Characterisation of yield components for wheat grain yields of 13 to 17 t/ha across three sowing dates in Canterbury, New Zealand.

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Abstract

High wheat yields are pursued globally to improve profitability, efficiency and resilience of grain production. Quantifying yield component targets provides a method to identify management strategies to achieve the desired number of heads/m^2 to maximise the number of grains/m^2. However, there is a lack of description of yield component targets for grain yields above 10 t/ha, which limits management decision making. This research quantified the number of heads and grains/m^2, number of grains/heads and grain size of wheat crops that yielded over 12 t/ha. The wheat cultivars 'Kerrin', 'Graham', 'Voltron' and 'Sorrial' were sown on the 27th of March, 19th of April and 18th of May in 2023 at Lincoln, New Zealand. Two extra cultivars, 'Stockade' and 'Cesario', were added in the last sowing date, as independent plots from the main experiment. Results showed that number of grains/m^2 was the component that corresponded to high yields. However, cultivars had different strategies to achieve their high number of grains/m^2 that determined final grain yield. Understanding these specific strategies can be used to develop cultivar specific management decisions to increase the efficiency of resource use.

Keywords

Number of grains, heads, thousand seed weight, grain size, components, yield, sowing dates

Introduction

Crop yield potential is a function of the genotype (G), with recent cultivars enabling the yield potential of the environment (E) to be met provided appropriate management (M) strategies are used. Therefore, the interaction of GxExM needs to be acknowledged in the pursuit of wheat grain yields above 10 t/ha. The Yield Enhancement Network (YEN) reported the results of 10 years of yield survey in the United Kingdom (YEN 2023). They found a "farm factor" (Silvester-Bradley et al. 2019), related to social and behavioural aspects of farming, was a significant contributor to yield. These could be argued as influencers of decision-making and hence, could affect the quality of management decisions and strategy used. Aspects such as pairing cultivars to sowing dates, with target dates for Z31 and Z61, plant population of ~180 plants/m^2, targets of 600 fertile tillers/m^2 and ~20 spikelets/head were needed for yields of ~15 t/ha, within the surveyed environments (YEN 2023).

Slafer et al. (2021) pointed out that yield components analysis are useful for retrospective analysis of yield but not for yield prediction, as they are a response to management strategies. However, benchmark targets for yield components are useful to guide management adaptations to support the targets identified in high yielding crops. The requirement is for non-limiting growth conditions to achieve potential yields and limit the feedbacks that can characterise the compensation that occurs among components (Slafer et al. 2021).

A hindrance to understand how yield component targets can be set and attained is the lack of data that explains the strategies that modern cultivars use to construct their yields. As a result, generic management strategies are used across a wide range of cultivars, which may hinder the expression of cultivar characteristics using the adopted management. Beres et al. (2020) highlighted this problem discussing variety performance evaluations that quantify the actual yield, instead of the potential yield, as a consequence of constant and conservative management programs. Maximizing yield requires sowing cultivars that can take advantage of favourable environmental conditions and optimising their in-season management.

The aim of this study was to use sowing date to generate crops of different yield potential and identify yield component targets to characterise crop yields in high yielding environments. Cultivars with different phenological responses to sowing date may result in a range of strategies to maximise the number of grains/m^2, which is the key metric for yield characterisation (Slafer et al. 2014). Therefore, discerning strategies could lead to more appropriate, and cultivar specific, agronomic management to ensure yield potential is achieved in the field.

Methods

Experimental design and site

The experiment was a split-plot design with sowing date (SD) as the main plot and cultivar as the sub plot in four replicates. Each plot was 42 m^2 and SD1 was the 27th of March, SD2 the 19th of April and SD3 the 18th of May, 2023. The four cultivars were 'Graham', 'Kerrin', 'Sorrial' and 'Voltron'. The experimental area was in Iversen Field, at the Field Research Centre (FRC) at Lincoln University (43°38'52.4"S 172°27'57.1"E) Canterbury, New Zealand. Annual rainfall was 718 mm in 2023, which was 117 mm more than the 20-year long-term mean. The mean monthly temperature was 12.6˚C. More details about cultivars and site can be found in TeMang et al (2024).

