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Contents:

Barley and ryegrass competition

Project code X22-01-02

Duration Year 1 of 3 (2023-24 season)

Authors Ben Harvey, Matilda Gunnarsson, Charles Merfield (FAR)

Location Chertsey Research Site, Mid-Canterbury (irrigated, 43°47'36.33"S, 171°57'38.02"E)

Funding FAR

Acknowledgements NZ Arable (trial management)

Key points

1. Ryegrass resistance to herbicide Mode of Action (MoA) Groups 1 and 2 is an increasing challenge both for perennial ryegrass seed and cereals crops such as barley.
2. Better understanding competition between perennial ryegrass and barley is important for determining competitive and economic thresholds for integrated weed management.
3. Autumn barley (cultivar (cv.) SY Silhouette) was under sown with five rates of perennial ryegrass cv. Nui giving five populations from 2 to 1,125 ryegrass plants/m^2.
4. While increasing ryegrass populations did not significantly reduce barley plant populations, there was a large reduction in yield from 11.55 t/ha for the lowest ryegrass population to 7.75 t/ha for the highest ryegrass population, a 35% reduction.

Background

Herbicide resistance (HR) in ryegrasses to common cereal herbicides based on Mode of Action (MoA) Groups 1 and 2 is a growing problem across New Zealand arable farms, particularly in the Canterbury and Southland regions. This poses a threat to ryegrass seed and cereal production due to reduced chemical options to control HR ryegrass in cereal crops, including barley. This aim of the trial was to investigate how much ryegrass as a weed affects barley yield. This trial is the first of three planned trials.

Methods

Autumn sown barley was undersown with five rates (treatments) of perennial ryegrass (*Lolium perenne*) from 0 to 50 kg/ha to determine the impact on barley yield. The trial design was a randomised complete block sown at the Chertsey Research Site under irrigation on 17 May 2023 and harvested on 19 January 2024. The main measurement was barley yield, with barley head count, ryegrass plant counts, and ryegrass seed heads also measured.

Overall trial details

Standard 10 m x 1.65 m wide plots were sown on the 17 May 2023, using the feed barley cv. SY Silhouette by NZ Arable at 225 plants/m^2 across all plots using a disc type plot drill sowing 9 rows at 15 cm spacing. A 50/50 mix of Chlorpyrifos (suSCon Green®) + Diazinon at 15 kg/ha was added down the spout at drilling. Seed of the perennial ryegrass cv. Nui was broadcast on the soil surface using the plot drill prior to sowing the barley to help incorporate the ryegrass seed. Plots were then levelled using a Cambridge roller.

On the 19 January 2024, 247 days after planting, all plots were harvested by NZ Arable with a Sampo plot combine harvester equipped with on board grain weighing and moisture testing, and adjusted to 14% moisture content (MC).

Analysis was by general ANOVA in Genstat 22nd ed, using Fisher's protected LSD test at 0.05% level, with CV generated by Genstat. A number of outliers in the data were removed based on statistical advice, the raw data is presented in Appendix 1 with removed outliers highlighted.

Results and Discussion

The results of the trial are presented in Table 1.

Table 1. Results for five perennial ryegrass (*Lolium perenne*, cv. Nui) sowing rates, including ryegrass plant and heads/m^2 and autumn feed barley (cv. SY Silhouette) plants/m^2 and yield in a trial at Chertsey Research Site under irrigation in the 2023-24 season.

Trt. No.	Ryegrass (kg/ha)	Ryegrass (plants/m^2)	Ryegrass (heads/m^2)	Barley (plants/m^2)	Barley yield (t/ha)*
1	0	2 a	0 a	184 ns	11.55 a
2	5	132 ab	172 b	185 ns	11.01 b
3	10	300 b	218 b	173 ns	10.35 c
4	30	575 c	388 c	177 ns	8.78 d
5	50	1125 d	450 c	172 ns	7.75 e
Mean		**426**	**246**	**178**	**9.89**
P value		**<.001**	**<.001**	**0.822**	**<.001**
LSD (p=0.05)		**227.4**	**89.9**	**N/A**	**0.487**
CV (%)		-	-	**-**	**3.2%**

*Yield was adjusted to 14% moisture content. N/A, not applicable.

The ryegrass established well, with a strong correlation between the amount of ryegrass sown and the number/m^2 of established ryegrass plants (Table 1, and Figure 1).

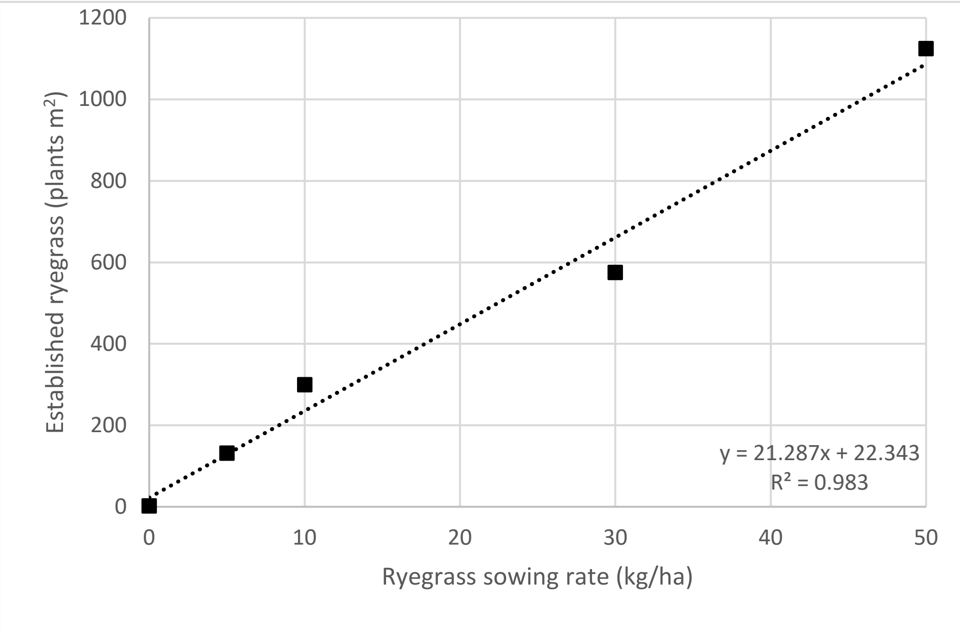

Figure 1. Relationship between the rate of perennial ryegrass (*Lolium perenne*, cv. Nui) sown (kg/ha) and the established population of ryegrass plants/m^2 at the Chertsey research site sown May 17 2023 under irrigation in the 2023-24 season.

The number of ryegrass seed heads increased with an initial increase in ryegrass population. However, the number of seed heads plateaued when plant population was above 600 plants / m^2. Treatments 4 (30 kg/ha) and 5 (50 kg/ha) corresponded to these high plant populations (Table 1 and Figure 2). This may indicate that plant competition was starting to negatively impact fitness of individual ryegrass plants and an individual's reproduction.

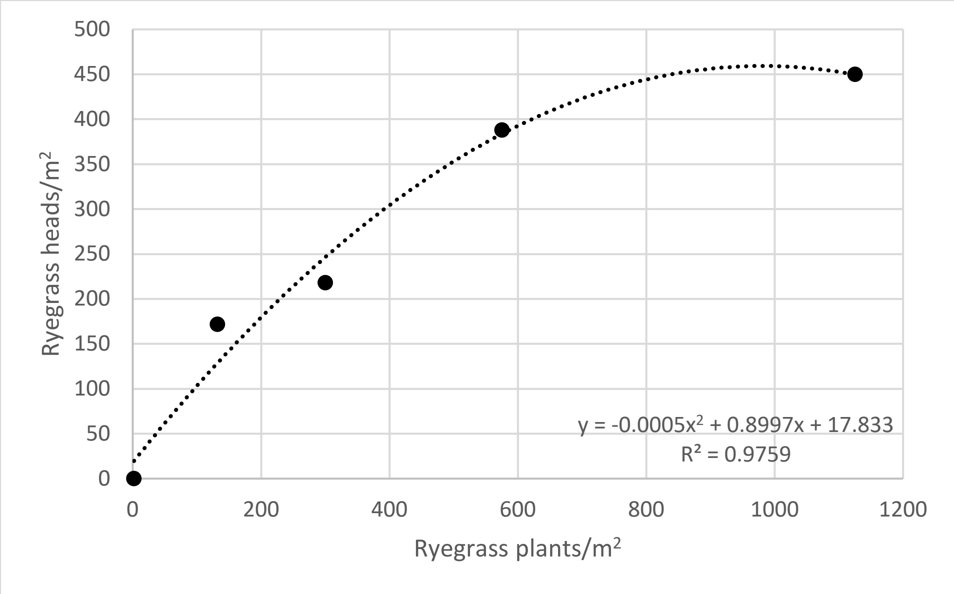

Figure 2. Relationship between perennial ryegrass (*Lolium perenne*, cv. Nui) plant population and the number of ryegrass seed heads in an autumn feed barley (cv. SY Silhouette) crop grown under irrigation at the Chertsey Research Site in the 2023-24 season.

The impact of ryegrass population on the barley plant population was not significant (p=0.822). In contrast, the impact of increasing ryegrass plant populations on barley yield was statistically significant, with differences between each of the yields for the five ryegrass sowing rates (treatments) (Table 1) and an overall decrease from 11.55 t/ha for the lowest ryegrass population to 7.75 t/ha for the highest ryegrass population, a 35% reduction (Figure 3).

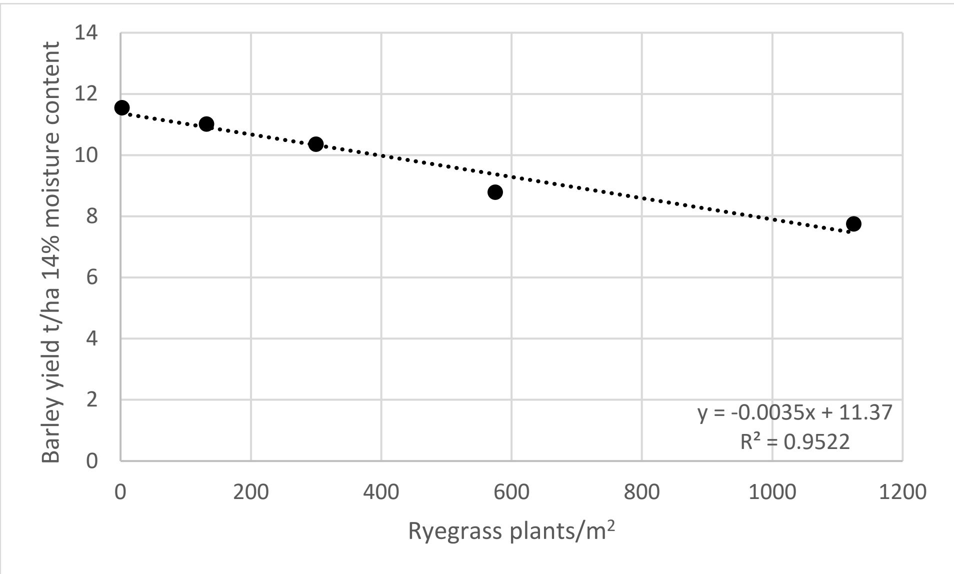

Figure 3. Relationship between perennial ryegrass (*Lolium perenne*, cv. Nui) plant population/m^2 and the barley (cv. SY Silhouette) yield (t/ha @ 14% moisture content) at the Chertsey research site under irrigation in the 2023-24 season.

Across a large range of ryegrass weed populations, barley yield decreased linearly. As the increasing ryegrass populations had no significant impact on barley population, the yield reduction must have been driven by a reduction in yield per barley plant. In this trial, only overall yield was measured so it is not possible to confirm where the loss of yield occurred.

In Western Australia, Paynter & Hills (2009) found increasing density of annual / rigid ryegrass (*Lolium rigidum*) from 16 to 125 plants/m^2 decreased barley grain yield by reducing crop biomass, tillers, grain number, harvest index, and TGW. Yield reductions varied with barley cultivar, planting density, site but not planting date. Seeding rate had a bigger benefit than cultivars. Paynter & Hills (2007) also studied the effect of barley row spacing on annual (rigid) ryegrass (*L. rigidum*) populations (4 to 124 plants/m^2) at five sites and using four barley cultivars, with increasing ryegrass populations and wider row spacings reducing barley yield. Increasing ryegrass populations also decreased grain quality. Building on the above two studies Paynter, Malik, & Curry (2017) investigated 12 newer barley cultivars, across nine sites with nil to 200 ryegrass plants/m^2 (assumed to be *L. multiflorum*). Yield loss was less than 10% across all trials, and at this low level of loss there was little difference among cultivars.

In the United Kingdom, the effect of a range of weeds, mainly wild oat and blackgrass have been studied. Dhima, Lithourgidis, Vasilakoglou, & Dordas (2007) compared 29 six-row and 21 two-row barley cultivars competitiveness with winter wild-oat *(Avena sterilis* spp. *ludoviciana*) and German-madwort (*Asperugo procumbens*), finding that the most competitive cultivars reduced weeds biomass by up to 76% compared to the least competitive. Cook & Roche (2018) compared a six-row and a two-row barley cultivar for competitiveness against black-grass, finding that black-grass head counts were lower in the 6-row barley, with the critical competition phase occurring after winter. When comparing 29 barley cultivars in competition with oats, Watson, Derksen, & Van Acker (2006) found that competitiveness varied mostly in six-row cultivars, which represented both the least and most competitive cultivars, whereas two-row cultivars generally showed intermediate levels of competitiveness, with yield loss varying from 6% to 79%, with dwarf and hull-less cultivars the least competitive.

Barley competitiveness with weeds and the impact of weeds on barley yield can therefore be influenced by location (which may include soil and climate (year-to-year) effects), cultivar, sowing rate and row spacing. The competitiveness of different ryegrass cultivars (within the same species) has not been studied, but, it would be expected that ryegrass cultivars should also vary in competitive ability. The barley yield components affected by competition can include overall crop biomass, TGW, tillers, grain number and grain quality (e.g. protein content, i.e. all aspects of yield). This is in keeping with crop-weed competition across a range of arable crops.

Summary

This trial investigated five different populations of perennial ryegrass (cv. Nui) for its competitive ability and impact on autumn feed barley (cv. SY Silhouette) yield. Barley was sown at 225 plants/m^2 on 15 cm row spacing.

The ryegrass established well and populations were strongly correlated to sowing rate. Ryegrass seed heads increased up to around 300 plants/m^2 before appearing to level off, indicating that at these higher populations the ryegrass suffered from increased competition.

Ryegrass weed populations produced an agronomically, economically and statistically clear barley yield reduction from 11.55 t/ha for the lowest ryegrass population to 7.75 t/ha for the highest ryegrass population, a 35% reduction. It is not possible to tell from this trial where barley yield was being lost, apart from it not being due to a reduction in barley plant populations as these reductions were much smaller than the yield reduction. There are multiple ways yield could be lost including: less tillering / heads, lower thousand grain weight (TGW) i.e. smaller grains, lower number of grains per head, increased screenings. There may also be impacts on grain quality, e.g. protein levels. The limited overseas research that was found showed that many factors impact barley-weed competition including barley population, cultivar, rows spacing, and likely soils and climate. To fully understand the impacts of weed competition would require more extensive experiments.

Beyond the current FAR trials looking at the impact of perennial ryegrass on a single barley cultivar, at standard populations and row spacing, there are clearly many more factors (such as barley population, cultivar and row spacing) that could be important for informing future weed management strategies in barley. Future trials would also benefit from a deeper analysis of how yield loss is occurring.

References

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Paynter, B. H., & Hills, A. L. (2009). Barley and rigid ryegrass (Lolium rigidum) competition is influenced by crop cultivar and density. *Weed Technology*, 40-48.

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Watson, P., Derksen, D., & Van Acker, R. (2006). The ability of 29 barley cultivars to compete and withstand competition. *Weed Science, 54*, 783-792.

Appendix 1

Table 2. Raw data for the 2023-24 perennial ryegrass (cv. Nui) competition with barley (cv. SY Silhouette) trial at the Chertsey Research Site under irrigation in the 2023-24 season. Red cells are outliers that have been removed before data analysis.

Plot!	trt!	Block!	RG_kg_ha!	Ryegrass plant count m2	Barley plant count m2	Ryegrass head count m2	Barley yield t.ha 14 PC
101	1	1	0	7	213	0	11.55
202	1	2	0	0	150	0	11.82
303	1	3	0	0	207	0	11.98
405	1	4	0	0	167	0	10.86
103	2	1	5	153	200	104	11.30
204	2	2	5	127	177	272	11.13
305	2	3	5	133	177	132	11.08
402	2	4	5	113	187	72	10.54
104	3	1	10	393	170	176	10.74
201	3	2	10	147	160	28	10.12
302	3	3	10	287	177	264	10.73
403	3	4	10	247	183	196	9.79
105	4	1	30	533	183	400	8.81
203	4	2	30	607	190	336	9.04
301	4	3	30	513	153	168	8.77
404	4	4	30	640	183	436	8.49
102	5	1	50	1333	187	456	8.01
205	5	2	50	987	177	472	7.36
304	5	3	50	1407	130	412	7.66
401	5	4	50	773	193	264	7.97

Appendix 2. Trial management inputs

Nitrogen:	25/8/2023	160 kg/ha as Ammo 36
	21/9/2023	135 kg/ha as SustaiN
	5/10/2023	40 kg/ha SustaiN
Herbcide:	22/5/2023	3 L/ha Glyphosate 470 (prior to barley emergence)
	11/8/2023	4L/ha Trimec® (600g/L Mecoprop, Group 4, 150g/L MCPA, Group 4 and 18.7g/L Dicamba, Group 4)
	10/10/2023	750mL/ha Starane® (333 g/L fluroxypyr, Group 4)
PGR:	8/9/2023	400ml/ha Moddus Evo® (250 g/L Trinexapac-ethyl)
	13/10/2023	1 L/ha Terpal (305 g/L Mepiquat chloride, 155 g/L, Chlorethephon) with Contact® sticker
Fungicide:	31/8/2023	800 ml/ha Proline® (250 g/litre prothioconazole, Group 3) + 800 ml/ha Comet® (250 g/L pyraclostrobin, Group 11)
	19/9/2023	400 ml/ha Proline® (as above), 600 ml/ha Seguris Flexi® (125 g/L Isopyrazam, Group 7) and 800 ml/ha Comet® (as above)
	18/10/2023	1.5L/ha Revystar® (100 g/L mefentrifluconazole, Group 3, 50 g/L fluxapyroxad, Group 7), plus 1.5 L/ha Phoenix® (500g/L folpet, Group 4)

Irrigation:

Date	Amount mm
15/9/2023	5
6/10/2023	15
1/11/2023	25
19/11/2023	20
23/11/2023	15
28/12/2023	25
10/1/2024	20
Total	**135**

Barley row spacing and population trial

Project code X22-01-01

Duration Year 1 of 3 (2023-24 season)

Authors Charles Merfield, Matilda Gunnarsson, Jacqueline Straathof (FAR)

Location FAR Chertsey Research Site, Canterbury

Funding FAR

Acknowledgements NZ Arable (trial management)

Key points

1. The use of Firebird® as a pre-emergence herbicide contributed to increased head counts, reduced weed biomass, and an overall yield increase of 0.39 t/ha.
2. Narrower row spacings (7.5 and 15 cm) produced higher barley populations and yield compared with the 30 cm
3. Increasing the sowing rate from 175 to 225 plants/m² improved plant populations and reduced weed biomass, although yield differences were not statistically significant.

Background

Herbicide resistance (HR) in ryegrass to Mode of Action (MOA) Groups 1 and 2 is a growing problem across New Zealand arable farms. An integrated weed management (IWM) approach is needed to combat herbicide resistance. Crop competition is an important part of IWM in cereal crops. Crop competition can be increased by a range of approaches including narrower row spacings and increasing crop plant populations to achieve denser and quicker crop canopy closure, which then supresses weed seed germination and better compete with emerged weeds. Herbicides with different MoA to Groups 1 and 2, particularly residual / pre-emergence, are also an important component of IWM.

Methods

The trial investigated the effects of row spacing, and barley populations with and without the pre-emergent herbicide Firebird® (500ml/ha Flufenacet 400 g/L Group 15 + Diflufenican 200 g/L Group 12) for their impact on barley performance including yield and weed biomass. A randomised complete block design with four reps, three factors and sixteen treatments was used (Table 1).

Table 1. Treatments and factors in barley (cv. SY Silhouette) row spacing and population trial planted 17 May 2023 under irrigation at the Chertsey Research Site.

Treatment No.	Row spacing (cm)	Barley target population (plants /m^2)	Firebird® Application
1	7.5	175	Firebird®
2	7.5	225	Firebird®
3	7.5	175	No Firebird®
4	7.5	225	No Firebird®
5	15	175	Firebird®
6	15	225	Firebird®
7	15	175	No Firebird®
8	15	225	No Firebird®
9	30	175	Firebird®
10	30	225	Firebird®
11	30	175	No Firebird®
12	30	225	No Firebird®
13	broadcast	175	Firebird®
14	broadcast	225	Firebird®
15	broadcast	175	No Firebird®
16	broadcast	225	No Firebird®

Note: Firebird® (500 mL/ha Flufenacet 400 g/L Group 15 + Diflufenican 200 g/L Group 12).

Measurements included:

- Barley plant populations were counted in the row treatments on two 50cm lengths of crop row (1 metre total length) and the broadcast treatment using a 25 x 25 cm quadrat on 21/06/2023, 35 days after sowing.
- Barley heads were counted in the row treatments 7.5 cm; 5 rowsx50 cm, 15 cm; 3 rowsx50 cm; 2 rowsx50 cm and broadcast; 50x50x cm quadrat on 16/1/2024, 28 days before harvest.
- Weed dry biomass/m^2 (dry weight) was harvested from a 50 x 50 cm quadrat on 16/01/2024 28 days before harvest.
- Barley yield in t/ha adjusted to 14% moisture content (with plot combine as described below).

Overall trial details

Barley (cultivar SY Silhouette) was established using a disc plot drill on May 17 2023. A 50/50 mix of Chlorpyrifos (SuSCon Green®) + Diazinon at 15kg/ha was drilled with the seed (down the spout).

All plots were then rolled with a Cambridge roller to consolidate the seedbed.

A base application of 295 kg/ha Super 7K (P 7.65%, K 7.5%, S 9.35% and Ca 18.7%) was applied on 16/05/2023. Nitrogen was applied on three occasions: 160 kg/ha Ammo 36 on 25/8/2023; 135 kg/ha N (Sustain®) 21/9/23 and 40 kg/ha N (Sustain®) on 5/10/23.

Herbicides included 3 L Glyphosate 470, Group 9 on 22/5/2023 five days after drilling to kill weeds present at drilling. 500 mL/ha Firebird® (Flufenacet 400 g/L Group 15 + Diflufenican 200 g/L Group 12) was applied on 22/5/23 (the same day as the glyphosate application), but only on the Firebird® treatments. 4 L/ha Trimec® (600 g/L Mecoprop, Group 4, 150 g/L MCPA, Group 4 and 18.7 g/L Dicamba, Group 4) on all plots on 11/8/2023 86 days post sowing.

The PGR (plant growth regulators) Moddus Evo® (250 g/L Trinexapac-ethyl) at 400 mL/ha was applied on 8/9/2023, then 1 L/ha Terpal® (305 g/L Mepiquat chloride, 155 g/L, Chlorethephon) with Contact® sticker was applied on 13/10/2023.

There were three fungicide applications: (1) 800 mL/ha Proline® (250 g/L prothioconazole, Group 3) plus 800 mL/ha Comet® (250 g/L pyraclostrobin, Group 11) on 31/8/2023. (2) 400 mL/ha Proline® (as above), 600 mL/ha Seguris Flexi® (125 g/L Isopyrazam, Group 7) and 800 mL/ha Comet® (as above) on 19/9/2023. (3) 1.5 L/ha Revystar® (100 g/L mefentrifluconazole, Group 3, 50 g/L fluxapyroxad, Group 7), plus 1.5 L/ha Phoenix® (500g/L folpet, Group 4) on 18/10/2023. Total amount of irrigation applied was 135mm.

The trial was harvested on 13/2/2024, using a Sampo plot combine harvester equipped with onboard grain weighing and moisture testing.

Statistical Analysis was by general ANOVA in Genstat 22nd ed, using Fisher's protected LSD test at 0.05% level, with CV (%) generated by Genstat.

Results and Discussion

Visually the broadcast treatment was considered to have not established well, due to difficulties manually incorporating the seed by hand raking. An analysis of the percentage of emerged plants versus the target sowing rate found that the difference between the target and measured populations decreased from the narrowest row spacing to the broadcast treatment, for both population rates (Table 2). This has also been observed by Collier et al. in spring wheat. When the spring wheat plant population increased from 200 plants/ m^2 to 400 plants/m^2 the percentage the percentage emergence went from 83 % down to 59 %. One theory could be the spacings between seed within the row. For this trial with the 175-plant population the seed spacings went from approx. 6.3 cm down for the 7.5 cm row spacing to 1.7 cm for the 30 cm row spacing went from (Table 3).

