Increasing wheat productivity through the use of early sowing and new generation fungicides

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Abstract

The current world record grain yield for wheat (*Triticum aestivum*) is 15.63 t/ha and is held by a farmer in Southland, New Zealand. Pushing the boundaries of wheat productivity is the focus of a new research programme called 20 by 2020, which sets the objective of producing a 20 t/ha wheat crop by the year 2020. The research reported is part of this research programme. Seven cultivars of feed wheat were established on 30 March 2012 at Leeston, Canterbury and farmed with four levels of management, to examine the influence of germplasm and agronomic input on yield and individual yield components. Grain yields in the trial varied from 13.91-16.95t/ha and were strongly related to the number of grains per unit area. There were significant yield differences in cultivar performance which correlated to cultivar canopy duration and level of leaf rust infection (*Puccinia recondita*). Applying fungicide programme based on succinate dehydrogenase inhibitors (SDHI) did not increase grain yield over the triazole standard when compared at the lower nitrogen (N) level tested (138 kg N/ha), but gave a significant yield advantage over the triazole programme (0.53 t/ha averaged over seven cultivars, range 0.25-1.14 t/ha) at the higher N level (240 kg N/ha). The highest yields (16.95 and 16.83 t/ha) were achieved with the later maturing cultivars Conqueror and Wakanui grown with the highest level of N 238 kg N/ha and fungicide input incorporating the new SDHI fungicides.

Additional keywords: succinate dehydrogenase inhibitor (SDHI) fungicides, triazole fungicides, yield components, green leaf retention, light interception

Introduction

The idea of extending the period of light interception of wheat (*Triticum aestivum* L.) to increase yield is one of the themes of a new research programme called 20 by 2020. The programme was developed by the Foundation for Arable Research, and has the ultimate goal of producing a wheat crop of 20 t/ha by the year 2020. This theme is, in part, inspired by the evidence that increasing the rate and duration of grain filling in wheat can result in improved grain weight and potentially yield (Spiertz, 1977). There are many agronomic tools currently available to extend the duration of green canopy and light interception. In the field the green canopy can be extended in duration by i) lengthening the growing season with the production of more leaves from sowing to maturity or ii) by better protecting the upper leaves of the canopy from premature senescence. The results presented in this paper combine both approaches. The tools for extending the duration of the green canopy include earlier sowing, cultivars with longer season phenology, disease management, irrigation, and fertilisers.

The flag leaf is noted to be the most important organ related to yield as it is the primary source of assimilates for grain filling due to its proximity to the spike and because it stays green longer than the other leaves (Reynolds *et al*., 2000; Ali *et al*., 2010). Recent progress in wheat yields have been seen with improved fungicides such as strobilurins (Gooding *et al*., 2000; Bertelsen *et al*., 2001; Ruske *et al*., 2003) and succinate dehydrogenase inhibitors (SDHI) (Berdugo *et al*., 2012). When applied at the start of stem elongation, leaf three emergence (flag-2), flag leaf, and ear emergence, fungicides can effectively control foliar diseases (Cromey *et al.*, 2004; Poole, 2009) as well as induce physiological changes that promote yield (Wu and Tiedemann, 2001; Jones and Bryson, 1998). The basic advantage of fungicides is the control of the disease-causing organisms that utilize carbohydrates in the plant that could otherwise be accumulated in the grains, but the subsequent benefits are delayed senescence and longer green leaf area duration (Lorenz and Cothren, 1989; Wu and Tiedemann, 2001; Cromey *et al*., 2004). Yield enhancements as a result of delayed senescence and a longer grain fill period were reported by Spiertz (1977) who saw a growth rate of 204 to 230 kg/ha per day from milk-ripe to dough-ripe stage. Strobilurin application has been seen to have the added benefit of improved soil N intake (Bryson, 2000; Ruske *et al*., 2003). In a recent study by Berdugo *et al.* (2012) in disease-free conditions, succinate dehydrogenase inhibitors (SDHI), strobilurin, and triazole fungicides all extended the duration of green leaf area compared with untreated plants, with the SDHI treatment having a significantly higher yield than all other treatments.

In New Zealand, leaf rust (*Puccinia recondita*) and septoria leaf blotch (characterized by the presence of the *Septoria* state of *Mycosphaerella graminicola*) are two prominent diseases affecting yield in wheat crops (Wallwork, 2000). Strobilurin and triazole fungicides have been effectively used to control these diseases in NZ (Poole, 2009), and the recent introduction of SDHI fungicides to the country presents another effective option with a different mode of action (FRAC Group 7). Strobilurins (Godwin *et al*., 1994) and SDHI (McKay *et al*., 2011) fungicides exhibit preventative control of fungal pathogens while triazoles are curative and are effective after fungal infection (Hanssler and Kuck, 1987).

An early sowing date in combination with a longer season phenology is a potential avenue for extending the duration of light interception and increasing productivity. FAR trials have shown 1 t/ha yield benefits to sowing wheat in April compared with May (FAR, 2002). More recently, a further 1 t/ha was gained by sowing in mid to late March compared with April or May (FAR, 2013). This research programme explores advancing yield benefits by sowing wheat in March and as early as February. However, agronomic management regimes need to be uniquely designed to fit the system in order to optimize the benefits. Yield consequences often depend on cultivar characteristics such as disease susceptibility and season phenology. The objective of the present study was to maximise the yield from early sown winter wheat by assessing the value of new SDHI fungicides and increased N inputs in a selected set of United Kingdom and New Zealand cultivars. Here, seven cultivars of feed wheat were compared at four levels of management to examine the influence of germplasm and agronomic input on yield and individual yield components.

