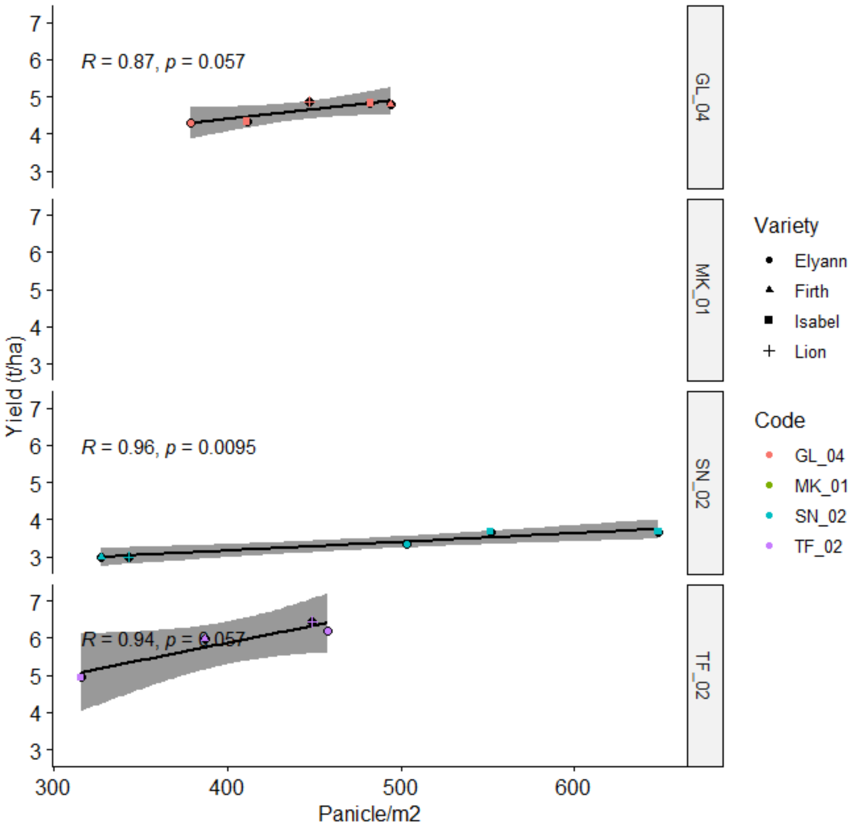

Figure A5. Relationship between panicle density and yield by Farm

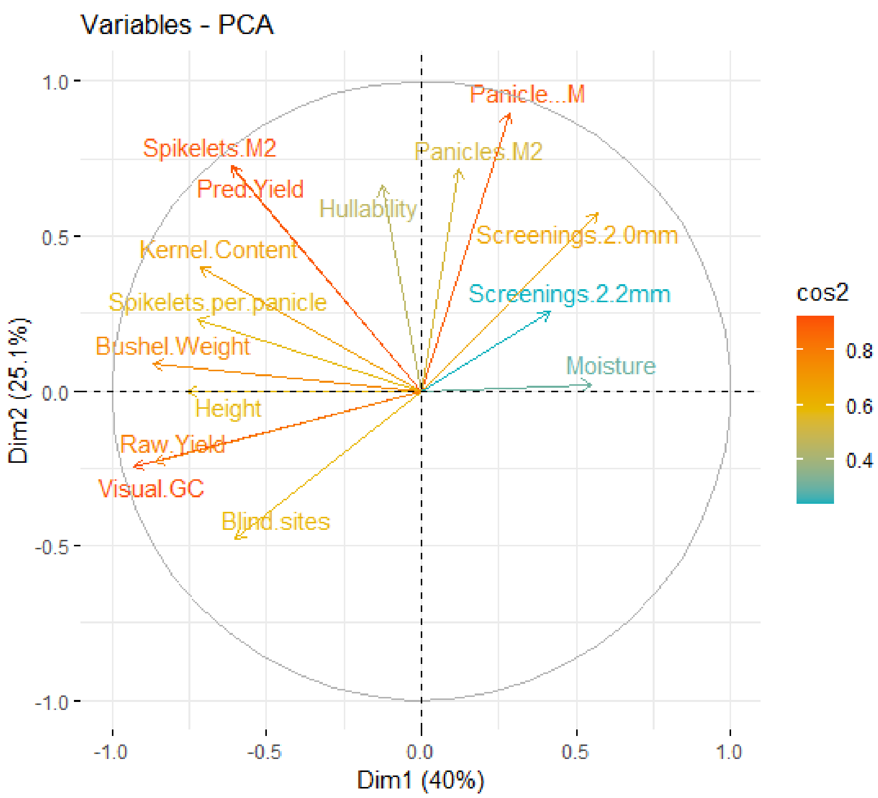

Figure A6. Principle component analysis showing the relationship between variables during the 2021 season.