Table 2. Target barley populations, measured barley populations (counted 35 days after sowing) and the percentage difference between them in a barley (cv. SY Silhouette) row spacing and population trial planted 17 May 2023 under irrigation at the Chertsey Research Site.

	Target plants/m^2	**Measured plants/m^2**	**% Difference**
Row spacing cm			
7.5	175	184	5%
15	175	133	-24%
30	175	99	-44%
broadcast	175	87	-50%
Mean	**175**	**126**	**-28%**
7.5	225	228	1%
15	225	162	-28%
30	225	112	-50%
broadcast	225	93	-59%
Mean	**225**	**149**	**-34%**
Overall mean	**200**	**137**	**-31%**

Table 3. Spacing between seeds within the row in a barley (cv. SY Silhouette) row spacing and population trial planted 17 May 2023 under irrigation at the Chertsey Research Site.

Plant population / m^2	Row spacing (cm)	Seeds/m row	Spacing between seeds (cm)
175	7.5	16.0	6.3
	15.0	31.9	3.1
	30.0	57.5	1.7
225	7.5	20.5	4.9
	15.0	41.0	2.4
	30.0	73.8	1.4

Row spacing

Row spacing had a highly significant difference (p>0.001) for all four measurements of barley populations, head count and yield and weed biomass (Table 4).

Table 4. The effect of row spacing in the barley (cv. SY Silhouette) row spacing and population trial planted 17 May 2023 in column 5 under irrigation and harvested 13 February 2024, 272 days after planting, at the Chertsey research site.

Row spacing (cm)	Barley plants (/ m^2)	Barley heads (/ m^2)	Weed dry weight (g/m^2)	Barley yield (t/ha)
7.5	206 a	1307 a	13.1 b	9.40 a
15	147 b	1045 a	14.5 b	9.67 a
30	105 c	856 a	43 b	8.63 b
Broadcast	90 c	692 b	198.9 a	6.13 c
Mean	137	975	67.4	8.46
P value	**<0.001**	**<0.001**	**<0.001**	**<0.001**
LSD$_{0.05}$	**24.9**	**108.1**	**47.7**	**0.51**
CV (%)	**26%**	**16%**	**100%**	**8%**

Generally narrower row spacings in arable crops increases competition of the crop against weeds (interspecific competition), which can be a significant component of overall weed suppression. Borger, Riethmuller, & D'Antuono, (2016) in an 11-year trial found narrower rows were more effective at supressing annual ryegrass (*Lolium rigidum*) seed production.

However, in this trial there was no statistical difference in weed biomass between the three row spacings up. Therefore, a limited amount can be read into these results, mainly that the two narrow spacings were similarly competitive, and the wider 30 cm row may be less competitive.

Barley populations

Two barley populations were sown, 175 and 225 plants/m^2 (Table 5).

Table 5. The effect of two sowing rates (target population) of in the barley (cv SY Silhouette) row spacing and population trial planted 17 May 2023 in column 5 under irrigation and harvested 13 February 2024, 272 days after planting, at the Chertsey Research Site.

Sowing rate plants (/ m^2)	Barley plants (/ m^2)	Barley heads (/ m^2)	Weed dry weight (g/m^2)	Barley yield (t/ha)
175	126 a	939 a	84.9 a	8.37 ns
225	149 b	1012 b	44.9 b	8.55 ns
Mean	137	975	62.4	8.46
P value	0.012	0.061	0.042	0.308
LSD$_{0.05}$	17.6	76.4	33.7	0.3586
CV (%)	26%	16%	100%	8%

Increasing the sowing rate produced a statistically significant increase in barley plants and heads and reducing in weed biomass, but, no difference in barley yield (Table 5).

The target sowing rate increases by 28% from 175 to 225 plants/m^2 while the emerged plants only increased by 18% from 126 to 149 plants/m^2, indicating emergence was lower than targeted and the gap was larger for the higher sowing rate.

The reduction in weed biomass is as expected, due to increased interspecific competition from the crop.

Use of Firebird® herbicide

"Firebird® is a pre-emergence herbicide for use in autumn and winter sown wheat and barley for the control of a wide range of key arable weeds. Weeds such as vulpia hair grass, annual poa, field pansy, speedwell and field madder"[1]. Firebird® was here applied pre-emerge to investigate its use when ryegrass resistance to group 1 and 2 herbicides might be present. Although ryegrass isn't listed on the Firebird® label as susceptible species FAR Herbicide screening (Arable extra Issue 129) trial has shown that Firebird has good efficacy on ryegrass, both annual and perennial. Glyphosate Group 9 was used five days post drilling to kill ('clean-up') all weeds present at drilling Trimec® Group 4 was applied 86 days post sowing. to to control of a wide range of broadleaf weeds.

Treatment interactions

The only statistically significant results in the two and three way interactions was for the barley population and herbicide interaction where the treatment with Firebird® at the higher sowing rate was statistically different from the other three at p = 0.011. There was no statistical difference of the use of Firebird® on emerged barley populations as expected. The treatments including Firebird® had increased barley heads and yield and also reduced weed biomass. (Table 5).

Table 6. The effect of using Firebird® pre-emergent herbicide (500 mL/ha Flufenacet 400 g/L Group 15 + Diflufenican 200 g/L Group 12) applied five days after planting, in the barley (cv. SY Silhouette) row spacing and population trial planted 17 May 2023 in column 5 under irrigation and harvested 13 Feb 2024, 272 days after planting, at the Chertsey research site.

	Barley plants (/ m^2)	Barley heads (/ m^2)	Weed dry weight (g/m^2)	Barley yield (t/ha)
Firebird®	139 ns	1020 a	45.9 a	8.65 a
No Firebird®	135 ns	930 b	88.8 b	8.26 b
Mean	137	975	67.4	8.46
P value	0.691	0.022	0.014	0.034
LSD (P=0.05)	NS	76.4	33.7	0.3586
CV (%)	26%	16%	100%	8%

Firebird®, as a pre-emergence herbicide, provided good initial weed control in the critical early stages of crop growth, thus increasing barley head count and yield. Trimec® then reduced broadleaf weed biomass during the mid-stage of crop growth, resulting in small overall weed biomass measurements before harvest.

Summary

Narrower row spacings (7.5 and 15 cm) produced higher barley populations and yield compared with the 30 cm and broadcast treatments. Yields were 9.40 t/ha for 7.5 cm, 9.67 t/ha for 15 cm, 8.63 t/ha for 30 cm, and 6.13 t/ha for broadcast. Weed biomass was lowest in the narrow and standard row spacings and highest in the broadcast plots.

Increasing the sowing rate from 175 to 225 plants/m^2 improved plant populations and reduced weed biomass, although yield differences were not statistically significant. The use of Firebird® as a pre-

[1] https://www.cropscience.bayer.co.nz/products/herbicides/firebird

emergence herbicide contributed to increased head counts, reduced weed biomass, and an overall yield increase of 0.39 t/ha.

Overall, the trial demonstrates that narrower rows and higher sowing rates enhance barley competitiveness against weeds, and that Firebird® provides effective early-season weed control. Broadcast sowing was unsuitable due to poor establishment and is not recommended for future trials.

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Spring barley weed control using a spring tine weeder and herbicides

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Author Charles Merfield, Matilda Gunnarsson (FAR)

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Key points

1. The spring tine weeder achieved good levels of weed control and slightly increased yields.
2. Herbicide performance differed considerably among the different products.
3. The spring tine weeder improved weed management and barley yield where herbicide performance was sub-optimal, an indication that integration of the two can be beneficial.
4. Delayed sowing slightly improved weed management with no statistically significant difference in yield, indicating that normal sowing dates are best, but, where delayed sowing is required, negative impacts should be minimal.

Background

Integrated Weed Management (IWM) is viewed as the future of weed management by the international and domestic weed science and management communities. Integrating physical / mechanical weeding with herbicides in arable crops is considered a key IWM approach to reducing herbicide use to prolong their efficacy, delay resistance, as well as providing an alternative means of controlling existing herbicide resistant weeds.

In the last ten years, mechanical weeding in Europe has moved from a niche technique used almost exclusively by organic growers supplied by specialist weeder machinery companies, to a mainstream tool with some of the world's largest agricultural machinery companies providing a suite of turnkey weeders. NZ machinery retailers are now importing European weeders into NZ, meaning that European mechanical weeding machinery is increasingly available in NZ.

The key mechanical weeder for arable crops is the spring tine weeder. These have a large number of thin sprung steel tines that rake through the soil surface breaking, burying and uprooting small weeds up to about two to four true leaves, depending on species. A key advantage of spring tine weeders is that no to minimal changes are needed to the rest of farm system, e.g. row spacings, drill setup. Spring tine weeders can thus be a direct substitute for herbicide application. However, the details of determining how to integrate them are more complex due to the multiple different types of herbicides, e.g. pre-crop emergence and post crop emergence.

This trial was an initial test and demonstration of the integration of spring tine weeders with herbicides in spring barley, and served as a demonstration of mechanical weeding to normalise it among NZ arable farmers.

Methods

A randomised complete block trial with ten treatments and four replicates / blocks in spring barley (cv. SY Silhouette) was undertaken at Kowhai Farm starting in September 2024.

The trial had the following treatments (Table 1).

Table 3. Treatments and post-hoc treatment factors for the barley autumn and spring weed control trial at Kowhai, Lincoln in 2023-24.

Treatment Number	Tine weeding	Sowing Date	Herbicide
1	No tine weeding	Delayed sowing	No herbicide
2	No tine weeding	Delayed sowing	Glufosinate pre-sowing
3	No tine weeding	Normal sowing	Pre-emergence Invado®
4	No tine weeding	Normal sowing	Post-emergence Othello®
5	No tine weeding	Normal sowing	No herbicide
6	Tine weeded	Delayed sowing	No herbicide
7	Tine weeded	Delayed sowing	Glufosinate pre-sowing
8	Tine weeded	Normal sowing	Pre-emergence Invado®
9	Tine weeded	Normal sowing	Post-emergence Othello®
10	Tine weeded	Normal sowing	No herbicide

Note: Normal sowing = 1 September 2023 and delayed sowing = 21 September. Tine weeding occurred on 4, 10 and 25 September 2023. Biffo® = glufosinate Group 10, (200 g/L) at 5.0 L/ha pre-sowing, Invado® = Flufenacet SC Group 15 (400 g/L) at 300 mL/ha, Othello® = diflufenican Group 12, (50 g/L), mesosulfuron methyl Group 2 (7.5 g/L), iodosulfuron methyl sodium Group 2 (2.5 g/L) + mefenpyr-diethyl (safener) (22.5 g/L) at 1 L/ha.

Tine weeding and sowing date were factorial. However, sowing date and herbicides were not factorial as, only Biffo® and a null herbicide was combined with the delayed sowing, while normal sowing date was coupled with Invado® or Othello® and a null control.

Due to the unbalanced design, analysis was undertaken in two ways, both using General ANOVA in Genstat 22ed, using Fisher's protected LSD test. The data were first analysed as a fully factorial design, with, the herbicide x sowing date interaction re-analysed separately. The treatments were then also analysed without any factorial structure, i.e. each as an independent variable, and are reported last.

All other crop management was standard for spring barley.

The timelines for the key trial activities are listed in Table 2.

Table 4. Timelines for key trial activities for the barley autumn and spring weed control trial at Kowhai, Lincoln in 2023-24.

Date	Activity	Days between	Days after sowing
1/09/2023	Normal (first) sowing	0	0
4/09/2023	Pre-em Invado®	3	3
20/09/2023	Pre-sow Biffo®	16	19
21/09/2023	Delayed (second) sowing	1	20
4/10/2023	First tine weeding	13	33
10/10/2023	Second partial tine weeding	6	39
19/10/2023	Post-em Othello®	15	48
20/10/2023	Weed score	1	49
25/10/2023	Third tine weeding	5	54
15/02/2024	Barley and weed weight	113	167
23/02/2024	Harvest	8	175

Data collected included:

- Visual weed score 49 days after first sowing,
- Barley plant fresh weight, from two 50 cm row lengths, sampled eight days pre-harvest,
- Barley plant dried weight from above fresh sample,
- Fresh weight of weeds from a 50 x 50 cm quadrat, sampled eight days pre-harvest

- Dried weight of above fresh weed sample
- Count of barley heads, from two 50 cm ow lengths, sampled eight days pre-harvest,
- Crop yield corrected to 14% moisture, harvested on 23 February 2024, 175 days after first planting, with a Sampo plot combine harvester with on board grain weighing and moisture testing.

Barley dry weight, head count and yield, plus weed dry biomass, were analysed.

Overall trial details

The trial was established on 1 September 2023, at the Kowhai Experimental site, column 1 with the centre at 43°38'19.17"S, 172°28'15.73"E.

The trial area was in a cereal cover crop over winter. It was minimum tilled in the weeks prior to planting leaving a small amount of plant residue on the surface.

Plots were 3m wide by 12 m long with a 6 m grass buffer between blocks to accommodate the width of the 3 m wide tine weeder and sufficient space for the tractor undertaking the tine weeding to manoeuvre. Plots were planted using a disc plot drill sowing 9 rows at 15 cm spacing, drilling two bouts to achieve the required 3 m plot width.

Sowing rate of barley was 145.5 kg/ha with a target plant population of 250 plants/m^2, at 95% germination, 95% emergence and thousand seed weight (TSW) of 52.51g. Seed dressings were the insecticide Poncho® (600 g/L clothianidin Group 4a), and fungicide Kinto® Duo (20 g/L triticonazole Group 3 and 60 g/L prochloraz Group 3). The first / normal sowing date was on 1 September 2023 and the second / delayed sowing date was 21 September.

Herbicide applications were by plot sprayer as per Table 2 and previously detailed products and rates. Mechanical weeding was undertaken using a 3 m wide Einböck spring tine weeder with a customised SPORT-STAR headstock and AEROSTAR-CLASSIC tine frames, with tines with 45° bends loaned by Tulloch Farm Machines (Figure 1).

Figure 4. Three metre wide Einböck AEROSTAR-CLASSIC spring tine weeder used in the barley autumn and spring weed control trial at Kowhai, Lincoln in 2023-24.

Tine weeding was undertaken on three occasions (Table 3).

Table 5. Date of tine weeding events, speed, weather, soil moisture and crop growth stage in October 2023 for the barley autumn and spring weed control trial at Kowhai, Lincoln in 2023-24. ET = evapotranspiration, SE = solar energy.

Date in Sept.	Speed (kph)	Weather during weeding	Soil	Daily weather	Crop growth stage
4th	5.3	21°C, cloudy, windy	Dry	Min 7°C, max 22°C, mean 14°C, no rain, SE 7 Mj/m², ET 4 mm/day	Delayed sowing 1 leaf Normal sowing 3-4 leaves
10th	2.6	11°C, cloudy	Dry	Min 4°C, max 14°C, mean 9.1°C, rain 7 mm, SE 7 Mj/m², ET 1.3 mm/day	Delayed sowing 1-2 leaves
25th	2.6	23°C sunny	Dry	Min 14°C, max 23°C, mean 19°C, no rain, SE 19 Mj/m², ET 4 mm/day	Delayed sowing 3 leaves Normal sowing 3 tillers

The buffer rows around the edge of the trial were used to determine the best tine weeder setting and speed. Tractor speed was kept constant by setting engine RPM at 1500 and using specific gears to achieve the required speed. Actual speed was then determined by timing how long the tractor took to travel a measured distance at a given RPM and gear setting. The angle of the weeder's tines can be adjusted through five angles / settings on a hole-and-pin adjustment setting. For all three weeding events the tine angle was set in the middle hole, giving a medium tine angle. Likewise, the height of the weeder is controlled by a hole-and-pin system on the depth wheels. For all weeding events the depth wheels were set at the fourth hole from the top. The top link on the weeder was then adjusted to ensure the weeder was level with the soil. The tine weeder was driven down the length of the plots twice, once in each direction. The tractor was lined up with the front wheels at the start of the plot, then the engine was brought up to the required RPM, put into gear and driven forward while lowering the tine weeder so that it was fully down before it entered the plot. At the end of the plot the tractor was driven beyond the plot such that the rear of the tine weeder exited the plot at operating speed while still on the ground before being lifted. Plots were weeded in block order.

Barley was not inspected until the 3 October, 33 days after the normal / first drilling on the 1 September and 13 days after the delayed / second drilling on the 21 September. By this time, there was a significant flush of weeds up to two true leaves, mostly wireweed (*Polygonum aviculare*) across the whole trial. Tine weeding is most effective against newly-emerged cotyledon stage weeds with efficacy declining considerably as weeds get older (Einböck GmbH, 2022). This meant that the optimal tine weeding date had been missed by up to three weeks.

By 3 October, barley sown on the 'normal' date was well established whilst the delayed sown barley had not emerged, so it was decided to tine weed the next day. However, the delayed-sown barley emerged overnight on the 3 October so it was newly emerged on the day of tine weeding. Generally, it is not recommended to tine weed cereals when they are newly emerged, due to the risk of severely damaging the crop. Barley can however, be 'blind weeded' i.e. just before emergence (Einböck GmbH, 2022, p. 29) which was the initial aim. It was therefore decided to tine weed only half the plot length of the delayed sowing in case this damaged the newly emerged barley. Fortunately, the newly emerged barley suffered no damage. On the 10 October the other half of the delayed sowing was tine weeded. On the 25 October all plots were tine weeded for a second time.

Soil moisture and weather conditions impact the effectiveness of tine (and all mechanical) weeding, with moderate to dry soil and hot drying weather optimal. Wet soil and cold damp weather are the least favourable conditions. On the 4 October there had been 32 mm of rain over the previous week, but due to an overall very dry winter and spring the soil conditions were still moist, and the weather was warm so assisting weed kill (Table 3 and Table 13). On the 10 October there had been no rain since the previous weeding event so the soil was dry but there was 7 mm later in the day which may have helped weed survival. On the 25 October, there had been 4 mm of rain in the preceding week and 24 mm in total since the previous weeding, so again soil conditions were moist and for spring, the weather was excellent for desiccating treated weeds (Table 3 and Table 13).

As tine weeding the newly emerged barley in the delayed sowing plots did not cause crop damage this half of the plots was used for crop and weed assessments.

Results and Discussion

The factorial results are presented first and then as independent treatments.

Factorial analysis

The results are presented first by the individual treatment effects and then the two-way interactions other than herbicide x sowing date as the two factors cannot be separated. The three-way interaction was not significant so it is not presented.

Overall, nearly all statistically and agronomically the significant treatment effects were on weed dry weight (biomass) and barley yield. Barley dry weight and head count showed no or small differences for most treatments, both statistically and agronomically. They are thus only discussed where there was a statistically significant difference, namely herbicides and the tine weeder x sowing date interaction. However, a key concern with mechanical weeders, such as the spring tine weeder, is causing crop damage including killing crop plants and thus negatively impacting yield. That both barley biomass and head count were the same between most tine weeding and non-tine weeding treatments is a good indication that despite the mechanical weeding physically moving barley plants around, partly burying them, and pulling some out (visual observations during tine weeding) this did not result in longer term damage to the barley including yield reductions. While barley dry weight and head count were not significantly different the results are still presented in the results tables for the record.

Tine weeding

Tine weeding compared to no tine weeding significantly reduced weed biomass and slightly increased yield (Table 5). The weed biomass reduction was highly statistically significant showing that tine weeding was achieving good levels of weed control. The increase in yield while statistically significant, was just over 0.5 T/ha so was modest. This indicates that the better weed control from tine weeding was not having as large an impact on barley yield as could be expected, which in part could be due to the later timing of weed control.

Table 6. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) with or without tine weeding, grown under irrigation at Kowhai farm planted 1 September 2023 the barley autumn and spring weed control trial at Kowhai, Lincoln in 2023-24.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
No tine weeding	200 ns	155 ns	38 a	10.34 a
Tine weeded	186 ns	149 ns	7 b	10.92 b
Mean	193	152	22	10.63
P value	0.247	0.529	<.001	0.005
$LSD_{0.05}$	24.1	20.1	7.0	0.406
CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Tine weeding occurred on 4th, 10th and 25th September 2023. ns = not significant, values in the same column with the same letter after them are not significantly different.

Sowing date

Delaying sowing compared with normal sowing date reduced weed biomass by half ($p = 0.014$) showing a statistically clear effect (Table 6). Delayed sowing and herbicides were not full factors and delayed sowing was only combined with Biffo® glufosinate pre-sowing while normal planting was combined with either pre-emergent Invado® or post-emergent Othello®.

The better weed control was not reflected in barley yield, which is not statistically significant with 0.4 t/ha reduction for delayed sowing. This may reflect two opposing factors, while delaying sowing improves weed control which should increase yield, it also reduced the duration of the crop, which is likely to decrease yield.

Table 7. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) under normal sowing date of 1 Sept 2023 and delayed sowing date of 21 Sept 2023, grown under irrigation at Kowhai farm, Lincoln in 2023-24.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
Delayed sowing	179 ns	144 ns	14 a	10.38 ns
Normal sowing	203 ns	157 ns	28 b	10.80 ns
Mean	191	151	21	10.59
P value	0.204	0.357	0.014	0.215
$LSD_{0.05}$	38.0	31.8	11.1	0.642
CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Normal sowing = 1st September 2023 and delayed sowing = 21st September. ns = not significant, values in the same column with the same letter after them are not significantly different.

Herbicides

Herbicides application significantly increased barley biomass (dry weight) (Table 7). However, the agronomic differences were small at 44 g with a mean biomass of 195 g. There is also no obvious pattern to the results. The pre-emergent and post-emergent herbicides had higher biomass while the Biffo® pre-sowing had the lowest weight, with the null control close to the average. Potentially due to the trial not being fully factorial and the pre-and post-emergent herbicides were only applied with the normal sowing date and the Biffo® only with the late sowing date, the different biomasses may reflect the different sowing dates associated with the different herbicides rather than an effect of the herbicides alone. That the null control which was used at both planting dates was close to the mean further supports this analysis.

There is a clear statistical difference in weed biomass (dry weight) among the herbicide treatments (Table 7). However, again, with a single sampling date, and herbicide treatment being related to sowing date (as discussed above) the weed biomass will at least in part reflect time since sowing and therefore the number of days that weeds had been growing and therefore able to accumulate biomass. The clear standout is the post-emergent Othello® which achieved very low biomass, i.e. it almost completely controlled all weeds (Table 7). In complete contrast the pre-emergent Invado® was the same as the null control (Table 7). As the no-herbicide treatment includes both tine-weeding and completely unweeded plots, this makes this comparison more tentative but when looking at the interactions (see below) it is still clear that Invado® alone did not achieve good weed control.

Barley yield was highly statistically significant (Table 7) with a difference of 1.5 t/ha between the highest and lowest yield. The post-emergent Othello® had the highest yields and was planted at the standard time and had very good weed control, so both factors will have contributed to yield. The later sown Biffo® pre-sow glufosinate and normal sown pre-em Invado® yielded the same. As before there could be conflicting drivers: the poorer weed control in the Invado® but earlier sowing cancelling each other out, as did the better weed control by the Biffo® but later planting date.

Table 8. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) under three herbicide treatments and a no-herbicide null control, grown under irrigation at Kowhai farm, Lincoln in 2023-24.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
No herbicide	185 ab	154 ns	34 c	10.12 a
Pre-emergent Invado®	207 bc	149 ns	30 c	10.52 ab
Biffo® pre-sowing	163 a	142 ns	13 b	10.77 b
Post-emergent Othello®	226 c	162 ns	0.3 a	11.58 c
Mean	195	152 ns	19	10.75
P value	0.011	0.631	<.001	0.001
$LSD_{0.05}$	46.59	31.8	11.1	0.642
CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Biffo® glufosinate Group 10, 200 g/L @ 5.0 L/ha, Invado® 400g/litre Flufenacet SC Group 15, @ 300 ml/ha, Othello® 50g/litre diflufenican Group 12, 7.5g/litre mesosulfuron methyl Group 2, 2.5g/litre iodosulfuron methyl sodium Group 2, + 22.5g/litre mefenpyr-diethyl (safener) @ 1 L/ha. ns = not significant, values in the same column with the same letter after them are not significantly different.

Interactions - herbicides and sowing date

As herbicides and sowing date were unbalanced, because the pre-emergent Invado® and post-emergent Othello® were only used with standard sowing date and the pre-sowing Biffo® was only used before the delayed sowing, the data for the two sowing dates have been analysed separately (Table 8).

Normal sowing date

For normal sowing date the pre-emergent Invado® was not statistically significant to no herbicide (Table 8). Invado® needs to have an unbroken cap or skin of herbicide on the soil surface to work. Therefore, where the Invado® plots were tine weeded this may have reduced the length of its residual control. However, comparing the non-tine treatments plots with Invado® and without herbicides there was no difference in the weed biomass (Table 9) indicating that tine weeding did not negatively impact it. Comparing the pre-emergent Invado® with the post-emergence Othello® in the non-tine weeded plots, where both were only used for the normal sowing date, Othello® achieved much lower weed biomass (Table 9) indicating that Invado® had a lower overall level of weed control. Othello® achieved very low weed biomass both with tine weeding and non-tine weeded treatments (Table 8).