Materials and Methods

Trial Design and Management

A field study was conducted in 2012/13 in Leeston (43° 45’ 52’’ S, 172° 15’ 33’’ E), in Central Canterbury on a Temuka silt loam. The paddock was previously planted in peas. Prior to N application, soil mineral N to 60 cm was assessed and reported to be 75 kg N/ha. Plots were sown on 30 March 2012 using a disc coulter plot drill with 15 cm row spacing, and were 11 m x 1.65 m. The trial design was a split plot design with four distinct management strategies as the main plots and seven cultivars as subplots, replicated four times. The trial was maintained as per the farmer’s management of the paddock, with the exception of fungicides. Farmer management involved weed control with an application of Firebird® (0.5 l/ha) (active ingredient (a.i.). flufenacet, diflufenican) (Bayer Crop Science) on 8 April, Othello® OD (1.0 l/ha) (a.i. diflufenican, mesosulfuron methyl, iodosulfuron methyl sodium) (Bayer Crop Science) on 30 June, and a mixture of Twinax® (0.3 l/ha) (a.i. pinoxaden) (Syngenta) and Starane™ Xtra (0.75 l/ha) (a.i. fluxoypyr) (Dow AgroSciences) on 9 September. The trial was not irrigated.

Treatments

The four management levels were selected to compare a basic triazole fungicide program with a new SDHI and strobilurin program, with or without an increased N application (Table 1). Timings of fungicide applications were a basic four spray program applied at the start of stem elongation, second node (leaf three (flag -2) emergence), flag leaf, and ear emergence (equivalent to Zadoks growth stages 30, 32, 39 and 59 (Zadoks *et al*., 1974)). Triazole fungicides used in the trial were Cherokee® (a.i. cyproconazole, propiconazole, chlorothalonil) (Syngenta), Opus® (a.i. epoxiconazole) (BASF), and Prosaro® (a.i. prothioconazole, tebuconazole) (Bayer Crop Science). Amistar® Opti (a.i. azoxystobin, chlorothalonil) (Syngenta) and Comet® (a.i. pyraclostrobin) (BASF) were the strobilurin fungicides used. The SDHI fungicide used in the trial was mixed with a triazole and is not currently registered in New Zealand, so it is referred to as FAR11/F1. The four cultivars (‘Wakanui’, ‘Phoenix’, ‘Claire’, and ‘Empress’) used in this trial are established in the New Zealand market. They were chosen because they are generally high yielding with the potential to perform well when sown early, due to being intermediate to late maturing cultivars. The remaining cultivars (‘Conqueror’, ‘Kingdom’, ‘Stigg’) were selected by collaborating NIAB TAG scientists in the UK for similar reasons for intercontinental trial comparisons (not discussed here). Fungicide treatments were applied using a 12V electric pump backpack type plot sprayer and a hand held boom with flat fan spray (4 x 110° 015 and 2 x 65° 01) nozzles, applying water at a rate of 250 l/ha. Nitrogen in the form of urea was applied to the whole trial at a rate of 138 kg/ha over a split application on 17 September and 9 October 2012. The additional 100 kg/ha of N was added by hand spreading in individual plots in the form of granular urea.

Assessments

Visual scores of crop canopy greenness were made at hard dough stage on 10

January on the basic fungicide (no Extra N) and SDHI fungicide + Extra N management treatments only. This assessment was conducted on a subjective 1-7 point scale (1 being least crop canopy senescence and 7 as most crop canopy senescence) on 1 replicate only. There were no further assessments of length of growing season or differences in growth stage at the late grain fill stage. At hard dough stage on 11 January 2013, disease scores were recorded on ten representative flag leaves from each plot. Each flag leaf was assessed for percentage of leaf area affected (% LAA) by leaf rust (LR) and septoria leaf blotch (SLB) (Figures 2a and 2b). Head counts were made on 4 February 2013 by counting the number of harvestable heads in two drilled rows over 0.6 m (0.18 m^2) at two points in each plot. All plots were harvested 10 February 2013 with a "Sampo" plot combine with on-board weighing and moisture testing equipment. A 1.0 kg subsample of grain from each plot was retained for quality testing. Quality testing was completed by the New Zealand SeedLab (Christchurch, New Zealand) and included protein analysis using near-infrared spectroscopy, screening percentage with a 2.0 mm Rota-screen, thousand grain weight (TGW), and test weight. Grain number (grains/m^2) and number of grains per ear were calculated from the head count and TGW data.

Data Analysis

Analysis of variance (ANOVA) was conducted on yield, disease scores, and quality components. Least significant difference (LSD) (α=0.05) test was used for means separation.

Table 1: Schedule of inputs for early sown wheat in Leeston, Canterbury in the 2012/13 growing season. Growth stages (GS) are in reference to the Zadok's scale.