Agronomy

The target plant population was 200 plants/m^2, sown in 15 cm rows at a target depth of ~5 cm. The measured residual soil N was 100 kg of N/ha and 270 kg of N/ha were applied as urea in splits of 100 kg of N/ha at Z30 and Z32. The third split of 70 kg of N/ha was at Z39 for each cultivar. Irrigation replaced evapotranspiration losses. The plant growth regulator (PGR) programme included an application of Stabilan® (chlormequat) at Z30 and a second application of Stabilan® and Moddus Evo® (trinexapac-ethyl). More detail about chemistry is available in TeMang et al. (2024).

Measurements

Final harvest occurred at physiological maturity. A quadrat of 1.5 m^2 of each plot was cut just above ground level and weighed. Sub-samples of ~10% of the total final harvest biomass were partitioned into leaf, stem, heads and dead material. Heads on each sub sample were counted, dried and threshed to calculate grain yield (t/ha). Yields are reported at 15% moisture content. All grains from the sub-sample were counted using a Pfeuffer Contador 2 seed counter. Grains were weighed to obtain thousand seed weight (TSW). The number of grains/m^2 was then calculated based on the average grain weight of each sample from the final harvest area of 1.5 m^2.

Data from all sowing dates for 'Graham', 'Kerrin', 'Voltron' and 'Sorrial' were analyzed as a split-plot ANOVA. Where the interactions were significant but F ratios were an order of magnitude less than first order effects, the interaction is shown and the main cause of systematic error attributed to the first order effect. Data obtained for 'Cesario' and 'Stockade' were analysed separately as a one-way ANOVA for SD3. All analyses used GenStat® 23rd edition. Means were separated using Bonferroni's test. When a significant interaction of the treatments was observed, means were subjected to Fishers Protected LSD (5%).

Results

Grain yield and number of grains/m^2

Grain yield (t/ha) was affected by the interaction (P = 0.041) between sowing date and cultivar. In SD1 'Kerrin', 'Graham' and 'Voltron' higher average yields than 'Sorrial' (Table 1). In SD2 'Kerrin' yielded more than 'Graham' and 'Voltron, while 'Sorrial' was not different to all three cultivars. In SD3 all cultivars averaged 15 t/ha grain yield.

Table 1. Final grain yield (t/ha), dried and at 15% mc, for 'Graham', 'Kerrin', 'Sorrial' and 'Voltron' sown on three dates in Canterbury, New Zealand during the season 2023/2024.

Cultivars	Yield				Grains/m^2			
	Sowing dates				Sowing dates			
	1	2	3	Mean	1	2	3	Mean
'Graham'	15.6^{bcd}	14.9^{abc}	15.5^{bcd}	15.3^{AB}	29290^{bc}	29590^{bc}	33470^{d}	30780^{A}
'Kerrin'	16.6^{cd}	17.3^{d}	15.3^{bcd}	16.4^{B}	33910^{d}	35805^{d}	35890^{d}	35200^{B}
'Sorrial'	12.9^{a}	16.5^{cd}	14.8^{abc}	14.8^{A}	24540^{a}	32290^{cd}	28380^{b}	28400^{A}
'Voltron'	15.1^{bc}	14.9^{abc}	14.3^{ab}	14.8^{A}	29040^{bc}	29415^{bc}	33680^{d}	30710^{A}
Mean	15.1	15.9	15.0		29190^{A}	31770^{B}	32855^{B}	
LSD(sd*cv)	2.05				3648			
LSD(cv)	1.13				2214			
LSD(sd)					1888			

LSD (sd*cv) and LSD (cv) refer to the least significant difference for the interaction between sowing date (sd) and cultivar (cv) and cultivars, respectively. Interaction means with the same lower case letters are not significantly different at P = 0.05.

These yields were all higher than the average yields of the same cultivars in the irrigated Cultivar Performance Trials (CPT) run by the Foundation for Arable Research (FAR) in Canterbury, for the season 2023/2024 (FAR 2024). The difference was 0.7 t/ha for 'Graham', 2.8 t/ha for 'Kerrin' and 0.2 t/ha for 'Voltron'. 'Sorrial' is not a commercial cultivar in New Zealand, hence not part of the CPT. There were no advantages for SD1 over SD2 or SD3. This contrasts to the data presented by Cragie et al. (2015) who presented a higher yield for March sowing dates. The yields in Table 1 for SD2 and 3 are higher than the yields for the April SD in 3 seasons presented by Craigie et al. (2015) though. It is important to note that the management strategies used, in this study and in Craigie et al. (2015), were common across sowing dates.

This raises the questioning of how appropriate generic management strategies can affect sowing dates that theoretically have higher yield potentials (Craigie et al. 2015).