Under normal sowing date the barley yield was

statistically significant with Othello® being different to the Invado® and null control, which were the same.

Delayed sowing date

Under delayed sowing the pre-sowing Biffo® glufosinate did not statistically reduced weed biomass (Table 8). Biffo® was better than no herbicide in the absence of tine weeding, but in the presence of tine weeding they were the same (Table 9).

Under delayed sowing, the barley yield is not significant between the Biffo® and the null control. When comparing the Biffo® with the no herbicide treatment excluding tine weeding there is a yield difference (Table 9) indicating that tine weeding is confounding this result.

Table 9. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) under a normal sowing date of 1 September with either pre-emergent Invado® or post-emergent Othello® herbicides or without herbicides, or under delayed sowing date of 21 September 2023 with and without Biffo® herbicide pre-sowing grown under irrigation at Kowhai farm, Lincoln in 2023-24.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
Normal sowing				
No herbicide	197 ns	161 ns	41 b	10.30 b
Pre-emergent Invado®	207 ns	149 ns	30 b	10.52 b
Post-emergent Othello®	226 ns	162 ns	0.3 a	11.58 a
Mean	210	157	24	10.35
P value	0.293	0.573	0.021	0.046
$LSD_{0.05}$	37.8	29.2	20.5	1.065
CV%	20%	22%	127%	10%
Delayed sowing				
No herbicide	173 ns	146 ns	27 ns	9.93 ns
Biffo® pre-sowing	163 ns	142 ns	13 ns	10.77 ns
Mean	168	144	20	10.80
P value	0.717	0.870	0.162	0.64
$LSD_{0.05}$	58.4	52.9	20.5	0.90
CV%	31%	33%	98%	9%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Normal sowing = 1st September 2023 and delayed sowing = 21st September. Biffo® glufosinate Group 10, 200 g/L @ 5.0 L/ha, Invado® 400g/litre Flufenacet SC Group 15, @ 300 ml/ha, Othello® 50g/litre diflufenican Group 12, 7.5g/litre mesosulfuron methyl Group 2, 2.5g/litre iodosulfuron methyl sodium Group 2, + 22.5g/litre mefenpyr-diethyl (safener) @ 1 L/ha. ns = not significant, values in the same column with the same letter after them are not significantly different.

Interactions - tine weeding and herbicides

Herbicides without tine weeding

The no tine weeding treatments showed the direct effects of the herbicides (Table 9). As discussed above, there are clear and statistical differences among the herbicides for both weed biomass and barley yield. The pre-emergent Invado® had no effect on either weeds or crop yield. Pre-sowing Biffo® did show a statistically significant difference in both yield and weeds, with weed biomass reducing by approximately two thirds and with just under a 1.5 t/ha yield increase over the control. The post-emergent Othello® was clearly the most effective, reducing weed biomass to very low levels and it had the highest yield of 11.9 t/ha, 2.4 t/ha more the null control. Yield therefore showed a clear relationship with weeds with lower weed biomass corresponding to higher yields.

Herbicides and tine weeding

When combined with tine weeding the differences among the herbicides are considerably reduced compared without spring tine weeding (Table 9). The overall means for weed biomass with and without tine weeding shows that tine weeding was making a significant contribution to weed management (Table 9).

Table 10. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) for the interaction of tine weeding and herbicides, grown under irrigation at Kowhai farm, Lincoln in the 2023-24 season.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
No tine weeding				
No herbicide	195 ns	149 ns	59 d	9.54 a
Pre-emergent Invado®	193 ns	143 ns	51 cd	9.49 a
Biffo® pre-sowing	185 ns	168 ns	20 b	11.01 bc
Post-emergent Othello®	234 ns	167 ns	0.3 a	11.93 e
Mean	202	157	38	10.61
Tine weeded				
No herbicide	176 ns	158 ns	10 ab	10.63 b
Pre-emergent Invado®	222 ns	154 ns	9 ab	11.56 de
Biffo® pre-sowing	141 ns	117 ns	6 a	10.53 b
Post-emergent Othello®	218 ns	157 ns	0.2 a	11.23 cd
Mean	189	147	7	10.99
Overall mean	195	152	19	10.74
P value	0.280	0.156	<.001	<.001
$LSD_{0.05}$	46.6	38.91	13.6	0.786
CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Tine weeding occurred on 4th, 10th and 25th September 2023. Biffo® glufosinate Group 10, 200 g/L @ 5.0 L/ha, Invado® 400g/litre Flufenacet SC Group 15, @ 300 ml/ha, Othello® 50g/litre diflufenican Group 12, 7.5g/litre mesosulfuron methyl Group 2, 2.5g/litre iodosulfuron methyl sodium Group 2, + 22.5g/litre mefenpyr-diethyl (safener) @ 1 L/ha. ns = not significant, values in the same column with the same letter after them are not significantly different.

Interactions - tine weeding and sowing date

As previously discussed, tine weeding reduced weed biomass. However, for the interaction with sowing date it was statistically significant only for normal sowing date with a large reduction in weed biomass. In the delayed sowing treatment while tine weeding reduced weed biomass by over half it was not quite statistically significant (Table 10). This is in line with the analysis of sowing date as a sole factor which shows that delaying sowing alone reduced weed biomass, so when combined with tine weeding there was a smaller starting amount of weed biomass for the tine weeder to control.

Barley yield varied by just under 1 t/ha between the lowest and highest treatments with normal sowing date with tine weeding having the highest yield and delayed sowing without tine weeding the lowest (Table 10), which is in keeping with other analyses finding that tine weeding increased yield, and delayed sown decreased it.

Table 11. Spring barley, cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight) for the interaction of tine weeding and sowing date, grown under irrigation at Kowhai farm, Lincoln in the 2023-24 season.

Treatment	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
No tine weeding				
Delayed sowing	206 ns	164 ns	20 b	10.17 a
Normal sowing	196 ns	149 ns	50 c	10.40 ab
Mean	201	157	35	10.29
Tine weeding				
Delayed sowing	151 ns	123 ns	8 ab	10.58 ab
Normal sowing	210 ns	166 ns	6 a	11.14 b
Mean	181	145	7	10.86
Overall mean	191	151	21	10.57
P value	0.075	0.072	0.007	0.597
$LSD_{0.05}$	45.65	38.13	13.33	0.770
CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Normal sowing = 1st September 2023 and delayed sowing = 21st September. Tine weeding occurred on 4th, 10th and 25th September 2023. ns = not significant, values in the same column with the same letter after them are not significantly different.

Non-factorial analysis

Due to the unbalanced design, the non-factorial analysis presented in Table 11 provides an additional perspective on the overall results.

The non-factorial analysis shows a small statistical significance (p=0.024) for barley dry weight, no significant difference for barley heads (p=0.256) and highly significant difference for weed biomass and barley yield (p<0.001, Table 11), which is in keeping with the factorial analysis.

The best performing treatments across all three statistically significant measurements are:

- Treatment 4, no tine weeding, normal sowing date with post-emergent Othello®
- Treatment 8, tine weeded, normal sowing with pre-emergent Invado®
- Treatment 9, tine weeded, normal sowing date with post-emergent Othello®

Table 12. Spring barley cv. Silhouette, biomass (dry weight) head count and yield, and weed biomass (dry weight), for all ten treatments analysed as independent variables by general ANOVA using Fisher's protected LSD test, grown under irrigation at Kowhai farm, Lincoln, in the 2023-24 season.

Trt	Tine weeding	Sowing date	Herbicide	Barley dry weight grams	Barley head count	Weed dry weight grams	Barley yield t/ha
1	No tine weeding	Delayed sowing	No herbicide	200 bc	157 ns	44 c	9.5 a
2	No tine weeding	Delayed sowing	Glufosinate pre sow	185 abc	168 ns	20 b	11.0 cd
3	No tine weeding	Normal sowing	Pre-em Invado®	193 abc	143 ns	51 c	9.5 a
4	No tine weeding	Normal sowing	Post-em Othello®	234 c	167 ns	0.3 a	11.9 e
5	No tine weeding	Normal sowing	No herbicide	190 abc	142 ns	74 d	9.7 ab
6	Tine weeded	Delayed sowing	No herbicide	146 ab	136 ns	11 ab	10.4 abc
7	Tine weeded	Delayed sowing	Glufosinate pre sow	141 a	117 ns	6 ab	10.5 bc
8	Tine weeded	Normal sowing	Pre-em Invado®	222 c	154 ns	9 ab	11.6 de
9	Tine weeded	Normal sowing	Post-em Othello®	218 c	157 ns	0.2 a	11.2 cde
10	Tine weeded	Normal sowing	No herbicide	205 c	180 ns	9 ab	10.9 cd
			Mean	193	152	22	10.6
			P value	0.024	0.256	<.001	<.001
			$LSD_{0.05}$	53.8	44.9	15.71	0.91
			CV%	26%	26%	118%	10%

Note: Barley dry weight and head count from 1 m row length. Weed dry weight from 0.25 m^2. Barley yield at 14% moisture content. Normal sowing = 1st September 2023 and delayed sowing = 21st September. Tine weeding occurred on 4th, 10th and 25th September 2023. Biffo® glufosinate Group 10, 200 g/L @ 5.0 L/ha, Invado® 400g/litre Flufenacet SC Group 15, @ 300 ml/ha, Othello® 50g/litre diflufenican Group 12, 7.5g/litre mesosulfuron methyl Group 2, 2.5g/litre iodosulfuron methyl sodium Group 2, + 22.5g/litre mefenpyr-diethyl (safener) @ 1 L/ha. ns = not significant, values in the same column with the same letter after them are not significantly different. ns = not significant, values in the same column with the same letter after them are not significantly different.

Summary

The barley autumn and spring weed control 2023-24 (spring tine weeder and herbicides) X22-01-04 experiment was the first trial undertaken by FAR to start investigating the use of mechanical weeding and its integration with herbicides. Three factors were studied: (1) tine weeding, (2) sowing date and (3) herbicides, in an unbalanced design (Table 12), for their impact on weed dry matter, and barley dry weight, head count and yield at or just before barley harvest.

Table 13. Treatments and post-hoc treatment factors for the barley autumn and spring weed control trial at Kowhai in 2023-24.

Treatment code	Tine weeding	Sowing Date	Herbicide
1	No tine weeding	Delayed sowing	No herbicide
2	No tine weeding	Delayed sowing	Glufosinate pre-sowing
3	No tine weeding	Normal sowing	Pre-emergence Invado®
4	No tine weeding	Normal sowing	Post-emergence Othello®
5	No tine weeding	Normal sowing	No herbicide
6	Tine weeded	Delayed sowing	No herbicide
7	Tine weeded	Delayed sowing	Glufosinate pre-sowing
8	Tine weeded	Normal sowing	Pre-emergence Invado®
9	Tine weeded	Normal sowing	Post-emergence Othello®
10	Tine weeded	Normal sowing	No herbicide

Note: Note: Normal sowing = 1st September 2023 and delayed sowing = 21st September. Tine weeding occurred on 4th, 10th and 25th September 2023. Biffo® = glufosinate Group 10, 200 g/L @ 5.0 L/ha pre sowing, Invado® = 400g/litre Flufenacet SC Group 15, @ 300 ml/ha, Othello® = 50g/litre diflufenican Group 12, 7.5g/litre mesosulfuron methyl Group 2, 2.5g/litre iodosulfuron methyl sodium Group 2, + 22.5g/litre mefenpyr-diethyl (safener) @ 1 L/ha.

Tine weeding achieved good levels of weed control, though less than the best performing herbicide the post-emergence Othello®. When combined with herbicides spring tine weeding reduced weed populations in the less effective herbicide treatments, indicating it was providing additional weed control. As Othello® reduced weeds to very low levels tine weeding was unable to reduce them any further. Tine weeding had some small negative impacts on barley biomass and head counts in a few treatments but this did not impact yield, rather tine weeding slightly increased yield by 0.6 t/ha from 10.3 t/ha to 10.9 t/ha.

There were clear differences among the herbicides with the pre-emergence Invado® performing poorly on both weed control and barley yield, the reason for the poor performance is unknown. The post-emergent glufosinate used prior to sowing the delayed sowing treatment achieved medium levels of weed management, and slightly improved yields, but, this effect was confounded due it being only used with the delayed sowing which by itself somewhat decreased weeds and increased yield. Othello® was the clear standout among the herbicides, achieving highly effective weed control and producing the first and third highest yields, of 11.9 t/ha without tine weeding and 11.2 t/ha with tine weeding, though statistically the two yields are the same.

Delayed sowing slightly reduced weed biomass but also slightly reduced barley yield by 0.4 t/ha from 10.8 t/ha for normal sowing date to 10.4 t/ha for delayed sowing though the yield difference was not statistically significant. This is viewed as neither strong support for, nor strong evidence against later sowing, such that standard sowing date is most likely to be optimal but that delaying sowing, e.g. due to weather, will not cause a large yield loss and could be a useful tactic under high weed pressure allowing the use of false seedbeds.

Overall the trial showed that tine weeding is a viable weed management option in spring barley, both achieving medium levels of weed control and slightly increasing yields by itself. It also worked in conjunction with herbicides reducing weed biomass where herbicide weed control was less effective, and assisting in maintaining or slightly increasing yields. Delayed sowing achieved a minor reduction in weeds but also a non-statistically significant yield reduction, and can be viewed as an option where farming factors conspire against standard planting date.

In conclusion, the trial indicates that mechanical weeding, in the form of spring tine weeding, is a viable option for spring barley, both alone and in conjunction with herbicdes. The tine weeder also proved valuable in improving weed management and supporting yield where herbicide performance was sub-optimal. Considering the ongoing challenges to herbicides due to evolved resistance, lost of chemistry etc., spring tine weeders and other forms of mechanical weeding are likely to be of increasing importance for arable farmers. Therefore further spring tine weeder demonstration trials in barley using false seedbeds, blind harrowing and integration with herbicides are being undertaken, with a view to trials in other arable crops with different mechanical weeders in future years for example, using interrow hoes in maize.

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Einböck GmbH. (2022). The organic farming handbook. Retrieved from https://www.einboeck.at/en/know-how/organic-farming-handbook

Appendix 2

Table 14. Weekly weather record for 2023-24 spring barley tine weeding and herbicide trial.

Week	Mean Max Air Temp. (°C)	Mean Min Air Temp. (°C)	Mean Air Temp. (°C)	Total Rainfall (mm)	Mean Total Solar Energy (Mj/m²)	Total Evapo-transpiration (mm/d)
1/09/2023 - 7/09/2023	17	7	12	1	6	11
8/09/2023 - 14/09/2023	19	5	12	0	10	17
15/09/2023 - 21/09/2023	21	9	15	0	10	26
22/09/2023 - 28/09/2023	11	3	7	47	6	8
29/09/2023 - 5/10/2023	19	6	12	10	14	23
6/10/2023 - 12/10/2023	17	5	11	7	12	17
13/10/2023 - 19/10/2023	19	6	12	20	14	23
20/10/2023 - 26/10/2023	19	8	14	7	14	20
27/10/2023 - 2/11/2023	18	8	13	20	17	19
3/11/2023 - 9/11/2023	16	6	11	48	12	13
10/11/2023 - 16/11/2023	22	9	16	0	21	28
17/11/2023 - 23/11/2023	21	9	15	51	19	23
24/11/2023 - 30/11/2023	19	7	13	13	17	20
1/12/2023 - 7/12/2023	20	10	15	28	15	21
8/12/2023 - 14/12/2023	19	9	14	17	16	22
15/12/2023 - 21/12/2023	24	12	18	18	18	25
22/12/2023 - 28/12/2023	21	13	17	47	11	16
29/12/2023 - 4/01/2024	25	12	19	5	22	30
5/01/2024 - 11/01/2024	24	12	18	15	19	26
12/01/2024 - 18/01/2024	24	13	18	3	17	25
19/01/2024 - 25/01/2024	25	14	20	32	18	29
26/01/2024 - 1/02/2024	25	13	19	1	20	29
2/02/2024 - 8/02/2024	24	11	18	2	12	20
9/02/2024 - 15/02/2024	24	9	16	21	16	25
16/02/2024 - 22/02/2024	23	9	16	3	17	21

Appendix 3

Table 15. Raw trial data

Plot	trtl	Blockl	Tineweedingl	SowingDatel	Herbicide l	dry_wt_barley	Dry_wt_weeds	Barley_heads	Yield t.ha 14pc mc
101	2	1	No tine weeding	Delayed sowing	Glufosinate pre sow	247.5	3	184	11.60
102	7	1	Tine weeded	Delayed sowing	Glufosinate pre sow	214.8	0	158	11.20
103	5	1	No tine weeding	Normal sowing	No herbicide	225.2	63	154	10.41
104	9	1	Tine weeded	Normal sowing	Post-em Othello	215.6	0	167	11.65
105	4	1	No tine weeding	Normal sowing	Post-em Othello	244	0	192	12.56
106	8	1	Tine weeded	Normal sowing	Pre-em Invado	240.1	0.9	151	12.34
107	10	1	Tine weeded	Normal sowing	No herbicide	274.4	6.6	205	10.73
108	1	1	No tine weeding	Delayed sowing	No herbicide	262.9	25.7	169	9.50
109	3	1	No tine weeding	Normal sowing	Pre-em Invado	233.3	37.3	171	9.31
110	6	1	Tine weeded	Delayed sowing	No herbicide	142.3	23.7	126	10.12
201	9	2	Tine weeded	Normal sowing	Post-em Othello	218.3	0	169	11.31
202	8	2	Tine weeded	Normal sowing	Pre-em Invado	269.2	1.3	177	11.59
203	1	2	No tine weeding	Delayed sowing	No herbicide	224.4	38.3	194	*
204	5	2	No tine weeding	Normal sowing	No herbicide	197.3	53.8	152	9.69
205	7	2	Tine weeded	Delayed sowing	Glufosinate pre sow	139.2	2.4	104	11.53
206	6	2	Tine weeded	Delayed sowing	No herbicide	161.5	0.2	201	11.19
207	3	2	No tine weeding	Normal sowing	Pre-em Invado	172.3	69.2	141	9.66
208	10	2	Tine weeded	Normal sowing	No herbicide	180.3	11.7	196	10.57
209	2	2	No tine weeding	Delayed sowing	Glufosinate pre sow	167.5	9.4	189	11.62
210	4	2	No tine weeding	Normal sowing	Post-em Othello	163.1	0	97	11.80
301	10	3	Tine weeded	Normal sowing	No herbicide	156.9	8.6	119	10.83
302	3	3	No tine weeding	Normal sowing	Pre-em Invado	130.2	44.8	104	9.94
303	2	3	No tine weeding	Delayed sowing	Glufosinate pre sow	118.4	40.7	118	10.80
304	6	3	Tine weeded	Delayed sowing	No herbicide	86.8	10.4	30	10.72
305	8	3	Tine weeded	Normal sowing	Pre-em Invado	186.7	13.4	135	11.13
306	1	3	No tine weeding	Delayed sowing	No herbicide	155.5	41.1	138	9.11
307	4	3	No tine weeding	Normal sowing	Post-em Othello	213.9	0	143	12.58
308	7	3	Tine weeded	Delayed sowing	Glufosinate pre sow	121.4	3.5	76	10.15
309	9	3	Tine weeded	Normal sowing	Post-em Othello	191.1	0	115	10.08
310	5	3	No tine weeding	Normal sowing	No herbicide	162.2	85.4	113	9.65
401	4	4	No tine weeding	Normal sowing	Post-em Othello	315.3	1.3	234	10.77
402	6	4	Tine weeded	Delayed sowing	No herbicide	194.9	7.6	188	9.37
403	3	4	No tine weeding	Normal sowing	Pre-em Invado	234.9	51.7	156	9.05
404	10	4	Tine weeded	Normal sowing	No herbicide	207.7	8.9	199	11.54
405	1	4	No tine weeding	Delayed sowing	No herbicide	157.6	70.8	125	9.48
406	2	4	No tine weeding	Delayed sowing	Glufosinate pre sow	206.3	27.3	179	10.04
407	5	4	No tine weeding	Normal sowing	No herbicide	175.1	93.7	149	8.96
408	9	4	Tine weeded	Normal sowing	Post-em Othello	247.6	0.9	178	11.89
409	8	4	Tine weeded	Normal sowing	Pre-em Invado	190.4	19.9	153	11.16
410	7	4	Tine weeded	Delayed sowing	Glufosinate pre sow	90.3	18.5	130	9.24

Crop competition in weed control

Project code X22-01-12

Duration Year 1 of 4 (2023-24 season)

Authors Charles Merfield (FAR), Pieter-Willem Hendriks (Lincoln University)

Location Chertsey, Canterbury

Funding Lincoln University and FAR

Acknowledgements NZ Arable (trial management)

Key points

- Herbicide resistance is a growing issue and Integrated Weed Management approaches such as improve crop competitiveness with weeds are required.
- Utilising the existing 2023-24 wheat cultivar performance trial (CPT) at Chertsey the light interception, canopy cover and tiller numbers of 15 wheat cultivars were compared, as an initial exploration of wheat competitiveness against weeds.
- Significant differences among the cultivars for light interception and canopy cover were found but not tiller numbers.
- As this research was conducting within the existing CPT trial, actual weed competitiveness and its impact on yield could not be measured. The results do however show there are considerable differences in plant architecture among wheat cultivars that are known to impact competitiveness with weeds. This supports undertaking more comprehensive trials, which include competition with natural weed flora and taking the crop to harvest for yield and economic analysis.

Background

The increase in herbicide resistance in weeds, the lack of new herbicide active ingredient chemistry and increasing legislative and market pressure are all significant challenges for herbicide-based weed management New Zealand arable cropping. Integrated Weed Management (IWM) is the global answer to these challenges through the integration of physical, chemical biological and ecological weed management approaches. Ecological management of weeds through increasing crop competitiveness by increased early biomass and faster canopy closure is a key aspect of IWM in arable crops. However, there is large variability among species and cultivars regarding their competitiveness. Early shoot vigour, leaf area, different plant architectures, e.g. vertical, erect vs horizontal leaves, rate of germination, are considered key aspects of crop competition. Thus, there is a need to better understand which aspects of plant architecture maximise the competitive ability of cereal crops and assess the variability of these traits in New Zealand cultivars.

This research leveraged the existing 2023-24 Cultivar Performance Trial (CPT) site at Chertsey to undertake light interception and canopy cover measurements to study the above ground competitiveness of wheat cultivars.

Methods

This research was instigated and undertaken by Dr Pieter-Willem Hendriks to utilise the existing 2023-24 Cultivar Performance Trial (CPT) site at Chertsey to measure differences in light interception and canopy cover of the different wheat cultivars as a starting point for future research into variation in weed competitiveness among wheat cultivars. This report is based on the publication 'Canopy closure and light interception of New Zealand wheat genotypes for integrated weed management' (Hendriks, Gunnarsson, Holmes, Drummond, & Merfield, 2024).

Overall trial details

The experiment was undertaken in the 2023-24 CPT site at Chertsey under irrigation. The CPT was sown on 24/04/2023 with a target population of 150 plants/m2 at a row spacing of 15 cm in a Southwest-Northeast direction. The experiment was fertilised and maintained as for a standard wheat crop. In growing-season rainfall was approximatively 480 mm. In addition, the trial received a seasonal total of 125 mm of water over seven passes of irrigation.

Fifteen commercial and pre-commercial cultivars measured were CK130, CK25, CRWT267, CRWT268, Firelight, Graham, Ignite, Kerrin, KFW2102, KFW2201, Reflection, Starfire, SY119179, Voltron and Whopper, both milling and feed wheats.

Light interception, canopy cover and tiller numbers were measured at the following four growth stages, Zadoks growth scale and date:

- Early tillering, Z21, 28/07/23
- Mid tillering, Z30, 18/08/23
- Early stem elongation, Z31, 12/10/23.
- Canopy closure, Z32, 25/10/23

Light interception (%) was calculated by measuring the difference in photosynthetically active radiation (PAR; mol m^{-2} s^{-1}) above and below the crop canopy using a ceptometer (AccuPAR LP-80 Ceptometer, Decagon Devices®). Canopy closure was calculated from periodic images of approximately 1 m^2 taken directly above the canopy at 120 cm height using a digital camera. The leaf area in the images was calculated using the MS Visual Studio 2005® "Canopy Cover" program. Tiller numbers were counted on five randomly selected plants per plot.

All statistical analyses were performed, and figures were constructed in R®[2]. Each mixed model contained random components related to the structure of the experimental design for each experiment, such as plot position. An analysis of variance and estimation of least squares means were conducted, with genotypes as fixed effects using the function "lme" in "emmeans" in R software package. Pairwise comparisons between the genotype means were obtained using the pairs function in the "emmeans". Benjamin-Hochberg pairwise comparisons between genotype means were conducted by the pairs function in "emmeans" in R. Plots were generated using "ggplot2" in R with error bars representing standard error.