Treatment	GS 30 (28 Aug 2012)	GS 32 (10 Oct 2012)	GS 32-33 (23 Oct 2012)	GS 39 (21 Nov 2012)	GS 59 (4 Dec 2012)
Basic fungicide	Cherokee® (0.75 l/ha)	Opus® (0.5 l/ha) + Bravo® 720 (0.7 l/ha)	-	Opus® (0.75 l/ha) + Bravo® 720 (1.0 l/ha)	Prosaro® (0.6 l/ha)
SDHI fungicide	Cherokee® (0.75 l/ha) + Amistar® Opti (0.75 l/ha)	FAR11/F1 (1.0 l/ha) + Bravo® 720 (0.7 l/ha)	-	FAR11/F1 (1.5 l/ha) + Bravo® 720 (1.0 l/ha)	Prosaro® (0.6 l/ha) + Comet® 250 (0.4 l/ha)
Basic fungicide + Extra N	Cherokee® (0.75 l/ha)	Opus® (0.5 l/ha) + Bravo 720 (0.7 l/ha)	Additional N (100 kg/ha)	Opus® (0.75 l/ha) + Bravo® 720 (1.0 l/ha)	Prosaro® (0.6 l/ha)
SDHI fungicide + Extra N	Cherokee® (0.75 l/ha) + Amistar® Opti (0.75 l/ha)	FAR11/F1 (1.0 l/ha) + Bravo® 720 (0.7 l/ha)	Additional N (100 kg/ha)	FAR11/F1 (1.5 l/ha) + Bravo® 720 (1.0 l/ha)	Prosaro® (0.6 l/ha) + Comet® 250 (0.4 l/ha)

Note reference to a product in the table does not necessarily constitute a commercial label recommendation in New Zealand, since work was a collaboration with the NIAB TAG in the UK using identical chemistry

Results

Yields

Grain yields at harvest (corrected to 14% moisture) ranged from 13.91-16.95 t/ha (Table 2), with significant differences due to cultivar and management strategy (p<0.001). The two cultivars observed to have the least crop canopy senescence in both the highest and lowest input treatments on 10 January (Wakanui and Conqueror) were significantly higher yielding (16.12 and 16.08 t/ha respectively) than the other five cultivars in the trial when yield performance was averaged over the four management strategies. It is assumed that differences in crop canopy senescence were linked to cultivar maturity, Wakanui and Conqueror being later maturing cultivars, however this cannot be confirmed since no detailed assessment of crop development stage was carried out. Phoenix was significantly lower yielding than all other cultivars when grain yield was averaged over the four management approaches (14.56 t/ha).

Table 2: Wheat grain yield for seven cultivars grown under four management programmes in the 2012-2013 growing season in Leeston, Canterbury.

	---------------------Yield (t/ha)---------------------				
	Basic	SDHI	Basic + N	SDHI + N	Cultivar Mean
Conqueror	15.61	15.95	15.81	16.95	16.08
Empress	14.95	14.88	15.49	15.74	15.26
Wakanui	15.86	15.41	16.37	16.83	16.12
Stigg	14.51	14.29	15.49	15.90	15.05
Phoenix	14.24	13.91	14.82	15.27	14.56
Kingdom	14.66	14.96	15.46	16.04	15.28
Claire	15.21	15.40	15.95	16.39	15.74
Management Mean	15.01	14.97	15.63	16.16	15.44
	Management	Cultivar	Cult x Man		
p-value	<0.001	<0.001	0.039		
LSD (p=0.05)	0.39	0.23	0.45/0.57[1]		
CV (%)	2.4				

[1]LSD's for significant Management x Cultivar interactions are presented as within management level/between management levels

Grain yields for individual cultivars responded differently to the four management strategies and there was a significant interaction between cultivar and management (p=0.039) (Figure 1). None of the cultivars tested at the standard N level (138 kg N/ha) showed a significant increase to the use of SDHI fungicides (comparing cultivar yield means for SDHI (fungicide) with Basic (fungicide) means both programmes averaging approximately 15 t/ha). Cultivar yield response to additional N ranged from 0.2-0.98 t/ha (average 0.62 t/ha), and only four cultivars (Stigg, Phoenix, Kingdom and Claire) showed a significant increase to an additional 100 kg N/ha added at the second to third node growth stage (GS32-33). The three cultivars (Conqueror, Empress and Wakanui) that did not respond to additional N alone did give a significant yield increase over the Basic fungicide treatment when additional N and SDHI were applied in combination. With Conqueror, which was the most leaf rust susceptible of the seven cultivars, an extra 100 kg N/ha added to the crop resulted in increased LR flag leaf infection from 8.4 to 16.5% and Septoria leaf blotch from 3.3 to 4.9% (not significant) (Figure 2a and 2b), however under an SDHI fungicide programme LR infection was reduced down to 1.2% and Septoria leaf blotch to 0.8%. Kingdom responded to additional N and had a further significant yield increase in response to the addition of an SDHI fungicide programme (comparing the yield means of SDHI + N with Basic + N). Where the SDHI fungicide programme was used with the additional N, the range in cultivar yield response over the Basic fungicide programme was 0.79-1.39 t/ha (average 1.19 t/ha). A delay in crop canopy senescence was observed in plots treated with an extra 100 kg N/ha and SDHI fungicide, but it is not possible to confirm whether these inputs delayed crop development as no detailed measurements of crop development were taken during grain fill.