The number of grains/m^2 was affected by the interaction (P = 0.034) between sowing date and cultivar. The interaction occurred because 'Kerrin' produced a consistently higher average of 35200 grains/m^2 across sowing dates but it was not different from 'Graham' and 'Voltron' in SD3. In addition, 'Sorrial' had the lowest grain number/m^2 in SD1 and SD3 but was higher than average in SD2 (Table 1). The YEN benchmark (YEN 2023) recommendation of at least 30000 grains/m^2 needed for yields of ~15 t/ha was exceeded (Tables 1) for all cultivars that reached yields of ≥15 t/ha, except the 28380 for 'Sorrial' in SD3.

Number of heads/m^2, number of grains/head and TSW

Table 2. Number of heads/m^2, number of grains/head and TSW (g) for 'Graham', 'Kerrin', 'Sorrial' and 'Voltron' sown on three dates in Canterbury, New Zealand during the season 2023/2024.

Cultivars	Heads/m^2				Grains/head				TSW			
	Sowing dates				Sowing dates				Sowing dates			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
'Graham'	628	701	750	693^B	46.8^{abc}	42.2^a	44.9^{abc}	44.6^A	48.1^f	45.3^{def}	41.6^{bc}	45.0^{BC}
'Kerrin'	540	608	602	583^A	62.9^f	58.9^{ef}	59.6^f	60.5^B	44.1^{cde}	43.6^{cd}	38.6^{ab}	42.1^A
'Sorrial'	566	601	573	580^A	43.3^{ab}	53.8^{de}	49.5^{cd}	48.9^A	47.4^f	46.1^{def}	47.0^{ef}	46.8^C
'Voltron'	600	657	698	652^B	48.3^{bcd}	44.9^{abc}	48.6^{bcd}	47.3^A	47.2^{ef}	45.6^{def}	38.2^a	43.7^{AB}
Mean	584^A	641^B	656^B		50.3	50.0	50.6		46.7^B	45.1^B	41.3^A	
LSD(sd*cv)					5.73				3.07			
LSD(cv)	37.2				3.12				1.87			
LSD(sd)	35.1								1.54			

LSD (sd*cv), LSD (cv) and LSD (sd) refer to the least significant difference for the interaction between sowing date and cultivar, for cultivar and for sowing date, respectively. Interaction means with the same lower case letters are not significantly different at P = 0.05

'Graham' and 'Voltron' averaged more (P < 0.001) heads/m^2 than 'Kerrin' and 'Sorrial' (Table 2). The mean observed in SD1 was lower (P = 0.007) than SD2 and SD3. A detailed study of tillering efficiency is needed to explain this, as earlier sowing dates tend to produce more tillers/m^2. This is a result of delaying the start of the reproductive phase, when tiller bud initiation stops (Baker and Gallagher 1983).

'Graham' and 'Voltron' required at least 600 heads/m^2 to achieve ~ 30000 grains/m^2 (Table 2). In most cases, 'Kerrin' achieved a higher number of grains/m^2 with fewer heads/m^2 than 'Graham' and 'Voltron'. Therefore, there was a distinction between the mechanisms used by these cultivars. This could indicate that management strategies that prioritise tillering potential, such as low (100 plants/m^2) plant populations (Evers et al. 2006), may advantage cultivars such as 'Graham' and 'Voltron', more than 'Kerrin'. During the 2023/2024 Mid Canterbury wheat competition, the majority (~60%) of autumn feed wheat was 'Graham' (Andreucci pers. comm.). All farms had a plant population of <150 plants/m^2, which confirms the current management strategy used within Canterbury benefits cultivars that can support more heads/m^2 throughout the season rather than cultivars that produce more grains/head, such as 'Kerrin' (Table 2).

The number of grains/head was affected by the interaction (P = 0.005) between sowing date and cultivar but the cultivar (P < 0.001) main effect was dominant (Table 2).

Thousand seed weight (TSW) was also affected by the interaction between cultivar and sowing date (P = 0.012). 'Sorrial' had consistent high TSW at 46.8 g, across sowing dates (Table 2). In SD2, all cultivars had a lower TSW than SD 1. Overall, seed size was lower for 'Kerrin' and 'Voltron', which was not different to 'Graham' that was not different to 'Sorrial'.