Results and Discussion

Wheat crop canopy light interception

Throughout tillering and until near canopy closure at the two-node stage (Z32) there were significant differences in light interception among the different cultivars (Figure 1).

Cultivars that consistently intercepted more light were CRWT267, Firelight, KFW2201 and Voltron. Conversely, Ignite, Graham, KFW2102 and Reflection intercepted the least light at all growth stages. Differences between the best cultivars intercepted twice as much light as the poorest at early and mid-tillering. CRWT267 intercepted up to three times more light at mid-tillering than the least intercepting cultivars. At early stem elongation, there was still a highly significant (P<0.001) 30% difference between the high and low interception cultivars.

[2] https://www.r-project.org/

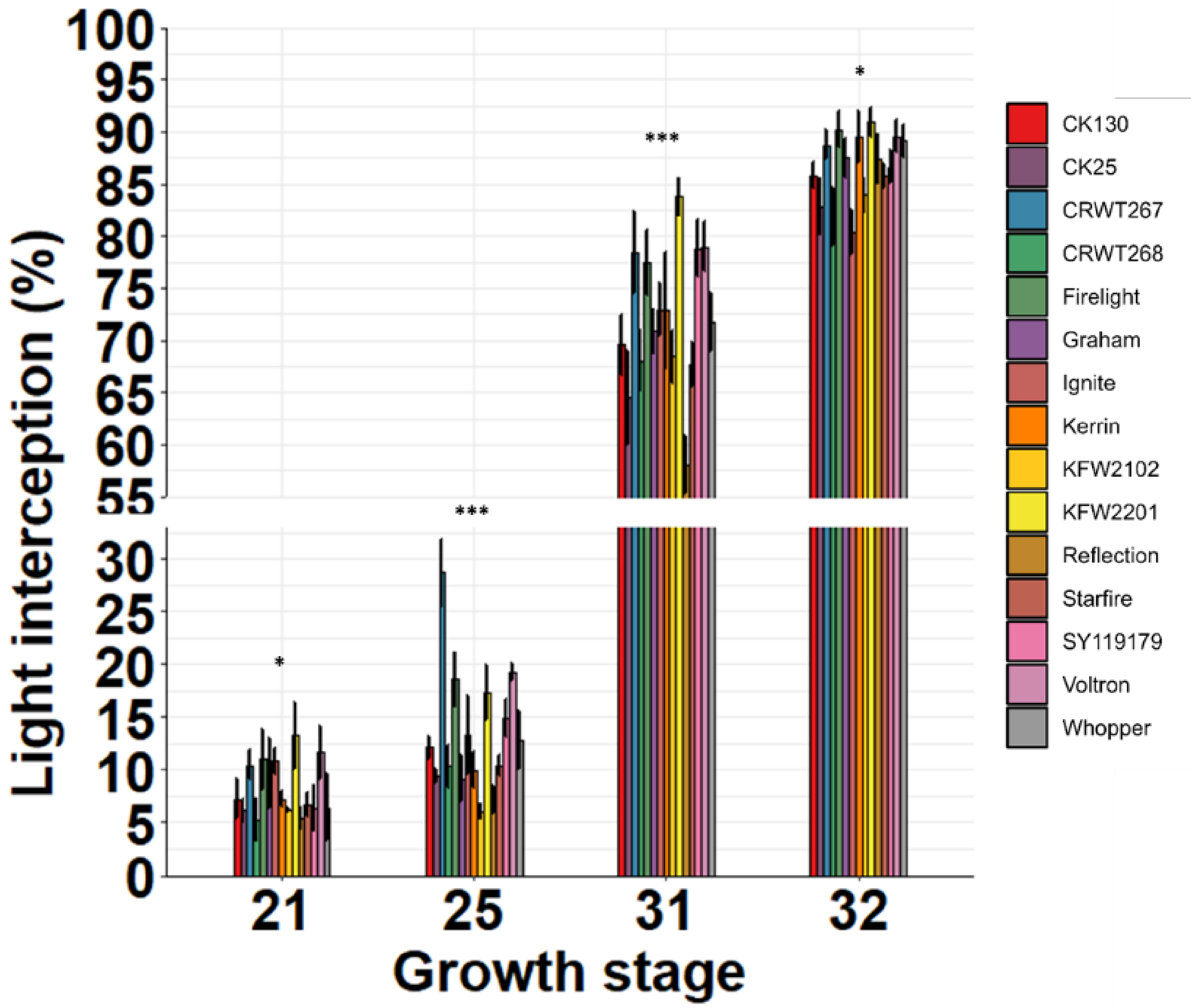

Figure 5. Comparison of light interception of different New Zealand wheat cultivars undertaken in the 2023-24 wheat cultivar performance trial (CPT) at Chertsey sown 24/04/2023. Assessments undertaken at early tillering (Z21), mid tillering (Z25), early stem elongation (Z31) and two node stage (Z32) n=4 for each genotype at each growth stage. The error bars represent standard errors. ns: no significant difference, *: P=0.05, **: P=0.01, *** P=0.001.

Wheat crop canopy ground cover and tiller numbers

Wheat crop canopy ground cover measured as a percentage of leaves covering soil (Figure 2) showed a highly significant difference (P<0.001) from mid-tillering to the second node stage.

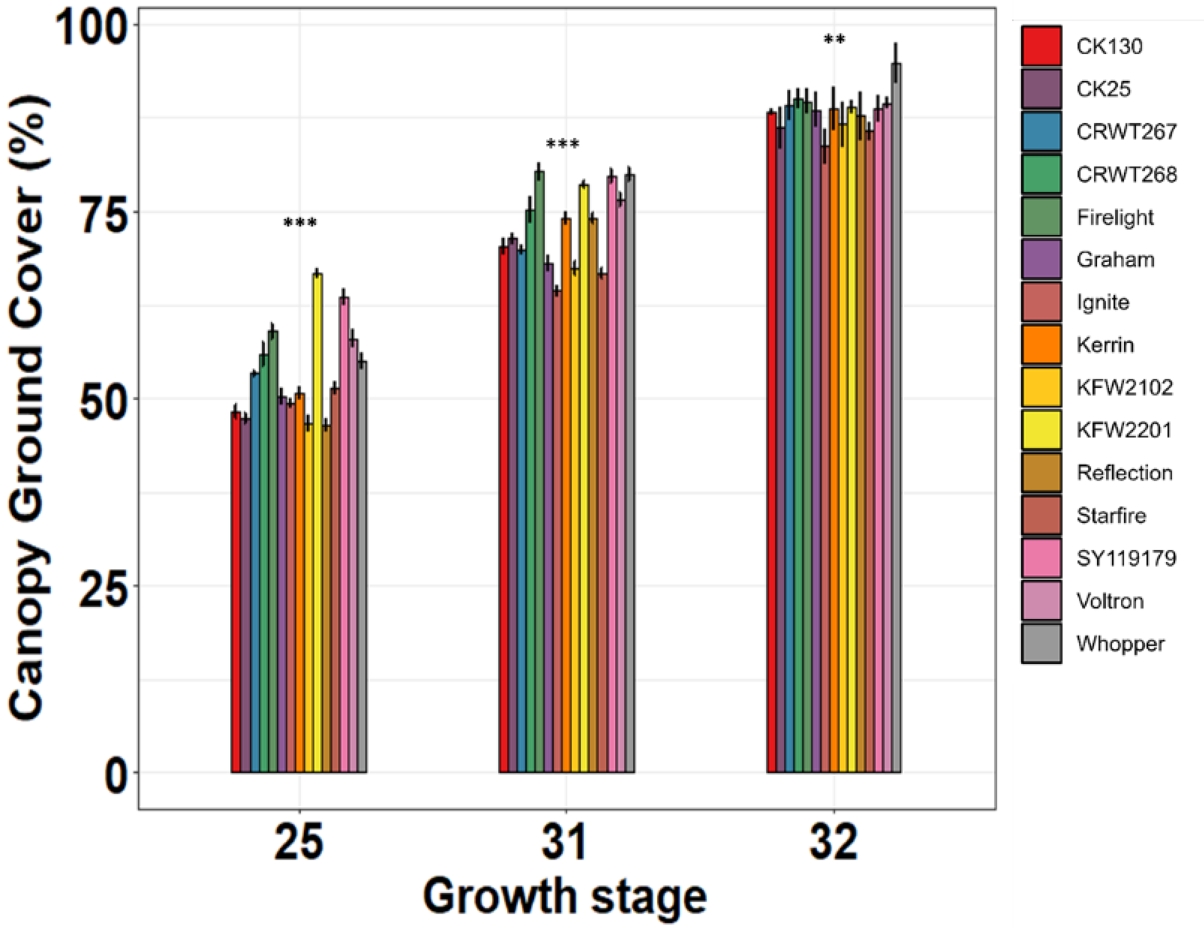

Figure 6. Comparison of crop canopy ground cover of different New Zealand wheat cultivars undertaken in the 2023-24 wheat cultivar performance trial (CPT) at Chertsey sown 24/04/2023. Assessments were realised at mid tillering (Z25), early stem elongation (Z31) and two node stage (Z32) n=4 for each genotype at each growth stage. The error bars represent standard errors. ns: no significant difference, *: P=0.05, **: P=0.01, *** P=0.001.

The number of tillers counted from mid-tillering to the second node showed no significant difference (data not shown) except for Reflection at the end of the experiment which possessed significantly more tillers.

The same cultivars that had a lower light interception also ranked at the bottom for ground cover. Over the measured growth stages, Reflection, Ignite, Graham and KFW2102 covered less ground than the other cultivars. The top-ranking cultivars for ground cover were KFW2201, SY119179, Firelight and Whopper.

Relationship between different measured traits

The relationship between light interception and tiller number (Figure 3) and light interception and canopy cover (Figure 4) over all growth stages only showed a significant positive relationship between tiller numbers and light interception ($P<0.05$) at mid-tillering (Figure 3a) with an R^2 of 0.14. At the other growth stages, there was no significant relationship between light interception and tiller number (Figures 3b and 3c).

Ground cover was highly significantly ($P<0.001$ and $P<0.01$) positively related to light interception from mid-tillering (Figure 4a) to the second node stage (Figure 4c). The R^2 values for these correlations were 0.21, 0.16 and 0.12 for Z25, Z31 and Z32, respectively.

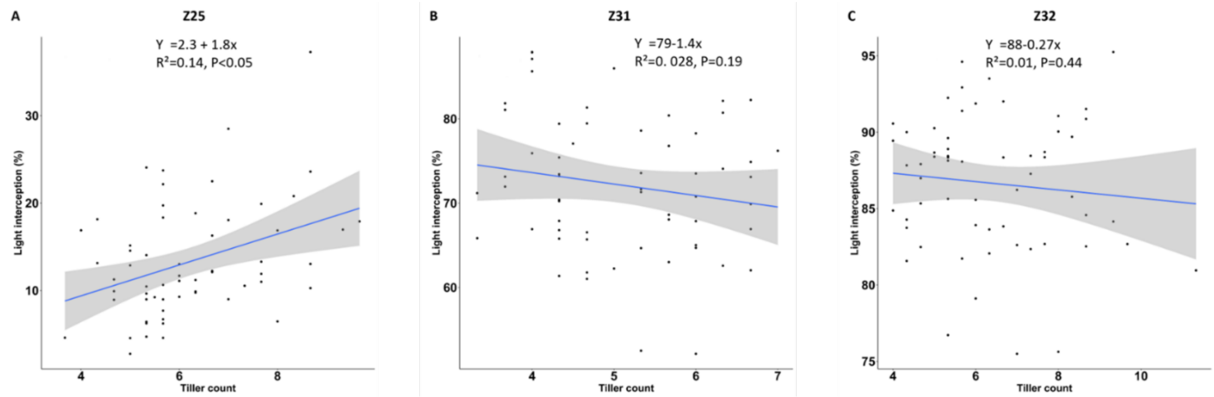

Figure 7. The relationship between light interception and tiller counts measured at Z25 (A), Z31 (B) and Z32 (C) of different New Zealand wheat cultivars undertaken in the 2023-24 wheat cultivar performance trial (CPT) at Chertsey sown 24/04/2023.

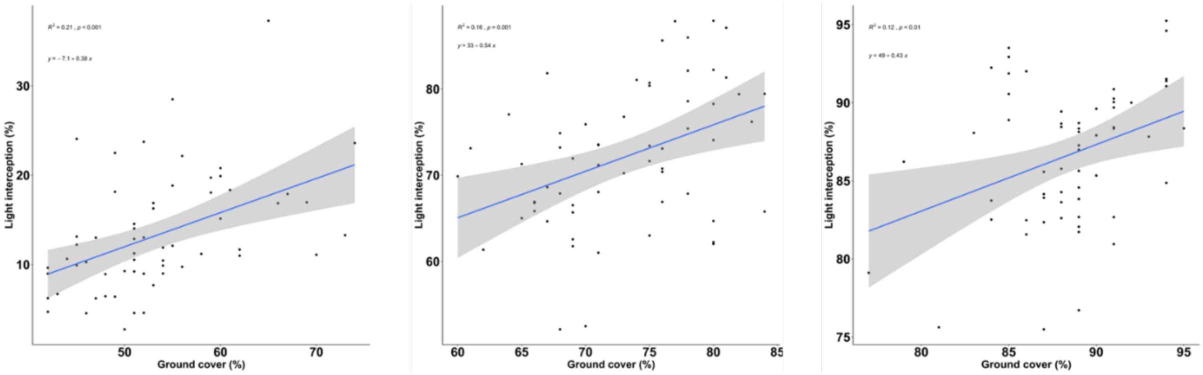

Figure 8. The relationship between light interception and ground cover measured at Z25 (A), Z31 (B) and Z32 (C) of different New Zealand wheat cultivars undertaken in the 2023-24 wheat cultivar performance trial (CPT) at Chertsey sown 24/04/2023.

Discussion and conclusions

The aim of this study was to assess whether New Zealand wheat cultivars have variability in above-ground competitive traits. Crop competition against weeds is a critical part of IWM in arable crops. A key component of above ground competition is early crop canopy closure as this reduces the amount of light available to weeds, and thus limits their growth. This is because the percentage of photosynthetically active radiation (sunlight) available under the crop canopy is generally positively correlated with weed growth and seed set. These results shows that these wheat cultivars display significantly different levels of light interception from early tillering onwards.

Previous research has demonstrated that light interception from the earliest crop growth stages is critical for maximising crop competition (Hendriks, Gurusinghe, Ryan, Rebetzke, & Weston, 2022). This suggests that some of these cultivars may be better competitors than others. While the current study shows significant differences in light interception, we could not confirm that this resulted in improved competitiveness because the trials were kept weed-free with herbicides as they were part of a larger cultivar comparison trial. Nevertheless, the results show that there are significant differences in light interception between the different cultivars, suggesting that cultivar choice could be a potentially important IWM technique in New Zealand wheat crops and should be studied further.

Interestingly, other measured traits, including tiller number and groundcover, only partially explain light interception differences between the cultivars. Leaf emergence and leaf angle may partially account for the genotypic variation in light interception and therefore also deserve further study.

The results from this study show that there is variability among New Zealand wheat cultivars for light interception which has been demonstrated to impact the competitive ability of wheat. Further research should assess the in-field competitiveness of these cultivars and further identify the physiological traits that allow improved competitiveness. Furthermore, to get a better understanding of the potential economic gains that would result from the introduction of more competitive crops in the New Zealand wheat industry, dedicated economic studies as well as farm scale field experiments should be attempted in the future.

Summary

Herbicide resistance is a growing issue on New Zealand arable farms. Integrated Weed Management (IWM) approaches are required as part of a whole-of-system approach to address herbicide resistance. For cereals, competition by the crop against weeds can be a large component of overall weed management. There is also a growing body of research demonstrating considerable differences in weed competitiveness among cultivars of cereal species, including wheat. However, no studies comparing the weed competitiveness of NZ cereal cultivars grown under NZ conditions has been undertaken.

Utilising the existing 2023-24 FAR wheat cultivar performance trial (CPT) at the Chertsey research site, light interception, canopy cover and tiller numbers of 15 wheat cultivars were compared, as an initial exploration of wheat competitiveness against weeds. These three factors have been shown in previous overseas research to be key wheat plant canopy architectural attributes linked to crop competitiveness with weeds.

Significant differences among the cultivars for light interception and canopy cover were found but not tiller numbers. Between tillering and canopy closure CRWT267, Firelight, KFW2201 and Voltron intercepted the most light while Ignite, Graham, KFW2102 and Reflection intercepted the least. Ground cover showed a significant difference from mid-tillering to the second node stage with the same cultivars that had the highest light interception also ranked best for ground cover. The top-ranking cultivars for ground cover were KFW2201, SY119179, Firelight and Whopper and the lowest ranking cultivars were Reflection, Ignite, Graham and KFW2102.

As this research was conducted within the existing CPT trial which was kept weed free, actual weed competitiveness and its impact on yield could not be measured. The results do however show there are considerable differences in plant architecture among NZ wheat cultivars that are known to impact competitiveness with weeds. This supports undertaking more comprehensive trials, which include competition with natural weed flora and taking the crop to harvest for yield and economic analysis.

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Managing Vulpia hairgrass in perennial ryegrass seed crops

Project code X22-01-03

Duration Year 6 of 6 (2023-24 season)

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Location Chertsey FAR Research Site, Lincoln (-43.791915, 171.959236)

FundingSeed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator)

Key points

1. Vulpia hairgrass (*Vulpia* spp.) is a common and problematic grass weed in perennial ryegrass seed crops.
2. To combat Vulpia hairgrass resistance, incorporating herbicides with diverse modes of action is essential.
3. Early intervention plays a crucial role in managing Vulpia hairgrass infestations in ryegrass seed crops.
4. Applying Nortron® solo or with Quantum® at pre-emergence (PE) showed very high efficacies for controlling Vulpia hairgrass whilst maintaining acceptable levels of crop safety.
5. Prominent® shows promise at early post-emergence (EPE), but its PE application raises crop safety concerns.

Background

Vulpia hairgrass (*Vulpia* spp.) poses a significant challenge in perennial ryegrass (*Lolium perenne*) seed production due to its impact on both yield and quality. Currently, the primary herbicide used to control Vulpia hairgrass in ryegrass crops is Nortron® (active ingredient: 500 g/L ethofumesate, Group 15). However, its repeated use, especially following cereal crops treated with Firebird® (active ingredients: 400 g/L flufenacet + 200 g/L diflufenican, Group 15 + Group 12), may lead to herbicide resistance development. In order to combat resistance in Vulpia hairgrass, it is essential to incorporate herbicides with diverse modes of action and integrate them with other effective weed management practices such as crop rotation. Identifying alternative herbicides that can effectively control Vulpia hairgrass at different growth stages (GS) of perennial ryegrass is therefore essential. Previous trials reported by Smith *et al.* (2019) and Gunnarsson *et al.* (2022) that Nortron® was moderately effective when applied at the 2-leaf stage (Zadoks GS 12) (Zadoks *et al.*, 1974) of Vulpia hairgrass, with some herbicides like Simatop™ (500 g/L simazine, Group 5), Asulox® (400 g/L asulam, Group 18), and Quantum® (500 g/L diflufenican, Group 12) also showing promise with similar or better efficacy (Smith *et al.*, 2019; Gunnarsson *et al.*, 2022). The main objectives of this trial were to:

1. Assess the effectiveness of various pre- and post-emergence herbicide options for controlling Vulpia hairgrass in perennial ryegrass seed crops.
2. Identify potential non-group 15 herbicides that could be used as alternatives to Nortron® for controlling Vulpia hairgrass in perennial ryegrass seed crops at different application timings.

Methods

A small plot trial was established during the 2023-24 growing season at FAR's Research Site near Chertsey (Column 5 - 43.791915, 171.959236) in an irrigated block of perennial ryegrass (cv. Nui) that was drilled at a rate of 12 kg/ha on the 24 April 2023. Within the trial site, Vulpia hairgrass seed was hand spread at a rate of 5 kg/ha at the time of the perennial ryegrass sowing and incorporated using a Cambridge roller. The trial had 17 herbicide treatments (Table 1) arranged in a complete randomised experimental design with four replicates and each plot size was 1.65 m by 10 m.

Herbicide treatments were applied at two different timings, either at the pre-emergence (PE) of ryegrass (GS 00-07) on the 27 April 2023 or early post emergence (EPE) when 50% of ryegrass plants had 2 true leaves (GS 12) on the 12 June 2023.

The number of emerged ryegrass plants per plot was determined by counting all ryegrass plants present within two 0.5 m rows on the 11 August 2023. The level of Vulpia hairgrass control was recorded on a plot basis relative to the untreated control on 25th August 2023 using a scale of 0% to 100%, where 0% = no control and 100% = full control. Herbicide treatments were assessed on a plot basis for phytotoxicity and crop biomass reduction on the 25 August 2023 using a scale of 0% to 100%, where 0% = no damage and 100% = all plants dead with no green leaf (data not presented). Total aboveground biomass was determined for each plot by collecting a representative cut from 3 rows by 50 cm (with row spacings of 15 cm) on the 4 January 2024. From each plot, a biomass subsample, ranging between 90 to 150 g, was taken and separated into either ryegrass, Vulpia hairgrass or other weed components. The number of seed heads in the ryegrass and Vulpia hairgrass portions were then counted from each subsample. Each subsample was dried in paper bags at 105°C until samples reached a constant weight and weighed using a precision balance to determine dry weight. Seed yield was obtained by windrowing plots using a modified John Deere plot windrower with a 1.6 m cut width on the 5 January 2024 and harvesting all treatment plots with a Wintersteiger Classic plot harvester on the 10 January 2024. Machine dressed yield, percentage dressing loss and thousand seed weight (TSW) were all determined post-harvest. To determine the percentage of Vulpia hairgrass contamination (purity of samples), a 3 g subsample of machine dressed ryegrass seed from each plot was weighed. Seeds were manually separated into three categories: ryegrass, Vulpia hairgrass, and other (including other weed seeds and inert matter). Each component was weighed separately, and the percentage by weight calculated relative to the total sample weight.

All analyses of trial data were conducted using R software programming language (R Core Team, 2024). The Akaike Information Criterion (AIC), which estimates prediction error, and thus the relative quality of statistical models, was computed using the R packages 'AICcmodavg' (Mazerolle, 2020) and 'VGAM' (Yee, 2010) for each variable. Models with lowest AIC values (AICc) and fewer parameters (K) were considered to have the best fit. All analyses were carried out using the R packages 'stats' and 'lme4' (Bates *et al.*, 2015). Data collected from seed quality variables including TSW and purity (% Vulpia relative to sample weight) were analysed using a multi-way analysis of variance (ANOVA), with a linear model treating treatment, replicate, block and column as fixed effects. All other variables were analysed using a two-way linear model with treatment, block and column treated as fixed effects. The adjusted means, least significant difference (LSD), and coefficient of variation (CV) were generated using the R package 'predictmeans' (Luo *et al.*, 2014). The percentage of control relative to untreated control was calculated using the number of Vulpia hairgrass seed heads per m^2 for all treatments using Abbott's formula for corrected efficacy described by Abbott (1925).

Overall trial details

A full description of trial management details is shown in Appendix 1. During the year of the trial there were no grass herbicides applied for maintenance within the trial site.

Results and Discussion

The findings of this trial underscore the crucial role of early intervention in effectively managing Vulpia hairgrass infestations in perennial ryegrass seed crops, as evidenced by past FAR/SIRC trials (Smith *et al.*, 2019; Gunnarsson *et al.*, 2022). For example, as shown in Tables 1 and 2, 4 L/ha Nortron® applied at PE in a tank mix with 100 mL/ha of Quantum® (Treatment 6) as well as 4 L/ha Nortron® applied at PE followed at EPE with either 2 L/ha of Prominent® (Treatment 4) or 4 L/ha of Asulox® (Treatment 5) were able to achieve the highest levels of seed yield and Vulpia hairgrass control (Abbot > 95%) with acceptable levels of crop safety (phytotoxicity <5%; data not presented) for the perennial ryegrass. However, it is worth mentioning that despite its potential to damage certain perennial ryegrass cultivars, the inclusion of diflufenican in Quantum® at both PE and EPE stages provided supplementary control over broadleaf weeds in this trial, notably field pansy (*Viola arvensis*), which possibly influenced the final count of ryegrass seed heads recorded before harvest. Though Asulox® performed well in this trial, it is also important to stress that previous work (Gibson *et al.*, 2022) has reported crop safety issues on specific perennial ryegrass cultivars treated with the active ingredient asulam. Therefore, at this point in time, Asulox® can only be recommended for use in managing severe Vulpia hairgrass infestations in areas such as headlands or around irrigation hydrants. The versatility of Prominent® in managing Vulpia hairgrass EPE was also evident when it was incorporated into a treatment where the 4 L/ha application of Nortron® was divided into two 2 L/ha applications (Treatment 9), resulting in effective control of Vulpia hairgrass without compromising crop safety of the perennial ryegrass. Conversely, applying Prominent® at 2 L/ha in tank mixes with either 4 L/ha of Nortron® PE (Treatment 3) or with 500 mL/ha of Atraflow™ and 80 g/ha of Sakura® (Treatment 16) EPE provided very high levels of Vulpia hairgrass control. However, the trade-off with these treatments is that the high levels of Vulpia hairgrass control (Table 2) came at the expense of crop safety. These treatments caused significant ($P \leq 0.001$) reductions in the number of perennial ryegrass plants per m^2 (Table 1) due to considerable phytotoxicity damage. While crop safety assessments were complicated by moderate to high levels of grass grub predation in the treatment plots, making it difficult to attribute all biomass loss solely to herbicide effects, the impact of phytotoxicity was nonetheless substantial. Although there was some compensation in terms of seed head production per m^2 (Table 1), this did not fully offset the plant losses experienced earlier in the season. As a result, these treatments ultimately led to a reduction in realised seed yield at harvest.