When the same additional N was superimposed on the SDHI fungicide programme there was a significant grain yield increase of 1.0 t/ha with Conqueror and LR infection was not significantly increased (0.4 to 1.2%). In contrast, more disease resistant cultivars, such as Stigg, that recorded no LR infection on the flag leaf gave significant yield increases to the additional N but there was no advantage to the SDHI fungicide programme over the basic fungicide programme.

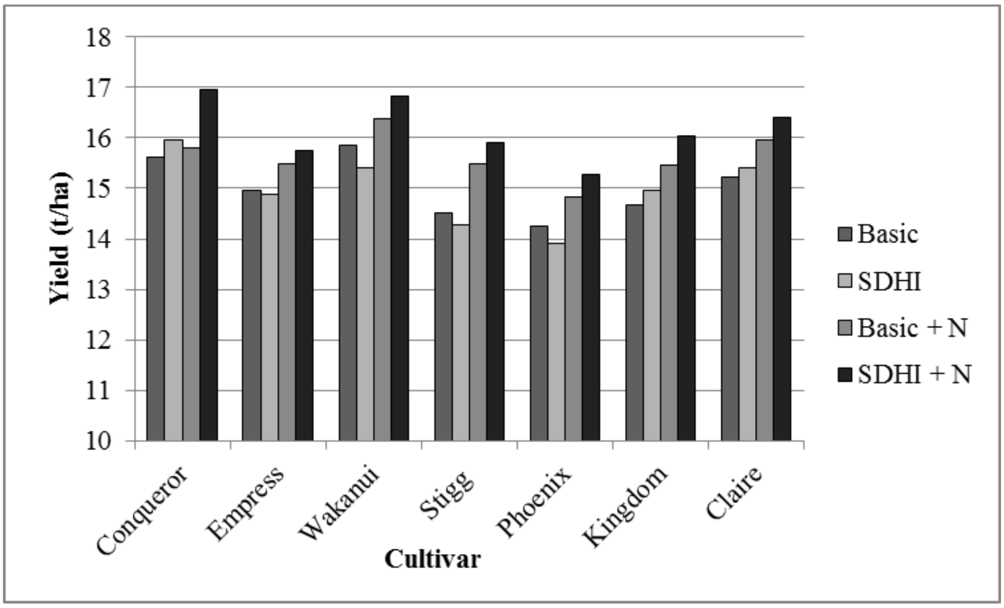

Figure 1: The interaction between seven wheat cultivars and four management input programmes on the yield of grain. LSD within management level = 0.45; LSD between management level = 0.57.

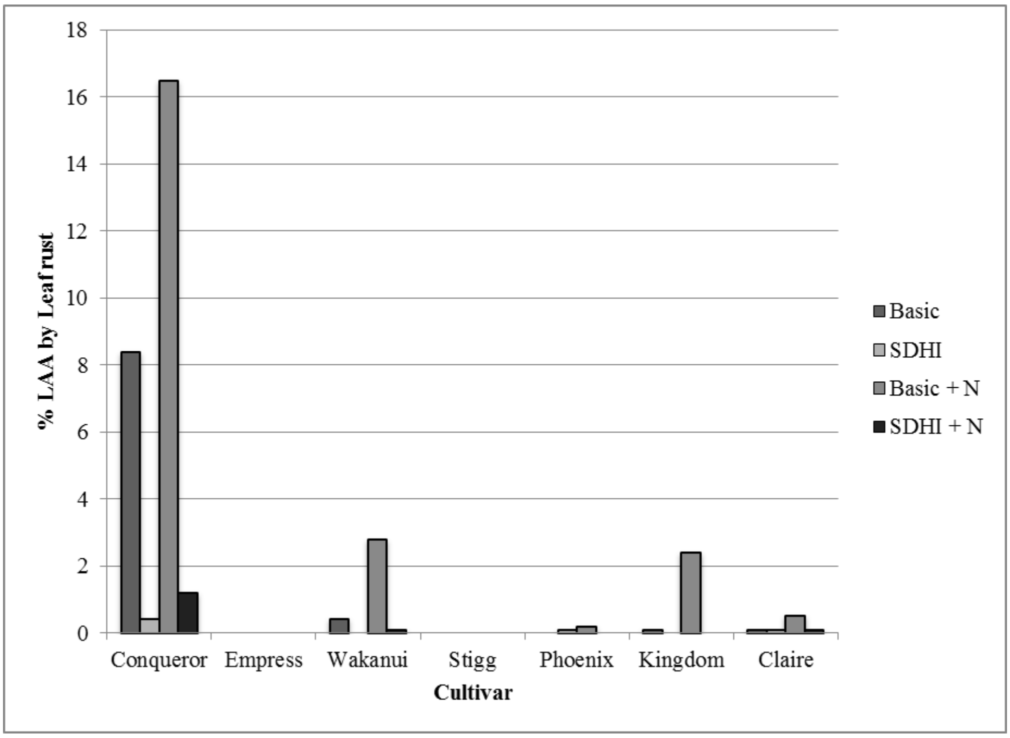

Figure 2a: Leaf rust disease scores, shown as percentage of leaf area affected (LAA), for flag leaves collected from wheat plants of seven cultivars grown under four management programmes in the 2012-2013 growing season in Leeston, Canterbury.