The benchmark proposed by the YEN (YEN 2023) of 40 to 60 grains/head to achieve at least 30000 grains/m^2 was confirmed by this experiment (Table 2). 'Kerrin' had consistently higher number of grains/m^2 (Table 1) and number of grains/head (Table 2). As a result, it consistently had lower TSW. This is in agreement with results summarised by Slafer et al. (2021), where a decrease in grain number is observed at higher number of grains/head. This is due to the hierarchy effect of grain number on the size of the grain (Slafer et al. 2021). 'Sorrial' however, was a cultivar that benefited from a larger grain size. This could be related to its lower number of heads/m^2 and lower number of grains/m^2 (Table 1).

Relationship of yield components

The strongest relationship (R^2 of 0.74) was between yield (t/ha) and number of grains/m^2 (Figure 1a). For every increase in number of grains/m^2, there was an increase of 0.2 kg of grain/ha. TSW was not related (R^2 = 0.08) to yield (Figure 1b). The second strongest relationship (R^2 = 0.76) was between TSW (g) and number of grains/m^2 (Figure 1d). This supports Slafer et al. (2014) because the relationship in Figure 1a shows that the number of grains/m^2 is influential on yield. Figure 1c and e indicate the previously mentioned strategy of 'Graham' and 'Voltron' (red regression). Extra data points are needed to confirm the relationship for 'Kerrin' but 'Graham and 'Voltron' seem to maintain the number of grains/heads (Table 2) as the number of heads/m^2 is the driver for number of grains/m^2 (R^2 = 0.60).

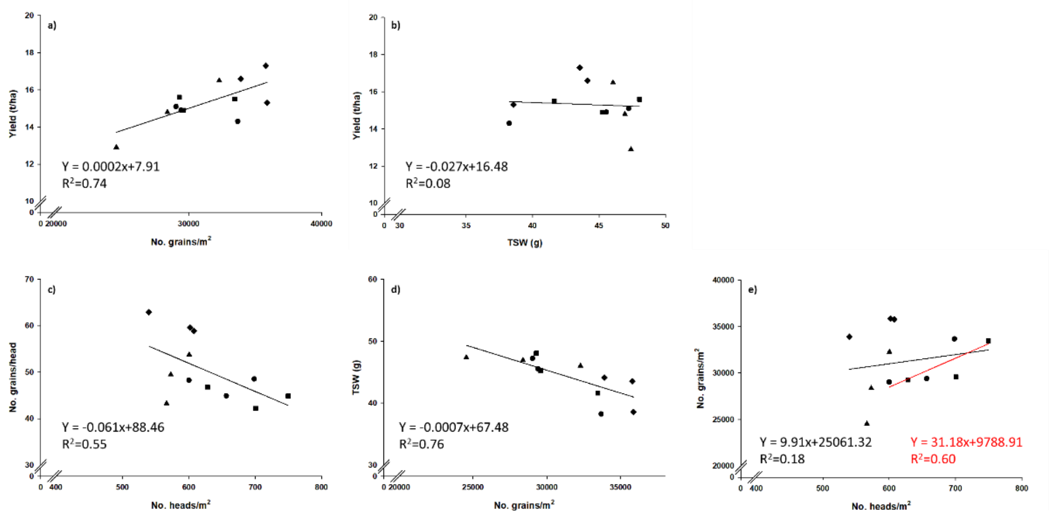

Figure 1. Relationships between yield components for a) yield (t/ha) and number of grains/m^2; b) yield (t/ha) and TSW (g); c) number of grains/m^2 and number of heads/m^2; d) TSW (g) and number of grains/m^2 and e) number of grains/head and number of heads/m^2 of 'Graham' (■, red line), 'Kerrin' (◆), 'Sorrial' (▲) and 'Voltron' (●, red line) sown on three dates in Canterbury, New Zealand during 2023/2024.

Conclusion

A number of grains/m^2 of between 28400 and 35000 is needed to guarantee yields of 15 t/ha or more. However, this number of grains will come from different strategies, which are cultivar dependent. 'Kerrin' prioritised the size of the heads, with more grains/head, while 'Graham' and 'Voltron' prioritised the number of heads/m^2. 'Sorrial' benefited from sowing dates where it increased the number of grains/m^2 due to more grains/head. Earlier sowing dates did not result in higher number of heads/m^2. In high yield environment, the size of grain still does not seem to be determinant as a yield descriptor. Yield components analysis can be a tool for yield diagnosis but still needs to be accompanied by more detailed descriptions of how tillering dynamics and efficiency affect the size and population of heads/m^2, especially for earlier sowing dates.

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