Purity represents a critical quality attribute in the production of ryegrass seed crops. According to the current standards set by the Ministry for Primary Industries (MPI) (Ministry for Primary Industries, 2014), the minimum acceptable purity level for first-generation ryegrass seed crops is 98.0%. Based on this criterion, only 5 out of the 17 treatments (Table 2) would meet this required certification standard.

Summary

This trial highlights the importance of early intervention in controlling Vulpia hairgrass infestations in perennial ryegrass seed crops using herbicides. Notably, treatments incorporating Nortron® and Quantum® at PE stages showed very high efficacies for controlling Vulpia hairgrass whilst maintaining acceptable levels of crop safety. However, although Quantum® shows promise for providing broadleaf control at both PE and EPE timing, it is important to emphasise that this product can be damaging to some perennial ryegrass cultivars. Prominent® shows promise at early EPE, but its PE application raises crop safety concerns. Due to past trials showing phytotoxicity issues with some perennial ryegrass cultivars, asulam would only be recommended for use in heavier Vulpia hairgrass infestations, particularly in areas like headlands and around irrigation hydrants. Despite having high efficacies against Vulpia hairgrass, some EPE treatments, especially those containing pyroxasulfone (Sakura® 850 WG), exhibited high phytotoxicity damage, emphasizing the need to balance efficacy and crop safety. Within the group 15 mode of action group, ethofumesate and flufenacet were safer than pyroxasulfone for ryegrass EPE applications.

Table 16. Machine-dressed yield, number of perennial ryegrass (*Lolium perenne*) plants and seed heads per square metre and thousand seed weight (TSW) from perennial ryegrass (cv. Nui) plots treated with 16 different herbicide treatments in a trial conducted at FAR's Chertsey research site during the 2023-24 season.

Treatment No.	Product [1], Application Rate and Timing		Machine dressed yield (kg/ha)	Perennial ryegrass plants/m² (11 Aug 2023)	Perennial ryegrass seed heads/m² (4 Jan 2023)	TSW (g)
	Pre-emergence (GS 00-07) 27 April 2023	Early post-emerge 2-leaf (GS 12) 12 June 2023				
1	Untreated		443	120	116	2.3
2	Nortron® (4 L/ha)		1351	140	937	2.4
3	Nortron® (4 L/ha) + Prominent® (2 L/ha)		1488	52	1033	2.4
4	Nortron® (4 L/ha)	Prominent® (2 L/ha)	1471	161	1436	2.3
5	Nortron® (4 L/ha)	Asulox® (4 L/ha)	1434	144	1063	2.3
6	Nortron® (4 L/ha) + Quantum® (100 mL/ha)		1664	121	1048	2.4
7	Nortron® (4 L/ha)	Invado® (250 mL/ha)	1199	115	1180	2.3
8	Nortron® (2 L/ha)	Nortron® (2 L/ha)	1179	146	959	2.4
9	Nortron® (2 L/ha)	Nortron® (2 L/ha) + Prominent® (2 L/ha))	1491	159	1330	2.4
10		Nortron® (4 L/ha)	1036	150	794	2.4
11	Headstart® (1 L/ha)	Nortron® (4 L/ha)	846	152	846	2.3
12		Nortron® (4 L/ha) + Quantum® (100 mL/ha)	1438	169	877	2.5
13		Nortron® (4 L/ha) + Simatop™ (0.5 L/ha)	1214	169	799	2.4
14		Nortron® (4 L/ha) + Protugan® (0.75 L/ha) + Prominent® (2 L/ha)	1352	145	1249	2.3
15		Sakura® (80 g/ha)	862	112	770	2.3
16		Prominent® (1.2 L/ha) + Atraflow™ (500 mL/ha) + Sakura® (80 g/ha)	652	66	1090	2.3
17		Nortron® (4 L/ha) + Protugan® (0.75 L/ha) + Quantum® (100 mL/ha)	1397	148	927	2.3
		Plot value range	**201-1860**	**13-233**	**11-1909**	**2.1-2.55**
		LSD (*P*≤0.05)	**301**	**30**	**520**	**NS**
		***P* value**	***P*≤0.001**	***P*≤0.001**	***P*≤0.01**	**0.20**

NS = No significant difference. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) (P≤0.05) for each presented variable.

[1] Asulox® (a.i. 400 g/L asulam, Group 18 Herbicide); Atraflow™ (500 g/L atrazine, Group 5 Herbicide); Headstart® (50 g/L flumetsulam, Group 2 Herbicide); Invado® (a.i. 400 g/L flufenacet, Group 15 Herbicide); Nortron® (a.i. 500 g/L ethofumesate, Group 15 Herbicide); Prominent® (500 g/L prometryn, Group 5 Herbicide); Quantum® (a.i. 500 g/L diflufenican, Group 12 Herbicide); Sakura®850 WG (850 g/kg pyroxasulfone, Group 15 Herbicide); Simatop™ (a.i. 500 g/L simazine, Group 5 Herbicide); Protugan® (500 g/L isoproturon, Group 5 Herbicide).

Table 17. Estimated and calculated (Abbott) Vulpia hairgrass control relative to untreated control and seed head density and percentage of Vulpia hairgrass (*Vulpia* spp.) seed per total sample weight (purity) in perennial ryegrass (*Lolium perenne*) (cv. Nui) plots treated with 16 different herbicide treatments in a trial conducted at FAR's Chertsey research site during the 2023-24 season. Vulpia hairgrass control score 0 = no control, 100% = 100% of Vulpia hairgrass plants controlled.

Treatment No.	Product[1], Application Rate and Timing		Estimated Vulpia hairgrass control score (0-100%) (25 Aug 2023)	Vulpia hairgrass seed heads/m² (4 Jan 2024)	Vulpia hairgrass control (Abbott) (%) (seed heads) (4 Jan 2023)	% Vulpia hairgrass relative to total sample weight (3 g)
	Pre-emergence (GS 00-07) 27 April 2023	**Early post-emerge 2-leaf (GS 12) 12 June 2023**				
1	Untreated		-	2472	-	13.9
2	Nortron® (4 L/ha)		90	220	91	5.2
3	Nortron® (4 L/ha) + Prominent® (2 L/ha)		97	110	95	0.7
4	Nortron® (4 L/ha)	Prominent® (2 L/ha)	92	57	97	2.2
5	Nortron® (4 L/ha)	Asulox® (4 L/ha)	92	110	95	1.4
6	Nortron® (4 L/ha) + Quantum® (100 mL/ha)		87	39	98	3.4
7	Nortron® (4 L/ha)	Invado® (250 mL/ha)	95	65	97	0.3
8	Nortron® (2 L/ha)	Nortron® (2 L/ha)	65	1214	50	4.2
9	Nortron® (2 L/ha)	Nortron® (2 L/ha) + Prominent® (2 L/ha))	85	49	98	3.6
10		Nortron® (4 L/ha)	62	1749	29	6.1
11	Headstart® (1 L/ha)	Nortron® (4 L/ha)	47	1345	45	5.4
12		Nortron® (4 L/ha) + Quantum® (100 mL/ha)	70	1373	44	5.2
13		Nortron® (4 L/ha) + Simatop™ (0.5 L/ha)	65	1604	35	5.4
14		Nortron® (4 L/ha) + Protugan® (0.75 L/ha) + Prominent® (2 L/ha)	87	172	93	3.0
15		Sakura® (80 g/ha)	60	156	93	1.1
16		Prominent® (1.2 L/ha) + Atraflow™ (500 mL/ha) + Sakura® (80 g/ha)	100	14	99	0.0
17		Nortron® (4 L/ha) + Protugan® (0.75 L/ha) + Quantum® (100 mL/ha)	75	958	61	6.1
		Plot value range	**40-100**	**0-3553**	**-43-100**	**0-15.6**
		LSD (*P*≤0.05)	**12**	**889**	**39**	**4.0**
		***P* value**	***P*≤0.001**	***P*≤0.001**	***P*≤0.001**	***P*≤0.001**

[1] Asulox® (a.i. 400 g/L asulam, Group 18 Herbicide); Atraflow™ (500 g/L atrazine, Group 5 Herbicide); Headstart® (50 g/L flumetsulam, Group 2 Herbicide); Invado® (a.i. 400 g/L flufenacet, Group 15 Herbicide); Nortron® (a.i. 500 g/L ethofumesate, Group 15 Herbicide); Prominent® (500 g/L prometryn, Group 5 Herbicide); Quantum® (a.i. 500 g/L diflufenican, Group 12 Herbicide); Sakura®850 WG (850 g/kg pyroxasulfone, Group 15 Herbicide); Simatop™ (a.i. 500 g/L simazine, Group 5 Herbicide); Protugan® (500 g/L isoproturon, Group 5 Herbicide).
Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) (P≤0.05) for each presented variable.

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Appendix 1. Trial management details

Activity	Date	Product/Rate
Sowing Date (Ryegrass)	24 April	12 kg/ha Ryegrass
		5 kg/ha Vulpia (handspread)
		All seed incorporated with a roller
Herbicides	27 April	3 L/ha Weedmaster® TS470 (a.i. 470 g/L glyphosate, Group 9 Herbicide)
	11 Aug	4 L/ha Trimec® (a.i. 600 g/L mecoprop + 150 g/L MCPA + 18.7 g/L dicamba, Group 4 Herbicides)
	14 Dec	800 mL/ha Starane™ XTRA (333 g/L fluroxypyr, Group 4 Herbicide)
Fertiliser	16 May	295 kg/ha Super 7K (NPKS = 7.65-7.5-9.35-0)
	25 Aug	200 kg/ha Ammonium Sulphate (NPKS = 20-0-0-23)
	2 Nov	50 kg N/ha SustaiN® (NPKS = 45.9-0-0-0)
	22 Nov	50 kg N/ha SustaiN® (NPKS = 45.9-0-0-0)
Plant Growth Regulators	27 Oct	Moddus®Evo (a.i. 250 g/L trinexapac-ethyl) 1.6 L/ha
Fungicides	27 Oct	0.4 L/ha Proline® (250 g/L prothioconazole, Group 3 Fungicide)
	22 Nov	0.4 L/ha Proline® (250 g/L prothioconazole, Group 3 Fungicide) + 0.6 L/ha SEGURIS® Flexi (125 g/L isopyrazam, Group 7 Fungicide)
	14 Dec	0.4 L/ha Proline® (250 g/L prothioconazole, Group 3 Fungicide) + 0.8 L/ha Comet® (250 g/L pyraclostrobin, Group 11 Fungicide)
Irrigation	-	Total of 155 mm over 8 seperate passes
Rolling	18 Aug	Site rolled using a Cambridge roller

Herbicides to control chitted seed in tall fescue seed crops

Project code	H19-15-02
Duration	Year 1 of 2 (2023-24 season)
Authors	Ben Harvey, Owen Gibson and Richard Chynoweth (FAR)
Location	Kowhai Farm, Lincoln. 43°38'18"S 172°28'12"E
Funding	Seed Industry Research Centre (SIRC)
Acknowledgements	NZ Arable (trial operator)

Key points

1. Nine herbicide treatments were tested in a second-year tall fescue seed crop for their ability to control chitted seed from the previous year's crop.
2. Based on visual seedling counts, treatments including pre-emergence herbicides such as Sakura® were effective at controlling volunteer grass seedlings, with or without post-emergence herbicides.
3. No differences were observed in seed yield, suggesting that none of the herbicide treatments had crop safety issues.

Background

Tall fescue (*Festuca arundinacea*) seed crops are usually grown for multiple years in New Zealand (up to six years in seed certification, MPI, 2014); however, after the first year, volunteer tall fescue plants must be controlled from seed lost onto the ground during harvest. In New Zealand this is to reduce the competition to the main crop from volunteer seedlings, however in some instances (such as when growing seed under contract for re-export), control of chitted seed is a requirement of the contract (R. Chynoweth, pers. comm.). In the past, atrazine had been the herbicide of choice for control of volunteer seedlings (Hare, 1993). Hard post-harvest grazing can also limit the number of surviving volunteer seedlings, if stock are available.

Diuron, applied before the seedlings emerge, has been a more recent addition to atrazine to improve control. There are herbicide resistance issues, however (Heap, n.d.), as well as concerns about crop damage. Atrazine and diuron both work by absorption through the plant roots, so survival of the main crop depends on having deep roots. In this context new herbicide treatments were sought that could improve crop safety and provide alternatives when herbicide resistance is a concern.

Methods

A trial was set up 2023-24 in an existing stand of tall fescue sown in December 2021 at Kowhai Farm near Lincoln, Canterbury, New Zealand. The trial consisted of two cultivars, 'Quantica' (a Continental type) and 'Temora' (a Mediterranean type), with nine different herbicide treatments (including an untreated control – see Table 1). These were applied at two timings: pre-emergence (of the germinating grass seedlings), and when the seedlings were at the two-leaf stage (Table 1). Agrichemical details are given in Appendix 1. Plots were laid out in a randomised complete block design, with three replicates.

Table 1. Herbicide treatments for a trial to control chitted seed in a second-year tall fescue trial located near Lincoln in the 2023-24 growing season. Treatments were repeated across two cultivars: 'Temora' (treatments 1-9) and 'Quantica' (treatments 10-18).

Treatment Number	Herbicide treatment at pre-emergence (21/2/2023)	Herbicide treatment at two-leaf stage (24/3/2023)
1 & 10	None	-
2 & 11	Karmex® (1 kg/ha) + Atraflo (1 L/ha)	Goal™ (250 mL/ha) + Sencor® (0.26 L/ha)
3 & 12	Sakura® (125 g/L)	-
4 & 13	Sakura® (125 g/L)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)
5 & 14	Sakura® (125 g/L)	Alion® (56 mL/ha)
6 & 15	Sakura® (125 g/L) + Chateau® (70 g/ha)	-
7 & 16	Sakura® (125 g/L) + Chateau® (70 g/ha)	Goal™ (250 mL/ha) + Sencor®(0.26 L/ha)
8 & 17	Alion® (26 mL/ha)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)
9 & 18	Alion® (26 mL/ha)	Sakura® (125 g/L) + Chateau® (70 g/ha)

Herbicide treatments were applied using a 1.65m hand-held plot sprayer with 4 x 110 015 XR Teejet and 2 x 65 01 Teejet nozzles. Assessments of volunteer tall fescue seedling numbers were made on 8/3/2023 and 12/4/2023. Visual observations of crop damage were also made at this time. Pre-harvest seed-head counts were performed on 11/12/2023, on the 'Quantica' treatments only. The decision was made to only count one cultivar due to time and labour constraints, as well as a visual observation that there were few differences between treatments. Harvest was split into two separate dates; one for each cultivar. Plots were windrowed with a modified John Deere plot windrower ('Quantica' on 15/12/2023, 'Temora' on 27/12/2023) and harvested using a Wintersteiger classic plot combine harvester ('Quantica' on 20/12/2023, 'Temora' on 8/1/2024). Subsamples of field-dressed seed were machine dressed to calculate clean seed yields for each plot. Statistical analysis of variance (ANOVA) was performed using Genstat® 22nd edition.

Results and Discussion

Herbicide treatment effectiveness was measured by performing seedling counts of all grass weeds germinating in the plots. While there would have been other grass weeds apart from tall fescue volunteers, these would have been negligible in number and unlikely to be different between treatments. Grass weed control is also an important role of each of the herbicide treatments and therefore the total grass seedling number is a valid metric for determining the usefulness of each treatment.

In general, herbicide treatments were more effective on the Mediterranean-type cultivar ('Temora') than on the Continental-type ('Quantica'). The main difference between the two types is their seasonal activity (Continentals are more winter-hardy, while Mediterraneans are summer-dormant), but there may also be differences in seedling vigour which could account for the observed seedling count differences. In 'Temora', tall fescue seedling count reductions of up to 98% were observed in the best treatment, which was treatment 9; Alion® applied pre-emergence, followed by Sakura® and Chateau® applied post-emergence (Figure 1). A number of other treatments were statistically similar to treatment 9. The same sequence of herbicides gave the best reduction of seedling numbers in 'Quantica'; around 87%. There were no observed crop safety issues with any treatment, either visually (Figure 2), or in terms of tall fescue seed head numbers and clean seed yield (Table 2).

All of the herbicide treatments involved the use of pre-emergence herbicides – four of which did not have a follow-up post-emergence herbicide. However, all of the herbicides applied at the post-emergence timing also had pre-emergence activity. This was designed to catch later seedling germination, as well as (in the case of those herbicides that also had post-emergence activity, i.e. Sencor® and Goal™) have activity on seedlings that had already emerged. It was interesting to note that the treatments that had only one application at the pre-emergence timing (treatments 3, 6, 12 and 15) continued to reduce the number of seedlings from the first seedling count to the second seedling count.

Treatments containing Sakura® were particularly effective at controlling grass seedlings, while appearing not to compromise autumn and winter crop growth, or seed yield. The active ingredient in this herbicide, pyroxasulfone, works on the emerging root coleoptile of grasses, and would not be expected to affect mature plants.

Figure 1. Volunteer tall fescue seedling counts taken after pre-emergence (21/2/2023) and post-emergence (24/3/2023) herbicide treatments. Counts were taken on 8/3/2023 (blue bars) and 12/4/2023 (orange bars). Note: “fb” = followed by. Raw data can be found in Appendix 3.

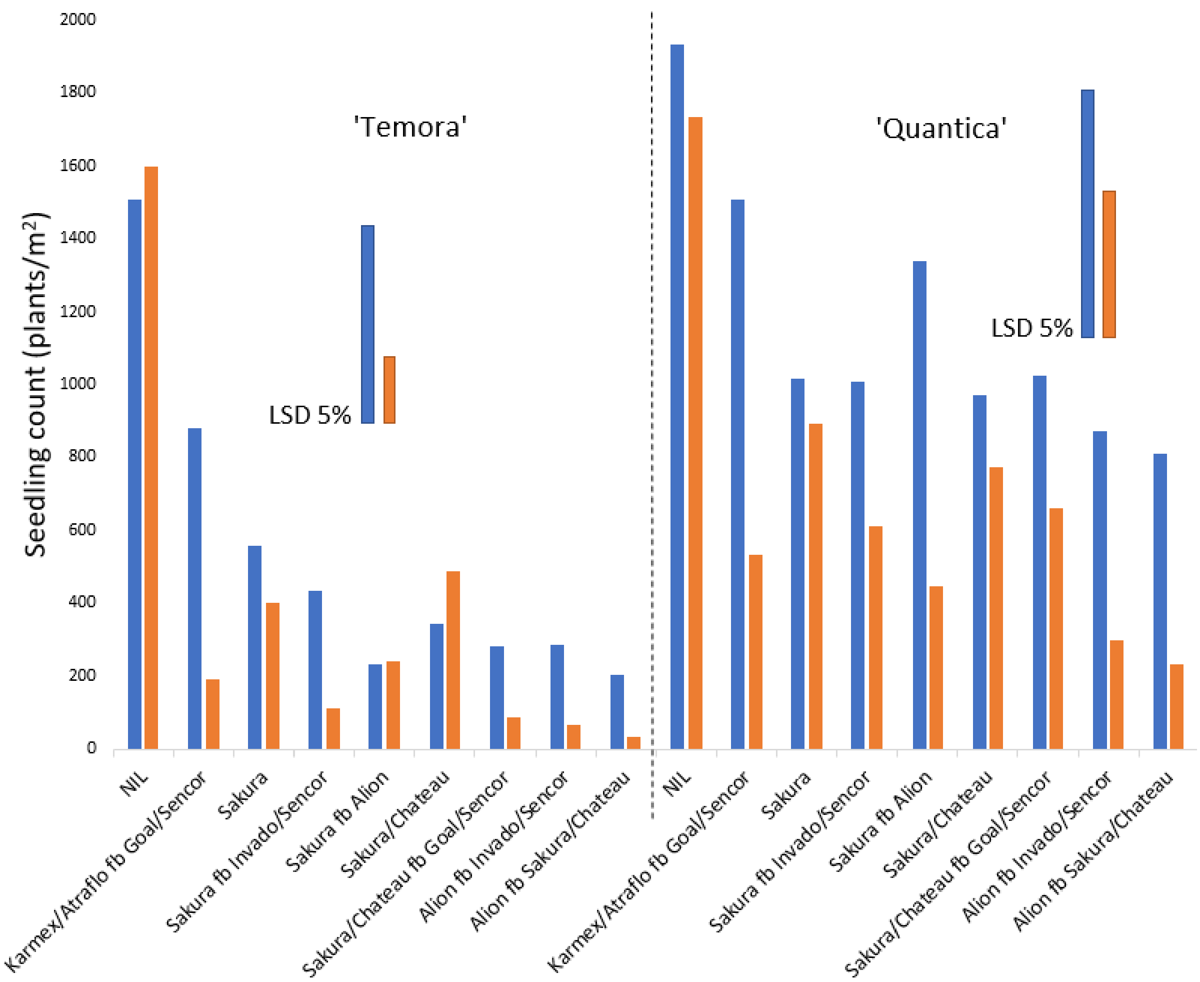

Figure 2. Visual image of the tall fescue herbicide trial at Lincoln, Canterbury, taken on 24/5/2023. The slightly lighter plots correspond to the plots containing 'Temora', but no treatment differences could be detected. (Note: this trial had no buffer plots.)

Table 2. Seed head counts and machine-dressed seed yield of two cultivars of tall fescue (grown as a second-year seed crop at Kowhai Farm, Lincoln, in the 2023-24 season) after treatment with various herbicide regimes to control volunteer seedlings.

Pre-emergence herbicide	Post-emergence herbicide	'Quantica' seed head count (heads/m^2)	'Temora' seed yield (kg/ha)	'Quantica' seed yield (kg/ha)	Cost of herbicide programme ($/ha)
None	-	746	1583	1796	-
Karmex® (1 kg/ha) + Atraflo (1 L/ha)	Goal™ (250 mL/ha) + Sencor® (0.26 L/ha)	870	1516	1702	79
Sakura® (125 g/L)	-	824	1502	2116	122
Sakura® (125 g/L)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)	888	1800	2082	273
Sakura® (125 g/L)	Alion® (56 mL/ha)	797	1464	1885	206
Sakura® (125 g/L) + Chateau® (70 g/ha)	-	724	1631	2007	145
Sakura® (125 g/L) + Chateau® (70 g/ha)	Goal™ (250 mL/ha) + Sencor® (0.26 L/ha)	823	1573	1884	186
Alion® (26 mL/ha)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)	825	1588	1922	234
Alion® (26 mL/ha)	Sakura® (125 g/L) + Chateau® (70 g/ha)	934	1517	1991	228
	P value	**0.823**	**0.144**	**0.116**	
	CV (%)		**6.9**	**6.1**	

Summary

There are a number of viable options for pre-emergence herbicide programmes to control volunteer tall fescue seedlings in multi-year seed crop stands. Alion® applied pre-emergence of the volunteer seedlings, followed by Sakura® and Chateau® post-emergence, reduced volunteer numbers by the highest amount, but a number of other, similar treatments also performed well. When grass weeds are anticipated to be a problem in multi-year tall fescue stands, or when controlling volunteer tall fescue seedlings is important, pre-emergence herbicides can play an important role in a herbicide programme. This study showed that these herbicide treatments had no effect on crop health, seed head numbers or seed yield.

References

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Appendix 4. Agrichemical treatment details.

Chemical	Active Ingredient(s)	Mode-of-Action Group
Atraflo	500 g/L atrazine	5
Karmex®	900 g/kg diuron	5
Sakura®	850 g/kg pyroxasulfone	15
Goal™	480 g/kg oxyfluorfen	14
Sencor®	480 g/L metribuzin	5
Invado®	400 g/L flufenacet	15
Alion®	500 g/L indaziflam	29
Chateau®	500 g/kg flumioxazin	14

Appendix 2. Other trial inputs

Date	Activity
29/3/2023	50 kg N/ha added as urea
14/4/2023	Broadleaf herbicides – Archer® @ 350 mL/ha + Starane® @ 600 mL/ha
17/5/2023	Trial topped and residue removed
7/7/2023	Trial topped and residue removed
16/8/2023	Trial topped and residue removed (‘Temora’ plots only)
25/8/2023	200 kg/ha ammonium sulfate (42 kg N/ha, 48 kg S/ha) applied to entire trial
20/9/2023	50 kg N/ha applied as urea
3/10/2023	800 mL/ha Moddus®EVO applied
19/10/2023	800 mL/ha Moddus®EVO + 400 mL/ha Proline® fungicide applied
20/10/2023	50 kg N/ha applied as urea (SustaiN)
21/11/2023	Fungicide applied: 400 mL/ha Proline® + 600 mL/ha Seguris Flexi®

Appendix 3. Volunteer tall fescue seedling count data

3a. Seedling count 8/3/2023 – after pre-emergence treatments only – seedlings/m²

Note: Results followed by the same letter are not significantly different from each other.