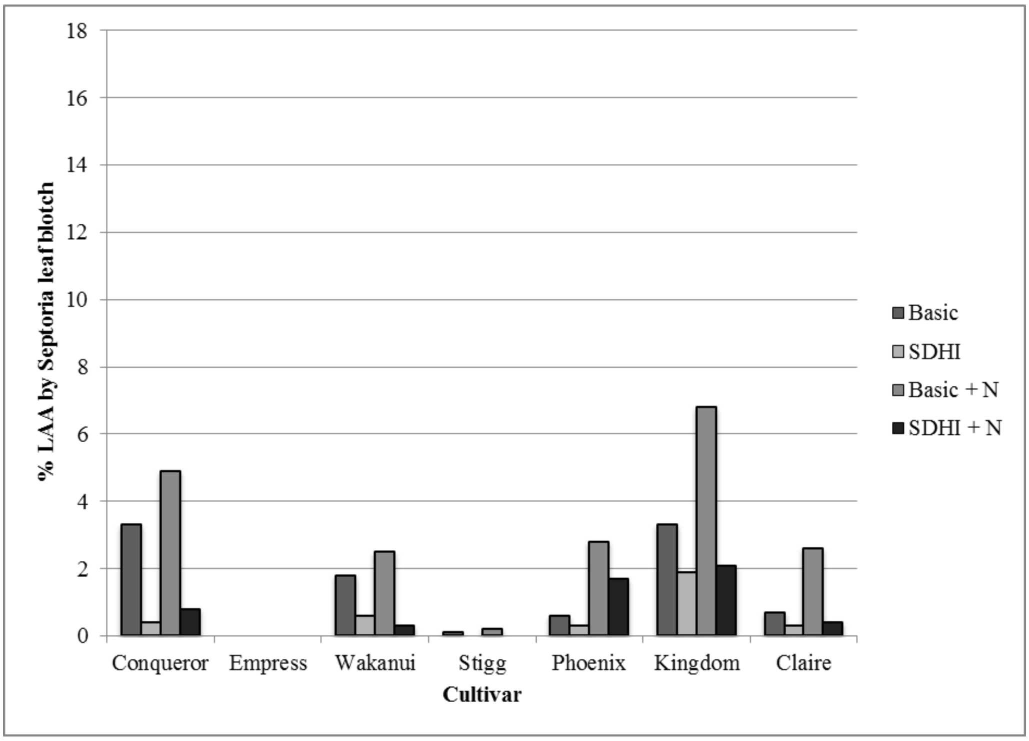

Figure 2b: Septoria leaf blotch disease scores, shown as percentage of leaf area affected (LAA), for flag leaves collected from wheat plants of seven cultivars grown under four management programmes in the 2012-2013 growing season in Leeston, Canterbury.

Yield components

There were no significant differences in head number when all cultivars and management treatments were compared. There was an average head number in the trial of 583 heads/m^2. There were significant differences ($p<0.001$) in TGW when all treatments were compared, however these differences were greatest when cultivars were compared rather than management treatments. In terms of management treatment (mean of seven cultivars) there was a range in TGW of between 58.5-60.75 g, whereas cultivars (mean of four managements) ranged from 54.4-66.6 g (data not shown). The lowest TGW's on average were produced by the cultivar Empress (54.4 g), which was significantly lower than all other cultivars and the highest by Phoenix (66.6 g). All other cultivars gave TGW which averaged between 58-60 g. In contrast, the calculated grains number per head for Phoenix was the lowest (mean 38.8 grains/ head). The two highest yielding cultivars Conqueror and Wakanui recorded the highest grain number per head (47.5 grains/head), though this was not significantly superior to Empress and Claire.

Combining the yield components revealed that higher grain number/m^2 was a major controller of grain yield in the trial results (Figure 3a), and that with the Phoenix and Empress the relationship was upheld at different thousand grain weights from the mean. In general, although not entirely consistent, there was a relationship between grain number per m^2 and grains per head (Figure 3b). There was no clear relationship between grain yield and grain weight or between grain number and head number (Figure 3c & 3d). Overall, for some cultivars the relationship between grain yield and grains per head was relatively good e.g. Phoenix and Stigg, however for others, such as Conqueror and Wakanui the relationship was weak and yield increases look to be more associated with changes in thousand grain weight and head number (Figure 3e). The highest grain numbers per m^2 were recorded with the management strategy that included an extra 100 kg N/ha and an SDHI based fungicide programme. The cultivars Conqueror and Wakanui (averaged over all management levels) produced significantly more grains per m^2 than all cultivars except Empress (27,622 and 27,160 respectively).