Herbicide Treatment	'Temora' seedling count (mean of three reps)	'Quantica' seedling count (mean of three reps)
None	1508 c	1932 bc
Karmex® (1 kg/ha) + Atraflo (1 L/ha)	880 b	1508 bc
Sakura® (125 g/L)	560 ab	1016 ab
Sakura® (125 g/L)	436 ab	1008 ab
Sakura® (125 g/L)	232 a	1340 abc
Sakura® (125 g/L) + Chateau® (70 g/ha)	344 a	972 ab
Sakura® (125 g/L) + Chateau® (70 g/ha)	284 a	1024 ab
Alion® (26 mL/ha)	288 a	872 ab
Alion® (26 mL/ha)	204 a	812 a
P value	**0.001**	**0.041**
L.S.D. (p=0.05)	**520**	**656**

3b. Volunteer estimate 12/4/2023 – after pre- and post-emergence herbicides applied - volunteers/m²

Note: Results followed by the same letter are not significantly different from each other.

Pre-emergence herbicide	Post-emergence herbicide	'Temora' volunteer estimate (mean of three reps)	'Quantica' volunteer estimate (mean of three reps)
None	-	1600 d	1733 e
Karmex® (1 kg/ha) + Atraflo (1 L/ha)	Goal™ (250 mL/ha) + Sencor® (0.26 L/ha)	193 ab	533 abcd
Sakura® (125 g/L)	-	400 c	893 d
Sakura® (125 g/L)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)	113 ab	613 abcd
Sakura® (125 g/L)	Alion® (56 mL/ha)	240 bc	447 abc
Sakura® (125 g/L) + Chateau® (70 g/ha)	-	487 c	773 cd
Sakura® (125 g/L) + Chateau® (70 g/ha)	Goal™ (250 mL/ha) + Sencor® (0.26 L/ha)	87 ab	660 bcd
Alion® (26 mL/ha)	Invado® (1.12 L/ha) + Sencor® (0.26 L/ha)	67 ab	300 ab
Alion® (26 mL/ha)	Sakura® (125 g/L) + Chateau® (70 g/ha)	33 a	233 a
	P value	**<0.001**	**<0.001**
	CV (%)	**11.3**	**21.0**
	L.S.D. (p=0.05)	**186**	**397**

Evaluating cocksfoot seed crop tolerance to the herbicide Kerb™500F

Project code	H19-11-00
Duration	Year 3 of 3 (2023-24 season)
Authors	Sean Weith, Matilda Gunnarsson and Richard Chynoweth (FAR)
Location	Wakanui (-43.976944, 171.913611) and Methven (-43.5593240, 171.6817330), Mid Canterbury
Funding	Seed Industry Research Centre (SIRC)
Acknowledgements	Andrew West (trial host); Hamish Marr (trial host); NZ Arable (trial operator)

Key points

1. Grass weed presence was minimal, hindering specific data collection on grass weed control efficacy in both trials.
2. Herbicide effects on seed yield varied by location, with treatment-related differences in machine-dressed yield observed only at Methven.
3. At Wakanui, herbicide treatments including Karmex®900 with Atraflow™ increased seed heads per m², with no effect on seed yield.
4. Herbicide treatments like Stratos®, Puma® S, and Jive® caused crop damage but only Stratos® showed a seed yield reduction of up to 29.5% at Methven.
5. Economic performance measured through margin-over-herbicide cost indicated varying economic viability of most herbicide treatments across two trial locations.

Background

Effective grass weed control in cocksfoot (*Dactylis glomerata*) seed crops is critical for maintaining crop productivity and quality, but this has become increasingly challenging due to the emergence of herbicide resistance.

Kerb™ 500F (500 g/L propyzamide, Group 3) has been identified by Buddenhagen *et al.* (2021) as a potential herbicide for controlling grass weeds resistant to Group 2 herbicides such as Hussar® (50 g/kg iodosulfuron). However, its suitability for use in cocksfoot seed crops remains uncertain, primarily due to concerns that higher application rates may pose a risk to crop safety through phytotoxic effects. Nevertheless, the herbicide is commonly employed in cocksfoot seed production in Oregon, where it appears to be integrated successfully into crop management practices. This pattern of use indicates potential for its adoption under New Zealand conditions, provided that phytotoxicity risks are carefully managed.

The Foundation for Arable Research (FAR) and Seed Industry Research Centre (SIRC) have undertaken extensive trials over multiple years investigating the efficacy and crop safety of Kerb™500F in cocksfoot revealing varied results across different seasons. For example, Rolston *et al.* (2021) documented declines in seed yield during the 2021-2022 trial when Kerb™500F exceeded 1 L/ha, underscoring the necessity for further investigation into its crop tolerance. Conversely, in a trial conducted during the 2022-2023 season that was reported by Gunnarsson *et al.* (2023), no instances of phytotoxicity or biomass reduction from applications of Kerb were observed. These findings highlight the complexity and variability in assessing the crop safety of Kerb™500F under differing application conditions. Thus, balancing the herbicide application rate to achieve effective weed control while minimising adverse effects on cocksfoot seed yield remains a critical challenge.

This study addresses this issue by systematically assessing the impact of different application rates of Kerb™500F on cocksfoot seed yield under commercial production conditions.

Methods

Two small plot trials were established in commercial seed crops of cocksfoot in two distinct locations within Mid Canterbury during the 2023-24 season. One trial was established in a three-year-old paddock (cv. Lazily) near Wakanui (-43.976944, 171.913611) whilst the other was in an irrigated two-year-old paddock (cv. Shawnee) near Methven (-43.5593240, 171.6817330). Table 1 presents the trial's 15 treatments, which were arranged in a complete randomised experimental design with four replicates. The design incorporated two blocking factors (replicate and block) and featured doubly resolvable rows and columns. This arrangement resulted in a total of 60 plots, distributed across 30 rows and two columns. Treatment plots within each replicate were 3.3 m wide and 10.5 m long (34.6 m^2) in the Wakanui trial and 10.7 m (35.3 m^2) long in the Methven trial. Puma®S (a.i. 69 g/litre fenoxaprop-P-ethyl, Group 1) was applied with 0.5 L/ha Hasten™ spray adjuvant (704 g/L ethyl and methyl esters of canola oil fatty acids with 196 g/L non-ionic surfactants).

All Kerb 500F treatments were applied in July onto mature cocksfoot plants with leaf regrowth following early winter defoliation but before normal plant growth regulator application timings. For the trial located at Wakanui, treatments were applied at two timings, either on the 21 July 2023 or the 4 October 2023 (Table 2). For the Methven trial, treatments were applied on either the 20 July 2023 or the 4 October 2023 (Table 1). Conditions at the timing of first application on 21 July 2023 at the Wakanui trial site were wet but clear and calm whilst conditions were clear and dry but with moderate wind during the application of the second application timing. At the Methven trial site, conditions were wet with rainfall occurring throughout the first application timing on the 20 July 2023 whilst conditions were clear and dry with moderate wind during the 4 October 2023 application timing. All treatments were applied at the first application timing using a 3.3 m spray boom fitted with either 6 x 110 015 XR Teejet® or 6 x 110 02 XR Teejet® standard nozzles at 33 cm spacing delivering a water rate of 200 L/ha at an operating pressure of 210 kPa at Methven and Wakanui, respectively. During the second application, all treatments were applied using the same spray apparatus as the first application timing but with 6 x 110 015 AIXR Teejet® air induction nozzles at a water rate of 180 L/ha due to wind.

Herbicide treatments were assessed on a plot basis for phytotoxicity and crop biomass reduction at fortnightly intervals following application 1, using a scale of 0% to 100%, where 0% = no damage and 100% = all plants dead with no green leaf. These assessments were conducted until no further herbicide-related damage symptoms were observed and plant recovery was evident. Seed head density was measured for each treatment by recording the number of cocksfoot seed heads within 2 x 1 row metre per plot on the 9 and 24 of January 2024 at the Wakanui and Methven sites respectively. Seed yield was obtained by windrowing plots at the commercial timing of the paddock using a modified John Deere plot windrower with a 1.8 m cut width on 1 February 2024 for the Methven trial and for the Wakanui trial on 9 January 2024. Both trials were harvested using a Sampo plot harvester, with the Methven trial harvested on 15 February 2024 and the Wakanui trial on 17 January 2024. Machine-dressed yield, percentage dressing yield and thousand seed weight (TSW) were all determined post-harvest.

All analyses were conducted using the R programming language (R Core Team, 2024) with the 'stats' and 'lme4' packages (Bates *et al.*, 2015). The Akaike Information Criterion (AIC), which estimates prediction error and thus the relative quality of statistical models, was computed using the R packages 'AICcmodavg' (Mazerolle, 2020) and 'VGAM' (Yee, 2010) for each variable. Models with lowest AIC values (AICc) and fewer parameters (K) were considered to have the best fit. Although both trials had a similar layout, the models fitted based on AIC differed to account for dataset-specific variability. In the Wakanui trial, treatment and block were treated as fixed effects, and column as a random effect. Replicate was excluded because all plots in Block 2 had to be omitted due to a harvest issue, making the replicate structure incomplete. In contrast, the Methven trial had no missing plots, so treatment, block and replicate were included as fixed effects, with column again as a random effect to account for spatial variation. Both trials were analysed using linear mixed-effects models with the residual maximum likelihood (REML) procedure to estimate treatment effects while accounting for trial-specific variation. Adjusted means, least significant difference (LSD), and coefficient of variation (CV) were calculated using the 'predictmeans' package (Luo *et al.*, 2014), and LSD tests were omitted for variables with non-significant ANOVA results ($P \geq 0.05$). Margin-over-herbicide cost (MoC) was calculated by subtracting treatment and application costs from revenue per hectare, further adjusted against the untreated control (nil herbicides), using a grower's price for cocksfoot seed of $5.25/kg.

Weather data were retrieved from the FAR Hortplus Weather Hub (https://far.metwatch.nz/) with applicable data taken from the Methven (Station ID: H81; -43.645920, 171.613800) and Wakanui (Station ID: I17, -44.009380, 171.874530) weather stations which were located 10 km and 4.8 km, respectively from the Methven and Wakanui trial sites.

Results and Discussion

Few grass weeds were observed in the trial area, precluding the collection of efficacy data for grass weed control. Overall, the untreated controls (Treatment 1) performed similarly to many herbicide treatments, indicating limited response to the applied herbicide treatments. Differences in machine-dressed yield (MDY) were observed only in the Methven trial (Table 1). Specifically, plots treated with 1.2 L/ha of Kerb™500F (treatment 8) had higher ($P \leq 0.01$) seed yield than some treatments.

In the Wakanui trial (Table 2), Karmex®900 (a.i. 900 g/kg diuron, Group 5) applied at 0.5 kg/ha with 1.5 L/ha Atraflow™ on the 20th July 2023 ($P \leq 0.001$) increased cocksfoot seed head density by 24.7% relative to the untreated control. This finding aligns with previous herbicide studies conducted in cocksfoot seed crops (Rolston & Chynoweth, 2020). However, this effect was not observed in the Methven trial. While products containing Group 5 (photosystem II inhibitors e.g. triazines) chemicals like diuron (Karmex®900) and atrazine (Atraflow™) may offer seed yield benefits by improving seed head density, it is important to note their limited efficacies. Relative to Group 3 herbicides such as propyzamide, against harder to control weeds such as rough-stalked meadow grass (*Poa trivialis*), hairgrass (*Vulpia* spp.), ryegrass (*Lolium* spp.), and bromes (*Bromus* spp.), which may require multiple seasons for effective eradication.

Kerb™500F caused no noticeable phytotoxicity, biomass reduction, or reductions in TSW in either the Methven (Table 1) or Wakanui (Table 2) trial, which is consistent with the results reported by Gunnarsson *et al.* (2023). During the 2022-23 season, high rainfall pre- and post-application likely mitigated potential crop damage. Similarly, in the current trials, accumulated rainfall at the Methven (Table A.3) and Wakanui (Table A.4) sites within 14 days of application timing 1 was 152 mm and 105 mm, respectively. Additionally, there were 43 and 41 days below 13°C between 20th July and 31st August 2023 at Methven and Wakanui, respectively, which meets the Kerb™500F label recommendations for application under cool conditions (<13°C) and during or immediately preceding rainfall. Similar to Gunnarsson *et al.* (2023), follow-up treatments after applying 1 L/ha Kerb™ 500F on 4th October 2023 caused varying phytotoxicity in both trials. At Wakanui, plots treated with Stratos® (a.i. 200 g/litre flamprop-M-isopropyl, Group 0), Puma® S or Jive® (70.5 g/L fenoxaprop-P-ethyl, Group 1), and Alion® (a.i. 500 g/L indaziflam, Group 29 Herbicide) caused up to 15% crop damage, persisting for up to two months (Figure 1). Alion® effects were less visible and minor but persisted for up to five weeks. MDY reductions from these treatments at Wakanui ranged from 8% (Jive®) to 14.5% (Stratos®), with no differences from the untreated control (Table 2). At Methven, where symptoms were less visible, MDY reductions ranged from 2.9% (Jive®) to 29.5% (Stratos®), however, the MDY of plots treated with Stratos® was lower ($P \leq 0.01$) relative to the untreated control (Table 1).

In the Methven trial (Table A.1), the treatment profitability, as measured by MoC, of many herbicide treatments resulted in negative economic responses ($P \leq 0.001$), indicating that costs outweighed returns. Kerb™500F at 1.2 L/ha was the only economically viable treatment, achieving a positive MoC of $251/ha, while the Kerb™500F applied at 1 L/ha followed by 4 L/ha Stratos® 4 L/ha showed the largest economic loss at -$1,371/ha. In the Wakanui Trial (Table A.2), MoC values varied widely from -$1,705/ha to $1,050/ha but the differences were not statistically significant.

Table 18. Cocksfoot (*Dactylis glomerata*) seed head density, machine-dressed seed yield, percentage dressing yield, thousand seed weight (TSW) and margin-over-cost (MoC) from cocksfoot (cv. Lazily) plots treated with 14 different herbicide treatments near Methven, Mid Canterbury during the 2023-24 season.

Treatment No.	Product, Application Rate and Timing [1]		Cocksfoot Seed Head Density (heads/(m^2))	Machine-Dressed Yield (kg/ha)	Dressing Loss (%)	TSW (g)	MoC * ($/ha)
	20 July 2023	**4 October 2023**					
1	Untreated	Untreated	433	697	12.5	1.2	-
2	Karmex®900 (0.5 kg/ha) + Atraflow™ (1.5 L/ha)		556	709	12.6	1.2	-4.4
3	Kerb™500F (0.6 L/ha) + Atraflow™ (1.5 L/ha)		525	691	11.5	1.2	-111
4	Kerb™500F (1 L/ha) + Atraflow™ (1.5 L/ha)		611	646	13.6	1.2	-373
5	Kerb™500F (0.6 L/ha)		509	680	13.7	1.1	-152
6	Kerb™500F (0.8 L/ha)		610	667	16.0	1.2	-235
7	Kerb™500F (1 L/ha)		524	684	14.1	1.2	-156
8	Kerb™500F (1.2 L/ha)		445	764	11.6	1.2	251
9	Kerb™500F (1.4 L/ha)		506	666	12.2	1.2	-277
10	Kerb™500F (1 L/ha)	Stratos® (4 L/ha)	582	494	17.4	1.1	-1371
11	Kerb™500F (1 L/ha)	Puma®S (0.75 L/ha) + Hasten™ (0.5 L/ha)	575	632	15.4	1.2	-533
12	Kerb™500F (1 L/ha)	Jive® (0.75 L/ha)	510	675	11.3	1.2	-288
13	Sakura® 850 WG (80 g/ha)		669	656	13.1	1.1	-313
14	Alion® (56 mL/ha)		596	716	11.4	1.2	-15
15	Chateau® (70 g/ha)		500	667	14.1	1.1	-207
		Plot Value Range	339-963	354-846	7.4-27.5	1-1.4	-1889-900
		LSD (*P*≤0.05)	NS	98	NS	NS	934
		CV		13.4			
		***P* value**	0.26	<0.01	0.25	0.10	<0.001

Cells highlighted yellow show the top statistical group based on least significant difference (LSD) (P≤0.05) for each presented variable.
NS = No significant difference. [1] Alion® (500 g/L indaziflam, Group 29 Herbicide); Atraflow™ (500 g/L atrazine, Group 5 Herbicide); Chateau® (500 g/kg flumioxazin, Group 14 Herbicide); Jive® (70.5 g/L fenoxaprop-P-ethyl, Group 1 Herbicide); Karmex® 900 (900 g/kg diuron, Group 5 Herbicide); Kerb™500F (500 g/L propyzamide, Group 3 Herbicide); Puma®S (69 g/litre fenoxaprop-P-ethyl, Group 1 Herbicide); Sakura® 850 WG (850 g/kg pyroxasulfone, Group 15 Herbicide); Stratos® (200 g/litre flamprop-M-isopropyl, Group 0 Herbicide). * MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $5.25 per kg (effective May 2024). MoC for treatments were calculated based on average industry standard pricing per litre with Alion® at $1491/L, Atraflow™ at $11.0/L, Chateau® at $0.32/g, Jive® at $70.3/L, Karmex® 900 at $0.044/g, Kerb™ 500F at $60.5/L, Puma® S at $98.8/L, Sakura® 850 WG at $0.85/g and Stratos® at $47.0/L.

Table 19. Cocksfoot (*Dactylis glomerata*) seed head density, machine-dressed seed yield, percentage dressing yield, thousand seed weight (TSW) and margin-over-cost (MoC) from cocksfoot (cv. Shawnee) plots treated with 14 different herbicide treatments near Wakanui, Mid Canterbury during the 2023-24 season.

Treatment No.	Product, Application Rate and Timing [1]		Cocksfoot Seed Head Density per m^2	Machine Dressed Yield (kg/ha)	Dressing Loss (%)	TSW (g)	MoC * ($/ha)
	21st July 2023	**4th October 2023**					
1	Untreated	Untreated	485	836	11.0	1.1	-
2	Karmex®900 (0.5 kg/ha) + Atraflow™ (1.5 L/ha)		605	868	14.6	1.1	100
3	Kerb™500F (0.6 L/ha) + Atraflow™ (1.5 L/ha)		566	891	9.6	1.1	209
4	Kerb™500F (1 L/ha) + Atraflow™ (1.5 L/ha)		354	865	9.0	1.1	45
5	Kerb™500F (0.6 L/ha)		430	843	13.3	1.1	-29
6	Kerb™500F (0.8 L/ha)		491	880	10.9	1.1	156
7	Kerb™500F (1 L/ha)		434	861	10.9	1.1	44
8	Kerb™500F (1.2 L/ha)		478	874	10.7	1.1	100
9	Kerb™500F (1.4 L/ha)		491	927	9.0	1.1	363
10	Kerb™500F (1 L/ha)	Stratos® (4 L/ha)	361	715	10.3	1.1	-940
11	Kerb™500F (1 L/ha)	Puma®S (0.75 L/ha) + Hasten™ (0.5 L/ha)	389	755	10.6	1.1	-619
12	Kerb™500F (1 L/ha)	Jive® (0.75 L/ha)	390	769	9.2	1.0	-525
13	Sakura® 850 WG (80 g/ha)		440	825	10.9	1.2	-152
14	Alion® (56 mL/ha)		382	748	11.6	1.2	-575
15	Chateau® (70 g/ha)		387	883	9.7	1.1	194
		Plot Value Range	259-716	639-986	7-16	0.9-1.3	-1705-1050
		LSD (*P*≤0.05)	111	NS	3.9	NS	NS
		CV		12.0			-
		***P* value**	<0.001	0.11	<0.05	0.24	0.33

Cells highlighted yellow show the top statistical group based on least significant difference (LSD) (P≤0.05) for each presented variable.
NS = No significant difference. [1] Alion® (500 g/L indaziflam, Group 29 Herbicide); Atraflow™ (500 g/L atrazine, Group 5 Herbicide); Chateau® (500 g/kg flumioxazin, Group 14 Herbicide); Jive® (70.5 g/L fenoxaprop-P-ethyl, Group 1 Herbicide); Karmex® 900 (900 g/kg diuron, Group 5 Herbicide); Kerb™500F (500 g/L propyzamide, Group 3 Herbicide); Puma®S (69 g/litre fenoxaprop-P-ethyl, Group 1 Herbicide); Sakura® 850 WG (850 g/kg pyroxasulfone, Group 15 Herbicide); Stratos® (200 g/litre flamprop-M-isopropyl, Group 0 Herbicide).* MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $5.25 per kg (effective May 2024). MoC for treatments were calculated based on average industry standard pricing per litre with Alion® at $1491/L, Atraflow™ at $11.0/L, Chateau® at $0.32/g, Jive® at $70.3/L, Karmex® 900 at $0.044/g, Kerb™ 500F at $60.5/L, Puma® S at $98.8/L, Sakura® 850 WG at $0.85/g and Stratos® at $47.0/L.

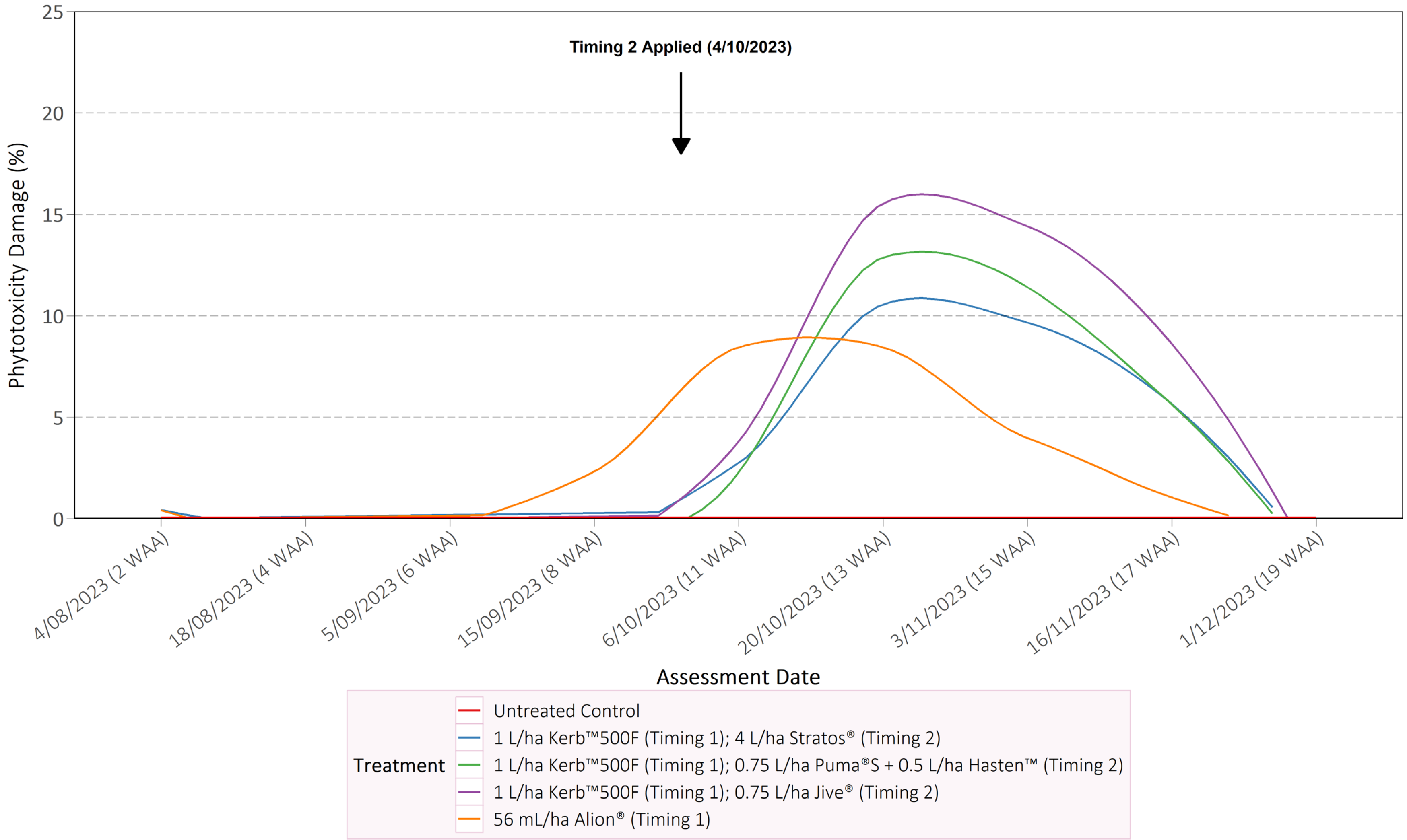

Figure 9. Phytotoxicity scores ranked on a scale of 0–100% in cocksfoot (*Dactylis glomerata*) (cv. Shawnee) plots from a herbicide trial conducted at Wakanui, Mid Canterbury, during the 2023–24 season. Only treatments exhibiting visible phytotoxicity damage are presented. Weeks after application (WAA) are relative to Timing 1, which was applied on 21 July 2023.

Summary

Overall herbicide impacts on MDY and MoC varied between trial locations. Grass weed presence was minimal at both sites, hindering specific data collection on grass weed control. In Methven, Kerb™500F at 1.2 L/ha increased MDY compared with Sakura®850 WG and Kerb™500F (1 L/ha) + 1.5 L/ha of Atraflow™, but these treatments were the same as the untreated control. At Wakanui, Karmex®900 with Atraflow™ notably increased cocksfoot seed head density while other treatments like Stratos®, Puma® S, and Jive® caused moderate crop damage. Economic analysis identified Kerb™500F at 1.2 L/ha as the only profitable treatment in Methven, while MoC values in Wakanui varied widely without statistically significant differences.

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Appendix 5

Table A.1. Cost per hectare per chemical, cost per application, cost per hectare and margin-over-cost (MoC) for 14 different chemical herbicide treatments in cocksfoot (*Dactylis glomerata*) (cv. Lazily) from a trial conducted at Methven, Mid Canterbury during the 2023-24 season.

Treatment	Product, Application Rate and Timing [1]		$/ha Chemical	$/Application*	Cost/ha ($/ha)	MoC** ($/ha)
	20 July 2023	**4 October 2023**				
1	Untreated	-	-	-	-	-
2	Karmex®900 (0.5 kg/ha) + Atraflow™ (1.5 L/ha)		39	30	69	-4.4
3	Kerb™500F (0.6 L/ha) + Atraflow™ (1.5 L/ha)		53	30	83	-111
4	Kerb™500F (1 L/ha) + Atraflow™ (1.5 L/ha)		77	30	107	-373
5	Kerb™500F (0.6 L/ha)		36	30	66	-152
6	Kerb™500F (0.8 L/ha)		48	30	78	-235
7	Kerb™500F (1 L/ha)		61	30	91	-156
8	Kerb™500F (1.2 L/ha)		73	30	103	251
9	Kerb™500F (1.4 L/ha)		85	30	115	-277
10	Kerb™500F (1 L/ha)	Stratos® (4 L/ha)	249	60	309	-1371
11	Kerb™500F (1 L/ha)	Puma®S (0.75 L/ha) + Hasten™ (0.5 L/ha)	135	60	195	-533
12	Kerb™500F (1 L/ha)	Jive® (0.75 L/ha)	113	60	173	-288
13	Sakura® 850 WG (80 g/ha)		68	30	98	-313
14	Alion® (56 mL/ha)		83	30	113	-15
15	Chateau® (70 g/ha)		22	30	52	-207
Product Name		**Cost per Litre or gram ($) *** **			**LSD (*P*≤0.05)**	934
Alion®		1491			***P* value**	<0.001
Atraflow™		11.0				
Chateau®		0.3				
Jive®		70.3				
Karmex® 900		0.04				
Kerb™ 500F		60.5				
Puma® S		98.8				
Sakura® 850 WG		0.85				
Stratos®		47.0				

Cells highlighted yellow show the top statistical group based on least significant difference (LSD) (*P*≤0.05) for each presented variable. NS = No significant difference. * Price per application is based on standard FAR operating costs. ** MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $5.25 per kg (effective May 2024).

Table A.2. Cost per hectare per chemical, cost per application, cost per hectare and margin-over-cost (MoC) for 14 different chemical herbicide treatments in cocksfoot (*Dactylis glomerata*) (cv. Shawnee) from a trial conducted at Wakanui, Mid Canterbury during the 2023-24 season.

Treatment	Product, Application Rate and Timing [1]		$/ha Chemical	$/Application*	Cost/ha ($/ha)	MoC** ($/ha)
	21 July 2023	h October 2023				
1	Untreated		-	-	-	-
2	Karmex®900 (0.5 kg/ha) +Atraflow™ (1.5 L/ha)		39	30	69	100
3	Kerb™500F (0.6 L/ha) +Atraflow™ (1.5 L/ha)		53	30	83	209
4	Kerb™500F (1 L/ha) + Atraflow™ (1.5 L/ha)		77	30	107	45
5	Kerb™500F (0.6 L/ha)		36	30	66	-29
6	Kerb™500F (0.8 L/ha)		48	30	78	156
7	Kerb™500F (1 L/ha)		61	30	91	44
8	Kerb™500F (1.2 L/ha)		73	30	103	100
9	Kerb™500F (1.4 L/ha)		85	30	115	363
10	Kerb™500F (1 L/ha)	Stratos® (4 L/ha)	249	60	309	-940
11	Kerb™500F (1 L/ha)	Puma®S (0.75 L/ha) + Hasten™ (0.5 L/ha)	135	60	195	-619
12	Kerb™500F (1 L/ha)	Jive® (0.75 L/ha)	113	60	173	-525
13	Sakura® 850 WG (80 g/ha)		68	30	98	-152
14	Alion® (56 mL/ha)		83	30	113	-575
15	Chateau® (70 g/ha)		22	30	52	194
					LSD ($P \leq 0.05$)	NS
					***P* value**	0.33

Product Name	Cost per Litre or gram ($) ***
Alion®	1491
Atraflow™	11.0
Chateau®	0.32
Jive®	70.3
Karmex® 900	0.044
Kerb™ 500F	60.5
Puma® S	98.8
Sakura® 850 WG	0.85
Stratos®	47.0

NS = No significant difference. * Price per application is based on standard FAR operating costs. ** MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $5.25 per kg (effective May 2024).

Table A.3. Daily rainfall (mm), total accumulated rainfall (mm), mean temperature (Mean Temp) and days below 13°C recorded between the 21 July 2023 and 17 January 2024 at FAR Methven weather station (Station ID: H81; -43.645920, 171.613800) located about 10 km away from the trial site. Data were retrieved from the FAR MetWatch weather portal (https://far.metwatch.nz/stations?station=H81) managed by HortPlus on the 9 January 2025.

Day	Month						
	Jul. 2023	Aug. 2023	Sep. 2023	Oct. 2023	Nov. 2023	Dec. 2023	Jan. 2024
1		10.4	0	0	0	0	0
2		0	0	0.8	0	0.8	2.6
3		0	0	0	3	3.6	0
4		0.2	0	0	19.2	0.2	1.6
5		0	0	0	16.4	0	6.4
6		0.2	0	3.8	0	0	0
7		10.6	0	5.2	0	1.6	0
8		0.2	0	0	1	0	0
9		5	0	0	1	4.4	0
10		0.6	0	14.8	0.2	2.4	0
11		0	1	0	0	0	0
12		0	0	0	0	9.6	0
13		0	0	0	0	0	0
14		0	0	2.2	0	0	3.6
15		0	0	0	3.4	0	2
16		2.8	0.8	6.6	0	0.8	0
17		0	0	-	6	1.8	0.8
18		0	0	-	0	0	
19		0.4	0	0	1.4	0	
20	11	4.6	0	0.6	0	0	
21	0.8	0	0.8	8	0	0.4	
22	64.2	0	42.8	0.6	0	0	
23	54.4	0	6	0	13.2	2.4	
24	1.6	0	4.6	0	2.2	0	
25	10	0	0	7.2	0	0	
26	0	1	0	2.8	0	10.4	
27	0	0.4	0.4	1.2	0	0	
28	0	0	19.2	0	12.6	0.8	
29	0	0	2.4	0	0	0	
30	0	0	0.2	0.2	5.8	0.4	
31	0	0		0		4.2	
Total Rainfall (mm)	**142**	**36.4**	**78.2**	**54**	**85.4**	**43.8**	**17.6**
Mean Temp (°C)	**5.8**	**6.2**	**9.4**	**10.5**	**11.7**	**14.4**	**16.7**
Days below 13°C	**12**	**31**	**25**	**23**	**18**	**8**	**3**

Table A.4. Daily rainfall (mm), total accumulated rainfall (mm), mean temperature (Mean Temp) and days below 13°C recorded between the 21 July 2023 and 17 January 2024 at FAR Wakanui weather station (Station ID: I17, -44.009380, 171.874530) located 4.8 km away from trial site. Data were retrieved from the FAR MetWatch weather portal (https://far.metwatch.nz/stations?station=I17) managed by HortPlus on the 9 January 2025.

Day	Month						
	Jul. 2023	**Aug. 2023**	**Sep. 2023**	**Oct. 2023**	**Nov. 2023**	**Dec. 2023**	**Jan. 2024**
1		2	0	0	0	0	0
2		0	0	0.2	0.2	0.4	0
3		0	0	0	5	0.2	0
4		0	0	0	15.2	0	0.4
5		0	0	0	8.8	0	0.8
6		0	0	0	0	0	0
7		0.4	0	0.2	0	2	0
8		0	0	0	1.2	0	0
9		0.4	0	0	0	5.4	0
10		0	0	5.4	0	0	0
11		0	0	0	0	0.4	0
12		0	0	0	0	8.4	0
13		0	0	0	0	0	0
14		0	0	0	0	0	0.4
15		0	0	0	0.4	0	3
16		0	0	16	0	0	0
17		0	0	1.2	2.6	1	0
18		0	0	0	0	0	
19		0	0	0	0	0	
20		1.2	0	0	0	0	
21	0	0	0	5.4	0	0	
22	63.6	0	34	0	0	0	
23	35	0.2	0.4	0	9.8	0.6	
24	0	0	0	0	1.2	0	
25	0.6	0.2	0	0	0	0	
26	0	5.4	0	8.6	0	7.6	
27	3.2	0	0.6	0	0	0	
28	0.6	0	0.4	0	3.8	3.6	
29	0	0	1.4	0	0	0	
30	0	0	0	0	3.6	0	
31	0	0		0		2.8	
Total Rainfall (mm)	**103**	**9.8**	**36.8**	**37**	**51.8**	**32.4**	**4.6**
Mean Temp (°C)	**6.6**	**6.6**	**10.5**	**11.8**	**12.5**	**15.8**	**16.4**
Days below 13°C	**11**	**30**	**20**	**17**	**17**	**7**	**4**

Small broomrape control in white clover seed crops

Project code X22-01-11

Duration Year 1 of 2 (2023-24 season)

Authors Nicholas Davies (BSI AgResearch Group)

Location FAR Chertsey Arable Site, Chertsey, Canterbury

Funding FAR

Acknowledgements NZ Arable (trial operator)

Key Points

1. A single trial has shown Imazethapyr to be effective in eliminating small broomrape when spring applied before emergence of small broomrape flower stalks in white clover seed crops.

Background

Small broomrape (*Orobanche minor*) is an obligate parasitic weed that poses an increasing threat to clover seed crops. This weed's unique biology and persistence have made it a significant concern for growers, especially in regions where clover seed production is economically important. Moreover, the regulatory implications of small broomrape infestations are growing, as the weed is a notifiable pest in several countries, including the United States. The stringent phytosanitary requirements of key export markets, such as South America, exacerbate the challenge, as clover seed crops must pass field inspections that demand the complete absence of small broomrape.

The life cycle of small broomrape is predominantly subterranean, making detection and control particularly challenging. Below the soil surface, the parasite undergoes germination, penetration of its host plant, and the formation of vascular connections through which it extracts water and nutrients. A single small broomrape plant can produce up to 500,000 seeds, which can remain viable in the soil for up to 50 years (Lins 2005).

Small broomrape seeds require the presence of a host or “false host” plant to germinate. Certain crops, such as wheat, ryegrass (both annual and perennial), barley, oat, and tall fescue, are known to act as false hosts. While these plants can induce germination, they fail to support attachment by the parasite’s haustorium, interrupting its life cycle. Among these, wheat appears to be the most effective false host (Ross 2004). However, reliance on false hosts alone has proven insufficient to ensure field inspection standards are met, emphasizing the need for complementary management practices.

The visible phase of small broomrape’s life cycle occurs late in its development when flower stalks emerge above ground. These stalks, which are typically 10 to 50 cm tall, lack chlorophyll and depend entirely on the host plant for sustenance. This reliance significantly limits the efficacy of many conventional herbicides. Herbicides that do not translocate effectively through the host plant have minimal impact on small broomrape, as it derives its water and nutrients directly from the host.

Similarly, herbicides targeting photosynthetic pathways are ineffective due to the parasite's lack of chlorophyll. Effective chemical control requires sufficient uptake and translocation of herbicide by the host plant, particularly after the parasite attaches to the root system. Field observations from the northern hemisphere suggest this attachment begins in July, providing a critical window for intervention (Lins 2005).

Field observations from the 2022-23 and 2023-2024 growing seasons provide insights into the emergence and reproductive behaviour of small broomrape (*Orobanche minor*) in clover seed crops in Canterbury. Typically, the first emergence of small broomrape regionally occurs in early November, although it has been noted as early as late October in some cases. The emergence period is prolonged, extending through to at least January. Observations suggest that second-year clover crops exhibit both higher levels of infestation and earlier emergence compared to first-year crops.

By mid to late December, the first mature seeds of small broomrape are usually detectable. International literature indicates that once the parasite has initiated flowering, control efforts become ineffectual, as the plant can still produce viable seed even if its flowering stalk is removed. This underscores the importance of implementing effective management strategies early in the growing season to prevent the parasite from reaching its reproductive stage.

Methods

This trial was conducted to evaluate the efficacy of Imazethapyr (Equate®) and Flumetsulam (Preside™), both Group 2 herbicides, in controlling small broomrape (*Orobanche minor*) in clover seed crops during the 2023-24 season. Seed collected from small broomrape infestations was spread over the trial area during the two preceding autumns to establish an approximately uniform infestation across the site.

The trial was set up as an 8-replicate randomized complete block design. Herbicide applications were timed based on predictions from a growing degree day model developed by Oregon State University (Eizenberg 2005), which was adjusted to local conditions (the start date of accumulation was moved to 1st of July) to accurately predict small broomrape emergence to within a week. Treatments included applications of Imazethapyr and Flumetsulam at various timings within the predicted herbicide efficacy window, as well as untreated control plots for comparison (see Table 1).

Field observations, consisting of counts of small broomrape stems within each plot, were conducted at three assessment timings following treatment application. Results from the final assessment, undertaken on 14 December 2023, are reported here.

Results and Discussion

The trial results demonstrated a clear distinction in small broomrape control between the two herbicides. Imazethapyr was highly effective in this trial, with no small broomrape observed in plots where it was applied, regardless of the timing of application. In contrast, 82% of plots that did not receive Imazethapyr exhibited some level of small broomrape infestation. Flumetsulam was not effective under the conditions of this trial.

While Imazethapyr proved effective in this trial, further research is needed to confirm these results over multiple seasons and to refine the timing of applications based on predictive models. Additionally, exploring the interaction of herbicide treatments with other management practices, such as the use of false hosts, may further enhance control outcomes. These results provide promising evidence for the use of Imazethapyr as an herbicidal control for small broomrape in clover seed crops.

Table 1. Mean small broomrape (*Orobanche minor*) (SBR) stems per plot in a clover seed crop trial conducted in Chertsey, Canterbury during the 2023–2024 season.

Treatment Number	25/09/2023	13/10/2023	16/11/2023	Mean SBR stems (14/12/23)
1	Negative Control			20.6
2	Imazethapyr (G2)			0
3	Imazethapyr (G2)	Imazethapyr (G2)		0
4	Imazethapyr (G2)		Imazethapyr (G2)	0
5	Flumetsulam (G2)			23

Data represent counts on 14 December 2023. None of the plots treated with imazethapyr (Mode of Action Group 2) had any small broomrape stems, while 82% of untreated plots showed presence of the weed. Treatments included: Equate® (240 g/L imazethapyr) at 400 mL/ha with Hasten™ (704 g/L ethyl and methyl esters of canola oil fatty acids with 196 g/L non-ionic surfactants) at 500 mL/ha and Preside™ (800 g/kg flumetsulam) with Uptake™ Oil at 1 L/ha. G2 indicates Mode of Action Group 2.

Summary

Preliminary results from a single year of trials indicate that spring applications of Imazethapyr show promise as a chemical control option for small broomrape in white clover seed crops. However, additional research is needed to confirm these findings and optimize application protocols. Crop infection is of concern due to restrictions in some export markets at field inspection. While no definitive data exist on the magnitude of crop loss caused by small broomrape infestation, it is generally believed that healthy, irrigated crops sustain minimal damage. In contrast, stressed crops, such as those grown under dryland conditions, may experience more significant yield losses.

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Grass weed herbicide screening trial

Project code	X18-35-04
Duration	Year 4 of 5 (2023-24 season)
Authors	Ben Harvey, Owen Gibson and Richard Chynoweth (FAR)
Location	Chertsey, Mid Canterbury. GPS 43.793170°S 171.963021°E
Funding	FAR
Acknowledgements	NZ Arable (trial operator)

Key points

1. A range of grass weed herbicides were investigated by spraying weeds at different rates using a log-sprayer.
2. Results showed that there are a number of options for growers needing to control grass weeds in different crop situations, including four new products (assigned codes in this trial) which were either not available in New Zealand or not registered for use in arable crops.
3. Using the most effective herbicide possible within the crop grown reduces the risk of herbicide resistance emerging to an active ingredient. It is also important to use a range of herbicide modes of action against a target weed.

Background

New Zealand arable farms are experiencing an increase in instances of herbicide-resistant grass weeds, with growers in some regions struggling to control populations, particularly of ryegrass (*Lolium* spp.), that have become resistant to Group 2 Mode-of-Action (MoA). This group, which all inhibit the plant enzyme acetolactate synthase, includes some important grass-control herbicides, such as iodosulfuron and mesosulfuron-methyl (Buddenhagen *et al.,* 2021). One of the key chemical tools for dealing with these weeds is active ingredients from the MoA Group 15 (e.g. pyroxasulfone and flufenacet). Low levels of resistance to this group of chemicals is beginning to be detected in some of the worst-hit areas for herbicide resistance (Shields, pers. comm.).

Increasing cases of herbicide resistance means annual screening of the efficacy of commercial and close-to-market grass weed herbicides belonging to a range of MoAs is more important than ever. This report describes 2023 data from FAR's ongoing herbicide screening trial at Chertsey, mid-Canterbury, where the efficacy and crop safety of a number of new and old herbicides were tested against several problematic weed species and in a number of common crop species. This is the third consecutive year that FAR has run this trial, after a nine-year break.

The trial is an un-replicated demonstration, but treatments can be compared across seasons to provide additional information on herbicide efficacy. Furthermore, the grass weeds were grown without crop competition and sown at a single depth. Thus, the data should be interpreted with such limitations in mind.

Methods

The trial was established on 17 April, 2023 at the FAR Arable Site, Chertsey, Mid Canterbury. Ten grass weed and crop species (Table 1) were sown in 18 metre strips. A specialised research disc drill was used to establish the trial for all species except ripgut brome, which was hand sown by spreading seed and hand-raking to incorporate seed below the soil surface.

Sixteen different herbicide treatments were applied (Table 2) across all species using a log sprayer which gave a concentration gradient down the length of the plots. Rates began at double the label rate and were diluted down the length of the plot to <10% of the label rate. Note that "label rate" was chosen as a typical grass weed application rate, as many products suggest a range. Application rates for products that did not list grass weeds on the label were chosen based on the rate for other weeds, or on advice from the manufacturer. All applications were made at a water rate of 250 L/ha with 4 x 110 02xr tee jet flat fan nozzles producing a very fine spray droplet.

The level of control was recorded by visual observation at double, one, half and quarter times the "label rate" as a score out of ten, with ten representing complete plant death and zero no control. Final weed control scores were taken approximately 70 days after the final herbicide treatment for the pre-drill and pre-emergence (27 July 2023) and post-emergence (22 August) treatments.

There were three herbicide timings (Table 2). Avadex® (pre-drill) was incorporated into the soil with the drill at sowing on 17 April. Pre-emergence treatments were applied on 27 April, while post-emergence treatments were applied at growth stage (GS) 12-21 of the grass weeds on 8 June (except for Treatment 13 which was applied on 22 May).

Table 1. Grass weed and cereal species sown in the herbicide screening trial sown at Chertsey in 2023. Species marked with a (*) were broadcast-sown by hand, while all others were drilled.

Treatment	Species/cultivar	Scientific name	Sowing rate (kg/ha)
1	Annual ryegrass 'Winterstar'	*Lolium multiflorum*	30
2	Perennial ryegrass 'Nui'	*Lolium perenne*	20
3	Lesser canary grass	*Phalaris minor*	2.5
4	Hairgrass	*Vulpia* spp.	10
5	Soft brome	*Bromus hordeaceus*	5
6	*Ripgut brome	*Bromus diandrus*	5
7	Prairie grass	*Bromus wildenowii*	5
8	Oats	*Avena sativa*	50
9	Wheat 'Firelight'	*Triticum aestivum*	100
10	Barley	*Hordeum vulgare*	140

Table 2. Herbicide treatments, rates, active ingredients, mode of action and cost per hectare for herbicides tested in the screening trial in 2023. Rates are given as "label rates", which correspond to the 1x rates in Table 3, and are given per hectare. Cost per hectare values were calculated using prices from the time of application.

Herbicide timing		Starting rate (double the "label rate")	Active ingredient(s)	Mode of Action Group(s)	Cost at label rate ($/ha)
Pre-emergence (27 April 2023)	**Post-emergence**				
***Avadex® + Sakura®**		2.8 L/ha 150 g/ha	tri-allate pyroxasulfone	15 15	238
Stomp® + Invado®		2.5 L/ha 0.5 L/ha	pendimethalin flufenacet	3 15	188
Gardoprim®	Glean®	1.5 L/ha 20 g/ha	terbuthylazine chlorsulfuron	5 2	29
Firebird®		0.5 L/ha	flufenacet + diflufenican	15 + 12	98
Firebird®	Karmex®	0.5 L/ha 1.5 kg/ha	flufenacet + diflufenican diuron	15 + 12 5	160
Sakura®		150 g/ha	pyroxasulfone	15	147
Sakura®	Karmex®	150 g/ha 1.5 kg/ha	pyroxasulfone diuron	15 5	209
Sakura® + Firebird®		150 g/ha 0.5 L/ha	pyroxasulfone flufenacet + diflufenican	15 15 + 12	244
H23/01**					N/A
H23/02**					N/A
H23/03**					N/A
H23/04**					N/A
	***Rexade™ GoDRI™	100 g/ha	halauxifen-methyl + pyroxsulam	4 2	93
	Prominent®	2 L/ha	prometryn	5	91
	Twister® + Glean®	3 L/ha 20 g/ha	isoproturon chlorsulfuron	5 2	71
	Twister® + Karmex®	3 L/ha 1.5 kg/ha	isoproturon diuron	5 5	113

***Avadex® applied pre-drilling and incorporated with the drill on 17 April 2023.**
**Experimental herbicides.
***Applied 22 May 2023.

Results and Discussion

Many of the products investigated in the 2023 trial had been tested in previous years (Gibson *et al.*, 2021; Harvey *et al.,* 2022). Results in 2023 were mostly similar to those observed in the past. A number of pre-emergent treatments provided both excellent grass-weed control and good crop safety. Treatments that included Sakura® (pyroxasulfone, Group 15) were particularly effective. The experimental coded products were often not as effective as similar commercially available products, which may cause a barrier to entry into the New Zealand market. The main advantage in considering such herbicides is that they provide alternative chemistry to deal with herbicide-resistant weeds. Although this problem is increasing here, it is much more advanced in Australia where these products are currently available and are important tools in fighting herbicide resistant grass weeds. This, combined with the smaller New Zealand market and the high cost of registration are currently barriers to these products being released here in the short-term time frame.

Many of the herbicide treatments were able to effectively control *Vulpia* hairgrass; this gives options for growers who find this weed particularly troublesome. Bromes remain relatively difficult to control, especially post-emergence. Rexade™ GoDRI™ (halauxifen-methyl, Group 4 + pyroxsulam, Group 2) is marketed as a specialist brome control product, and was effective here. The label recommends a follow-up spray if escapes are present, which was not deemed to be necessary in this trial. Follow-up applications are most useful when dealing with weeds that germinate throughout the season, which was not a factor in the trial.

The trial suffered from some grass grub predation during winter which may have affected some scores, particularly in the cereal crop species. Also, note that the weeds were sown at a uniform depth and therefore came up in one flush, and not throughout the season as would be the case in a real-world situation.

Note: Results in the summary below refer to the label (1x) rates. Complete results are shown in Table 3 for your interpretation. f.b. = followed by, which denotes a sequence of products.