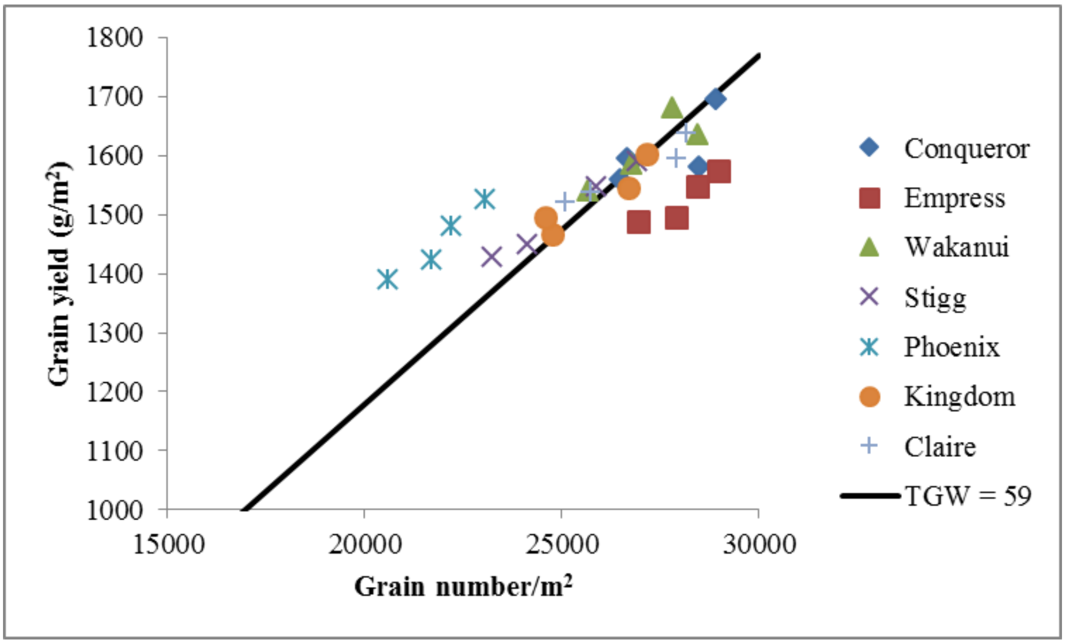

Figure 3a: Relationship between grain yield (g/m^2) and grain number (grains per m^2) in the seven cultivars.

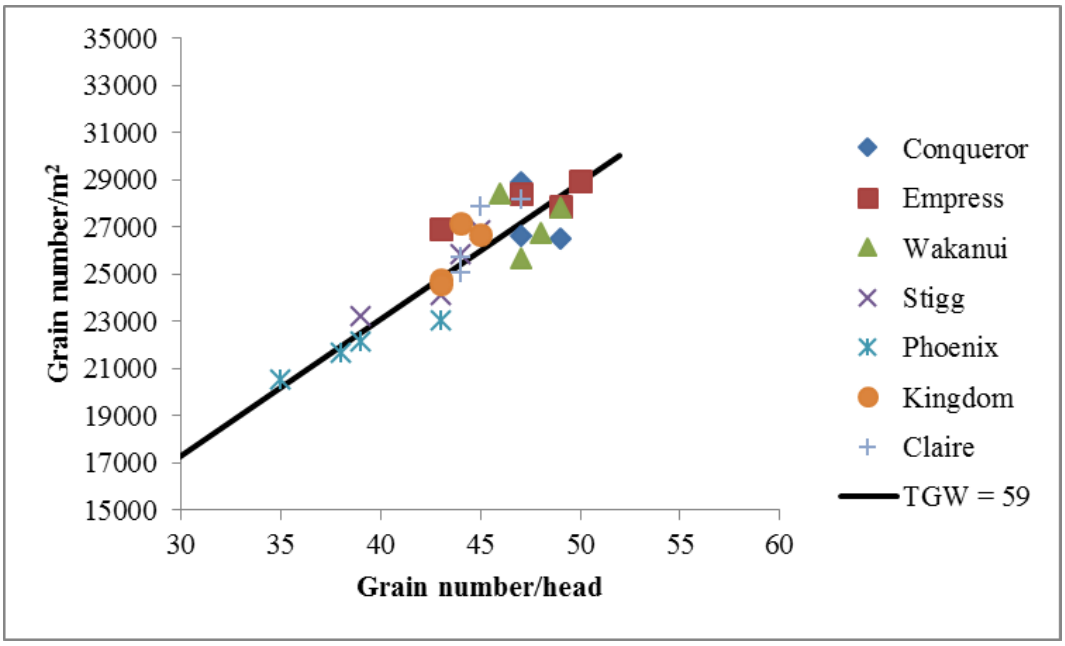

Figure 3b: Relationship between grain number (grains/m^2) and grain number per head in the seven cultivars.

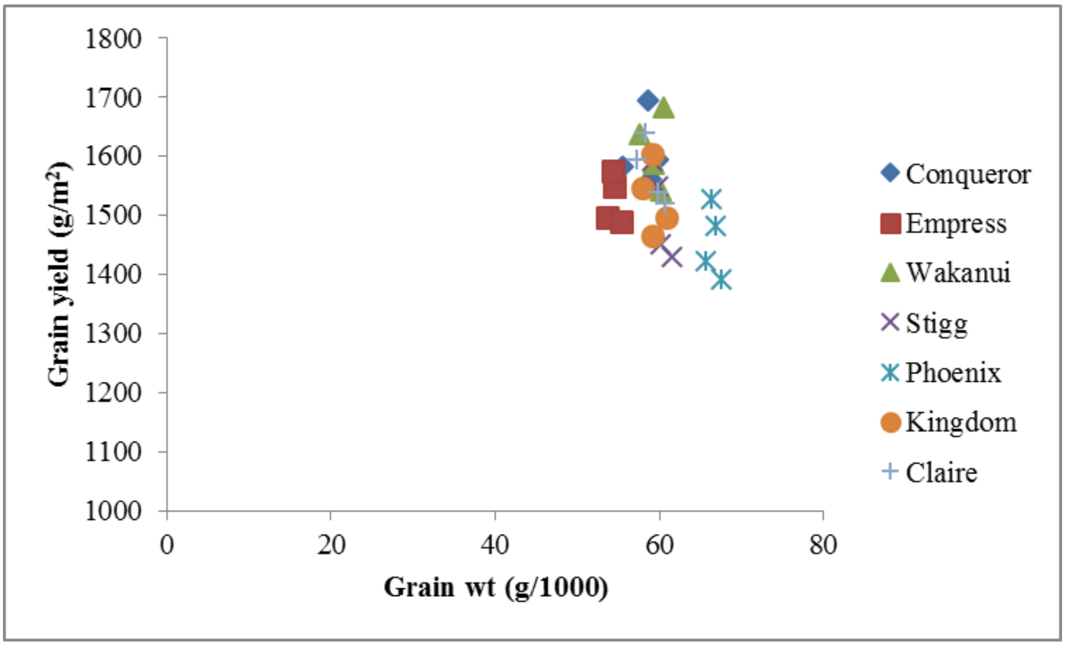

Figure 3c: Relationship between grain yield (g/m^2) and grain weight (Thousand grain weight g) in the seven cultivars.

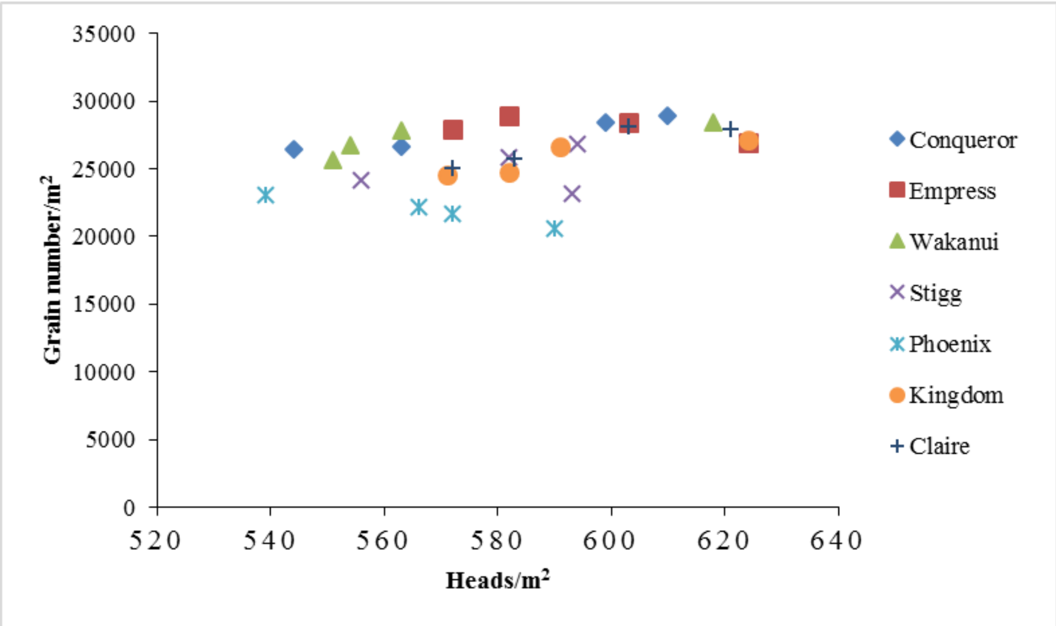

Figure 3d: Relationship between grain number (grains/m^2) and head number (heads/m^2) in the seven cultivars.

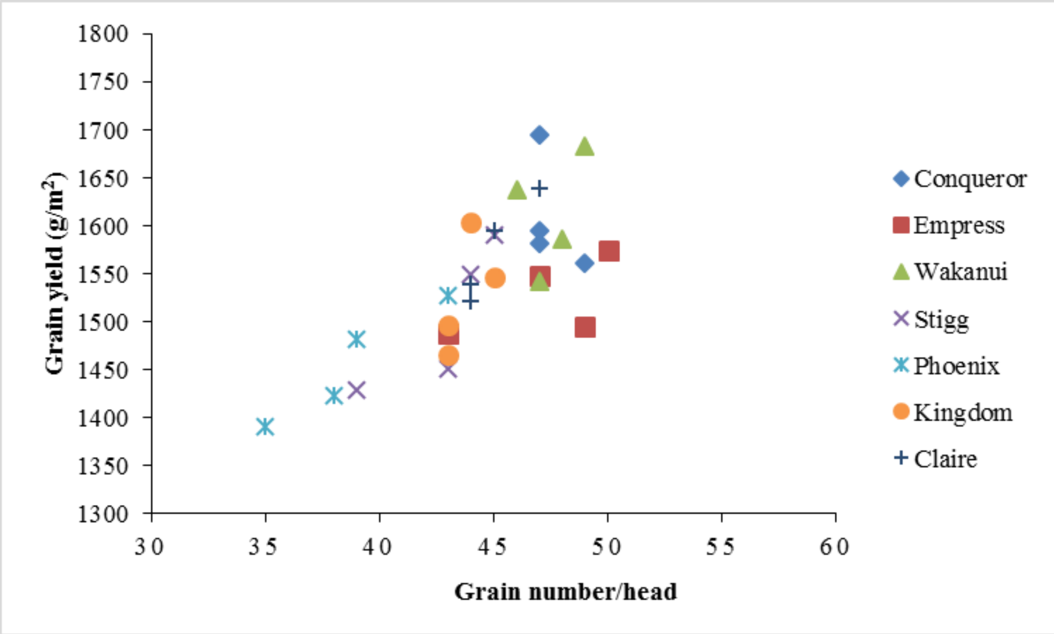

Figure 3e: Relationship between grain yield (g/m^2) and grain number per head in the seven cultivars.

Grain Quality

There were differences in grain quality due to cultivar. Increasing N application resulted in significantly higher protein (1.0-1.3%) and significantly lower TGW when results from all cultivars were averaged (Table 3). There were no differences in screenings and test weight due to management treatment.

Table 3: Grain quality for seven wheat cultivars under four management programmes in the 2012-2013 growing season in Leeston, Canterbury.

Management	Cultivar	Screen %	TGW g	Test weight kg/hl	Protein %
Basic fungicide	Conqueror	0.35	58.9	75.0	8.1
	Empress	0.18	53.6	76.1	9.3
	Wakanui	0.15	59.3	78.4	9.1
	Stigg	0.13	60.1	74.5	9.0
	Phoenix	0.10	65.7	77.2	9.8
	Kingdom	0.20	59.2	78.9	8.5
	Claire	0.20	60.7	76.5	9.1
SDHI fungicide	Conqueror	0.28	59.9	75.8	8.4
	Empress	0.15	55.3	76.9	9.5
	Wakanui	0.15	60.1	79.2	9.2
	Stigg	0.20	61.6	75.4	9.1
	Phoenix	0.13	67.6	78.0	10.1
	Kingdom	0.20	60.9	80.0	8.9
	Claire	0.20	59.9	77.0	9.5
Basic fungicide + Extra N	Conqueror	0.45	55.6	75.4	9.4
	Empress	0.18	54.5	77.6	10.6
	Wakanui	0.15	57.6	79.2	10.0
	Stigg	0.20	59.9	75.2	10.4
	Phoenix	0.15	66.8	78.2	11.0
	Kingdom	0.20	58.0	79.9	10.1
	Claire	0.15	57.2	77.3	10.3
SDHI fungicide + Extra N	Conqueror	0.33	58.6	76.2	9.4
	Empress	0.20	54.3	77.5	10.6
	Wakanui	0.18	60.5	79.7	9.8
	Stigg	0.20	59.2	75.5	10.2
	Phoenix	0.18	66.3	78.3	11.1
	Kingdom	0.25	59.1	80.2	10.1
	Claire	0.20	58.2	77.5	10.1
	Mean	0.20	59.6	77.4	9.7
	p-value	<0.001	<0.001	<0.001	<0.001
	LSD	0.12	2.2	0.8	0.4
	%CV	42.4	2.6	0.7	3.2

Discussion

Early sowing (30 March) seven wheat cultivars and subjecting them to four levels of management with varying amounts of nitrogen and fungicide input resulted in wheat plot yields higher than any previously recorded by FAR (range 13.91-16.95t/ha). The highest nitrogen input (238 kg N/ha) combined with a SDHI fungicide programme produced the highest grain yields (15.27-16.95 t/ha). Increasing yield in the trial was strongly correlated to higher grain number per unit area (r^2=0.65), which was in turn related to higher grain numbers per head, although the relationship between increased yield and increased grains per head was not consistent across all cultivars (r^2=0.57), being stronger in cultivars such as Phoenix and Stigg. The relationship between increasing yield and head number was much weaker, but there was evidence that increasing head number (540-610 heads/m^2) was more important with cultivars such as Conqueror. The influence of nitrogen on crop canopy duration and subsequent disease pressure played a key role in the results generated. Increasing N application (to 238 kg N/ha) increased green leaf retention, grain yield and disease pressure compared to the lower N level (138 kg N/ha). In order to maintain the green leaf retention observed at higher N inputs it was essential to keep the crop disease free and employ a more robust fungicide programme than the basic four spray triazole based programme. The use of the SDHI fungicide programme gave significantly better control of both leaf rust and Septoria leaf blotch than the basic fungicide programme at the higher N level and as a consequence significantly better yield. This was particularly the case with the leaf rust (*Puccinia recondita*) susceptible cultivar Conqueror and the Septoria susceptible cultivar Kingdom.

Conclusion

In conclusion, pushing wheat yields past the current global boundaries was dependent on maximising green leaf retention during grain fill, which was achieved by optimising cultivar selection for longer growing seasons and fungicide protection in order to keep the extended green leaf retention free from disease. This is particular important for cultivars that have a weakness in foliar disease resistance as was the case with Conqueror in this trial. Although not tested in this research trial it would be imperative to have the soil water availability in order to support a crop canopy that has the potential to grow for longer between sowing and maturity. Research in 2013 will repeat this work with the use of irrigation.

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