Annual ryegrass

As the most common herbicide-resistant weed in New Zealand, it is crucial to identify other MoA Groups that can control annual ryegrass when present as a weed. Pre-emergence herbicides remain a solid choice here, with Twister® + Karmex® providing a robust (if somewhat tough on some crops) post-emergence alternative.

- Tolerant to: Prominent®
- Mostly tolerant to: H23/02, Twister® + Glean®
- Mostly susceptible to: H23/01, H23/03, Rexade™ GoDRI™
- Susceptible to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, H23/04, Twister® + Karmex®

Perennial ryegrass

Perennial ryegrass was much more susceptible to Prominent® than in the same trial last year. Given the potential usefulness of a product that can control hairgrass in ryegrass seed crops, this has been included in other (ryegrass-specific) trials, and will continue to be assessed in further screening trials.

- Tolerant to: none of the treatments
- Mostly tolerant to: none of the treatments
- Mostly susceptible to: H23/01, H23/02, H23/03, Rexade™ GoDRI™, Prominent®
- Susceptible to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, H23/04, Twister® + Glean®, Twister® + Karmex®

Phalaris

It appears that growers have multiple pre- and post-emergence options to deal with *Phalaris* weeds.

- Tolerant to: none of the treatments
- Mostly tolerant to: Twister® + Glean®
- Mostly susceptible to: H23/02, H23/04, Prominent®, Twister® + Karmex®
- Susceptible to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, H23/01, H23/03, Rexade™ GoDRI™

Hairgrass

Hairgrass control remains most challenging when present in grass seed crops, as many of the effective options below will also damage the crop. Growers with particularly challenging paddocks could consider break crops or other integrated weed management techniques.

- Tolerant to: Rexade™ GoDRI™
- Mostly tolerant to: none of the treatments
- Mostly susceptible to: none of the treatments

- Susceptible to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, H23/01, H23/02, H23/03, H23/04, Prominent®, Twister® + Glean®, Twister® + Karmex®

Soft brome

In keeping with previous trials, Firebird® was ineffective against soft brome. The only effective post-emergence option remains Rexade™ GoDRI™, which is marketed for brome control.

- Tolerant to: H23/03, H23/04, Prominent®, Twister® + Glean®, Twister® + Karmex®
- Mostly tolerant to: Stomp® + Invado®, Firebird®, H23/01, H23/02
- Mostly susceptible to: Firebird® f.b. Karmex®
- Susceptible to: Avadex® + Sakura®, Terb 500® f.b. Glean®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, Rexade™ GoDRI™

Ripgut brome

Ripgut brome had a very similar pattern of response to herbicides as soft brome, except that Firebird® seems to be slightly more effective on ripgut.

- Tolerant to: H23/02, H23/03, H23/04, Prominent®, Twister® + Glean®, Twister® + Karmex®
- Mostly tolerant to: Stomp® + Invado®, H23/01
- Mostly susceptible to: Firebird®
- Susceptible to: Avadex® + Sakura®, Terb 500® f.b. Glean®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, Rexade™ GoDRI™

Prairie grass

Prairie grass was, in general, more susceptible to the range of herbicides than the other two *Bromus* species. Sakura® was slightly less effective on prairie grass than on soft or ripgut brome.

- Tolerant to: H23/01, H23/02, H23/03, H23/04
- Mostly tolerant to: Stomp® + Invado®, Twister® + Glean®, Twister® + Karmex®
- Mostly susceptible to: Sakura®, Prominent®
- Susceptible to: Avadex® + Sakura®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura® f.b. Karmex®, Sakura® + Firebird®, Rexade™ GoDRI™

Oats

This trial used tame oats as a proxy for wild oats. Wild oats are more difficult to control due to variable germination and emergence dates. There were a number of moderately effective treatments in this trial, but only two were highly effective. Wild oats are on the label as being controlled by Rexade™ GoDRI™.

- Tolerant to: Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, H23/01, H23/02, H23/03, H23/04, Prominent®
- Mostly tolerant to: Firebird® f.b. Karmex®, Sakura®, Twister® + Glean®, Twister® + Karmex®
- Mostly susceptible to: Avadex® + Sakura®, Sakura® + Firebird®, Rexade™ GoDRI™
- Susceptible to: Sakura® f.b. Karmex®

Wheat

The wheat growth in this trial appeared to have been affected by grass grub, which is the likely reason why some crop damage was recorded to Firebird®, which is labelled as safe to use on wheat. Some crop damage was observed with treatments containing Karmex®, which some growers use when Group 2 herbicide resistance is known or suspected. Anecdotal evidence suggests that the crop would be able to recover from such damage and still yield well.

- Tolerant to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird® f.b. Karmex®, Sakura®, Sakura® + Firebird®, H23/01, H23/02, H23/03, H23/04, Rexade™ GoDRI™, Prominent®
- Mostly tolerant to: Firebird®, Sakura® f.b. Karmex®, Twister® + Glean®, Twister® + Karmex®
- Mostly susceptible to: none of the treatments
- Susceptible to: none of the treatments

Barley

The barley in this trial also seemed to have been affected by grass grub predation, which may have led to results that suggest crop safety of some products is lower than might otherwise have been the case, but we cannot be sure. Barley was mostly tolerant to treatments containing Sakura®, but the label for this product does not include barley as a registered crop. Barley was more tolerant of Sakura in the 2021 and 2022 trials.

- Tolerant to: H23/01, H23/03, H23/04, Rexade™ GoDRI™, Prominent®
- Mostly tolerant to: Avadex® + Sakura®, Stomp® + Invado®, Terb 500® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Karmex®, Sakura® + Firebird®, H23/02
- Mostly susceptible to: Twister® + Glean®, Twister® + Karmex®
- Susceptible to: none of the treatments

Summary

Herbicide screening provides a valuable insight into how grass weeds respond to herbicides across a range of application rates. With herbicide-resistant weeds becoming more prevalent in arable systems, it is vital to identify herbicides from a range of MoA groups, and the rates at which they are effective. Although this trial is limited in that it is un-replicated, and only tests weeds growing in isolation (i.e. not within a crop), it can nevertheless provide important data that can inform spray decisions as well as future trials.

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Appendix 6

Table 3. Weed control using 16 herbicide treatments at four different application rates across 10 grass and crop species in a screening trial located at Chertsey in 2023. Scores were taken on 27 July (pre-emergence) and 22 August (post-emergence). 0 = herbicide ineffective, 10 = weed completely controlled.

Species	Rate	Pre-emergence treatments												Post-emergence			
		Avadex® + Sakura®	Stomp® + Flufenacet	Terb 500® f.b. *Glean®	Firebird®	Firebird® f.b. Karmex®	Sakura®	Sakura® f.b. Karmex	Sakura® + Firebird®	H23/01	H23/02	H23/03	H23/04	Rexade™ GoDRI™	Prominent®	Twister® + Glean®	Twister® + Karmex®
Annual ryegrass	2x	10	9	9	9	10	10	10	10	7	6	7	10	9	4	5	10
	1x	10	9	9	10	10	10	10	10	6	5	6	9	8	3	4	10
	½x	10	4	5	8	8	9	10	10	2	3	3	4	4	1	3	9
	¼x	10	2	1	4	4	8	8	10	0	1	0	0	2	0	2	2
Perennial ryegrass	2x	10	10	10	10	10	10	10	10	7	8	9	10	10	7	9	10
	1x	10	10	10	10	10	10	10	10	8	7	6	9	8	7	9	10
	½x	10	8	9	10	10	10	10	10	4	5	6	7	6	6	9	10
	¼x	10	6	7	6	7	9	10	10	1	3	0	1	3	2	6	5
Phalaris	2x	10	9	10	10	10	10	10	10	10	8	10	8	10	8	6	9
	1x	10	10	10	10	10	10	10	10	9	8	9	8	10	8	4	7
	½x	10	8	10	10	10	10	10	10	6	4	7	7	10	8	4	4
	¼x	10	3	8	5	10	10	10	10	2	2	0	0	4	2	2	1
Hairgrass	2x	10	10	10	10	10	10	10	10	10	10	10	10	6	10	10	10
	1x	10	10	10	10	10	10	10	10	10	9	10	10	2	10	10	10
	½x	10	9	10	10	10	10	10	10	8	9	9	10	2	10	10	10
	¼x	10	8	10	10	10	10	10	10	2	3	4	6	2	5	9	9
Soft brome	2x	10	4	10	3	9	10	10	10	4	7	0	5	10	2	0	3
	1x	10	4	10	4	8	10	10	10	5	4	2	3	10	2	0	3
	½x	10	3	10	2	9	8	10	9	1	2	3	2	10	1	0	2
	¼x	10	1	7	2	4	4	2	6	0	0	0	2	9	0	0	0
Ripgut brome	2x	10	5	10	10	10	10	9	10	6	8	2	2	10	2	0	3
	1x	10	5	10	7	10	10	10	9	4	1	0	1	10	2	0	3
	½x	10	2	10	3	5	3	8	8	1	0	0	1	5	1	0	2
	¼x	9	1	0	0	2	2	2	3	0	0	0	0	2	0	0	0
Prairie grass	2x	10	9	9	10	10	9	9	10	4	6	1	1	10	9	5	5
	1x	10	5	10	9	10	7	10	9	2	3	1	1	9	7	5	5
	½x	10	7	8	8	6	6	9	9	0	0	1	1	9	4	7	7
	¼x	10	4	3	2	2	1	8	4	0	0	0	0	8	2	2	6
Oats	2x	7	1	5	3	4	8	8	9	3	5	0	0	8	0	3	4
	1x	8	3	5	3	5	5	9	8	0	3	2	0	8	0	4	4
	½x	9	1	2	2	2	3	8	6	0	0	0	0	9	0	2	0
	¼x	4	0	2	1	1	1	4	0	0	0	0	0	2	0	0	0

Wheat	2x	0	1	2	2	3	0	4	3	0	3	0	0	0	2	0	0
	1x	2	2	3	4	3	2	4	2	0	3	0	0	0	2	2	4
	½x	4	1	1	2	2	0	2	1	0	0	0	0	0	0	0	0
	¼x	1	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0
Barley	2x	1	3	5	2	5	0	4	5	1	5	0	0	0	4	0	0
	1x	4	4	6	4	5	0	4	4	0	5	0	0	0	3	4	6
	½x	4	2	3	3	4	0	0	2	0	2	0	0	0	0	3	5
	¼x	3	0	2	2	3	0	2	0	0	0	0	0	0	0	0	5

Note: 2x = double the label rate, 1x = label rate, ½x = half the label rate, ¼x = quarter label rate). 0 = no effect, 10 = full control (all plants killed). Note that "label rate" here was chosen to be a typical grassweed application rate, as many product labels suggest a range. Scores are those from 70 days after application. Avadex® was incorporated at drilling. f.b. = followed by.

*Glean applied at post-emergence timing.

Rotational or strategic ploughing for weed management

Project code X22-01-14

Duration Year 1 of 4 (2023-24 season)

AuthorsCharles Merfield (FAR), Pieter-Willem Hendriks (Lincoln University)

Location FAR Chertsey Research Site, mid- Canterbury

FundingFAR

Acknowledgements Abie Horrocks (FAR) (Long-term Establishment Trial manager)

Key points

1. This research is only part way through the first year, so this is an interim report.
2. The Chertsey Long Term Establishment trial is an unparalleled opportunity to study the impact of full inversion (ploughing), non-inversion / minimum, and no- / zero-tillage (direct-drilling) on the weed seedbank and biomass of an NZ arable system. Unique globally is the ability to study the impact of once-off deep inversion at 40 cm undertaken on all three tillage regimes (to study the impact on soil organic carbon) on the weed seedbank and biomass, both immediately and over multiple years to see how long it takes to revert to the original weed flora. This work will be invaluable in understanding the role of tillage to manage grass weeds in reduced tillage systems and as a herbicide resistance management tool.
3. Only weed biomass measurements are currently available. There were clear differences among the three tillage regimes, with no-till and min-till having similar weed biomass and both more than twice the biomass of ploughing.
4. Deep ploughing caused approximately a 90% reduction in weed biomass in the no-till and min-till, but no change in the regular ploughing.
5. The no-till and min-till were completely dominated by grass weeds, while the ploughing treatment was about two thirds grass weeds. Deep ploughing reversed this with broadleaf weeds becoming a much larger proportion, especially for the no-till treatment. This is in the context of a large reduction in emerged weeds (biomass) post the deep ploughing in the min-till and no-till.

Background

Minimum and no-tillage as a sustainable agricultural practice has experienced increasing rates of adoption globally and in New Zealand. No-till in particular is dependent on herbicides, mainly glyphosate as a replacement for tillage, hence the term 'chemical ploughing', and arable systems as a whole are highly dependent on herbicides for overall weed management. However, herbicide resistance has been significantly increasing for the last few decades. In New Zealand, surveys of arable farms as part of the MBIE Herbicide Resistance project has identified widespread Groups 1 and 2 resistance and high levels of resistance in ryegrass to glyphosate (Group 9) in vineyards. Herbicide resistance and minimum tillage are therefore creating conflicting requirements on growers. Minimum and no-till address soil quality and cost issues. However, minimum tillage, particularly no-till, generally leads an increase and a modification of the weed populations that tend to favour perennial weeds and grasses, due to lack of burial, creating an increased reliance on herbicides for weed management, creating greater evolutionary pressure for selection of herbicide resistant weeds. Added to this herbicide resistance in grass weeds is a particular issue due to the New Zealand herbage seed industry and high proportion of grasses in arable crop rotations.

Strategic ploughing every five to seven years, buries the weed seedbank that has accumulated on the soil surface. The buried seeds loose viability at a speed that is dependent on environment and species, particularly grass weeds which lack the hard seed coats of broadleaf weeds tend to lose viability faster. Thus, after around five years most buried grass seeds will have become unviable. Strategically ploughing again after five to seven years will bring few viable grass weed seeds back to the surface, while burying grass weed seeds that have been accumulating on the surface over that time. Such strategic ploughing is also likely to have a large negative impact on the viable broadleaf seedbank as well, as despite their hard seed coat, as seed viability typically undergoes exponential decay.

There is very limited weed science globally, and none in NZ that has studied the effects of contrasting tillage systems, over the long term, on the weed seedbank and emerged weed flora in any cropping system. Further, exceptionally few studies have researched the impacts of full inversion tillage on weeds in long term no or min-till systems. The FAR Chertsey long term establishment trial (CLTET) that has been running since 2003 (20 years) comparing full inversion tillage (ploughing) minimum tillage, and no-tillage (direct drilling) is thus an unparalleled opportunity to study the long-term effects on weeds of contrasting tillage systems in an NZ arable system. In addition, in April 2024 half of the three tillage treatments were ploughed to 40 cm deep to study the effect on soil organic matter of burying the accumulated surface residues. The ability to study the effects on weeds of strategically ploughing a long-term tillage trial is unique globally. This trial is therefore studying the effects of the long-term tillage treatments, and the strategic ploughing of the three tillage treatments on the weed seedbank at three depths and emerged weed biomass.

Methods

This trial is only partway through its first year (of a minimum of four years) so only initial results for weed biomass are available.

The CLTET is comparing three contrasting cultivation (tillage) treatments since 2003:

- Full inversion tillage (ploughing) to 30 cm followed by one or two secondary tillage passes.
- Shallow non-inversion / minimum tillage.
- No-tillage / direct drilling.

For each treatment there are two sub-treatments (split plots) that vary in the type of machinery used. In April 2024, one of the sub-treatments for each tillage treatment was fully inverted / ploughed to 40 cm with the aim of studying the effect of burying at depth the soil organic matter / carbon that had accumulated on the soil surface. The ploughing was undertaken with skims with the aim of getting a high level of inversion and deep burial of the soil surface, i.e. a more 'traditional' plough than standard ploughing which tends to be shallower and focused on work rate and simply turning the surface under.

The weed seedbank is being sampled annually by taking soil cores at three depths, 0-10, 10-20 and 20-30 cm. The number of viable weed seeds in the soil are determined by using a standard glasshouse-based germination procedure. Emerged weed biomass in the plots is annually determined by excluding herbicide application by placing plastic sheets on the ground during herbicide spraying, and then harvesting the weed biomass, separating into monocots and dicots, oven drying and weighing.

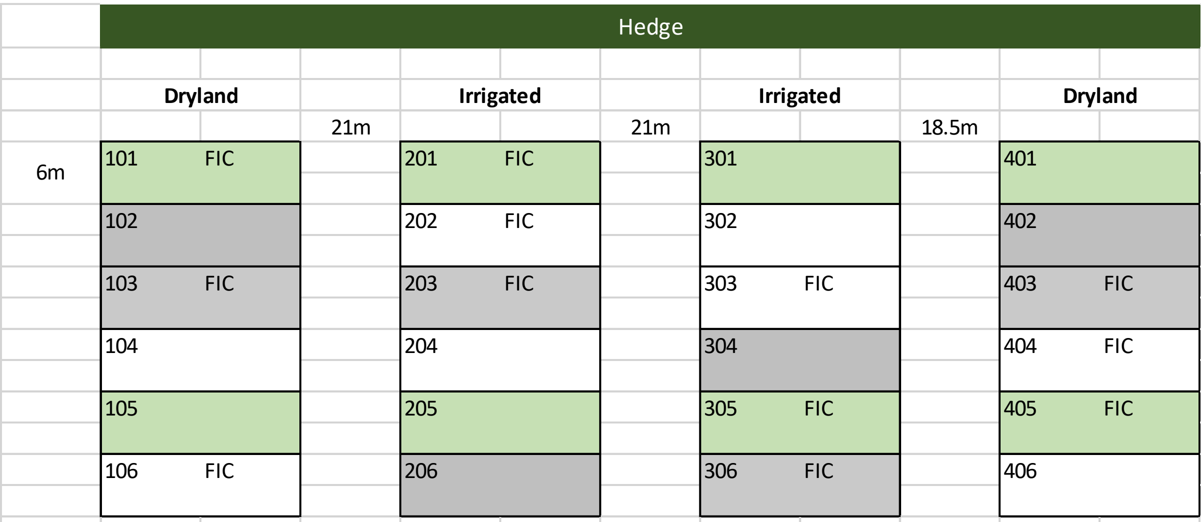
The weed seedbank in the plots that were strategically ploughed in April 2024 were sampled immediately before ploughing and then again after the all cultivation was complete to study the effect of the ploughing on the distribution of the weed seed bank.

This will allow the impact of the three tillage systems, and particularly the strategically ploughed treatments on the changes to the weed seedbank's size and distribution as well as emerged weed flora. This will be invaluable in determining the effect of different tillage systems in NZ arable crops on weeds, and particularly the value of strategic ploughing for weed management, which will be of particular value in the management of grass weeds in minimum tillage and herbicide resistance.

Overall trial details

Chertsey long-term arable crop establishment overall trial design / layout

Figure 1 shows the overall trial design / layout of the Chertsey long-term arable crop establishment experiment, including the strategically ploughed / full inversion cultivation (FIC) treatment in April 2024. The terms 'strategic ploughing' and 'full inversion cultivation' (FIC) are the same, strategic ploughing is being used in the context of weed management while FIC is being used in the CLTET. The terms are therefore being used interchangeably.



Trt	Cultivation	Degree of Cultivation
1	Inversion	Plough + 1 or 2 maxi-till passes + Drilled John Deere 750A double disc
2	Non-inversion	2 Pass topdown (shallow) + Drilled John Deere 750A double disc
3	No-till	Drilled John Deere 750A double disc
FIC	Plough to 40 cm	FIC = full inversion cultivation / strategic ploughing April 2024

Figure 10. Overall layout of the Chertsey long-term arable crop establishment trial, including the strategic ploughing / full inversion cultivation treatment (FIC) in April 2024.

Weed seedbank / soil coring

The weed seedbank was sampled to 30 cm at 0-10, 10-20 and 20-30 cm increments, using a 50 mm diameter soil corer, with a total of 12 cores per plot, sub-divided into three sub-plots of four cores, with the samples from each sub-plot being individually analysed (Figure 2). This sampling approach was taken to reduce within-plot variation and to ensure enough soil was collected for analysis. For each sub-plot, the soil samples for each of the three different depths per subplot were homogenised, placed in sealed plastic bags and stored in the dark at 4°C until they underwent germination tests.

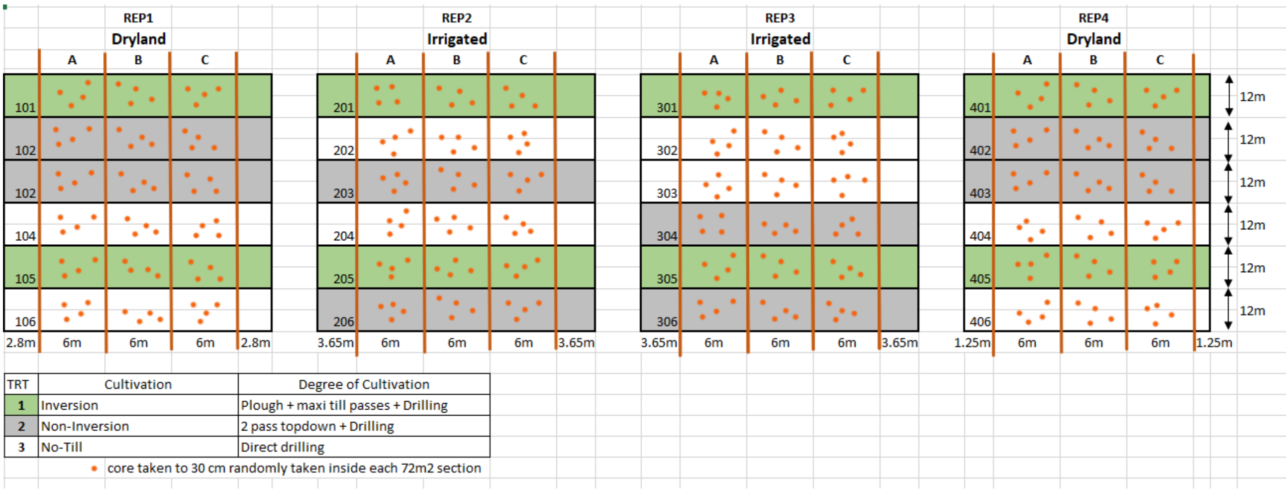


Figure 11. Soil core (50 mm diameter) sampling pattern in the rotational / strategic ploughing for Integrated Weed Management project utilising the Chertsey long-term establishment trial.

For the germination test, a standardised amount of soil was placed in germination trays in a glasshouse, and subjected to standard weed seed germination procedures. This includes multiple cycles of wetting / drying and minor soil disturbance. Weed seedlings were grown to sufficient size, typically first or second true leaves, to enable identification to species level where possible, and then removed from the trays. This determined the total number of emerged weeds at each of the three depths for each homogenised sample.

A baseline sampling of the weed seedbank was conducted at the end of March 2024, just before strategic ploughing / FIC. After FIC plots were fully cultivated they were re-sampled in late April 2024.

All plots will be re-sampled at the end of year 2, 3 and 4 to assess the interaction between tillage and rotation on the weed seedbank.

Emerged weed biomass

Emerged weed biomass was measured in two 30 x 60 cm quadrats in column C (Figure 2) at the west end of each plot, avoiding the outside two meters from the plot edge, and locations where soil cores had been taken. Black plastic sheets approximately one metre square were pinned to the soil on 24 April 2024 immediately prior to herbicide application (Firebird, 400 g/L flufenacet Group 12 and 200 g/L diflufenican Group 15) on 25/04/2024, to block the herbicides from the quadrat sample area. The sheets were removed the day after herbicide application, and the exact location for the quadrats were marked. 104 days after sowing (07/08/2024) the foliage of the weeds in each quadrat were manually cut. The weed foliage was taken back to the laboratory, where they were separated into monocots and dicots. The samples were then dried in an oven at 72°C for three days and then weighed (dry weight).

Emerged weed populations will also be re-sampled over the following three years.

Statistical analysis

All statistical analyses were performed, and figures were constructed in R® (R Core Team, 2020). Each mixed model contained random components related to the structure of the experimental design for each experiment, such as pot position, or plot position. An analysis of variance and estimation of least squares means were conducted, with genotypes as fixed effects using the function “lme” in “emmeans” in R® software package. Pairwise comparisons between the genotype means were obtained using the pairs function in the “emmeans”. Benjamin-Hochberg pairwise comparisons between genotype means were conducted by the pairs function in “emmeans” in R. Plots were generated using “ggplot2” in R with error bars representing standard error.

Results and Discussion

As noted above, this research is only part-way through the first year so no only weed biomass results have been completed.

A key factor driving these results is that as most seeds of arable weeds are small (e.g. < 5 mg), they can only emerge from the top 2-5 cm of the soil (the emergeable zone), as any deeper than this they will die due exhausting the energy and/or nutrients contained in the seed (called suicidal germination). The original tillage treatments, and the strategic ploughing / FIC treatment have differing effects on the distribution of the weed seedbank and therefore the proportion of the seedbank in the emergeable zone. Weed seeds can determine their depth of burial through detecting factors such as diurnal temperature variation and oxygen levels, and therefore will only germinate if they are in emergeable zone. In addition, approximately 90 % of the weed seedbank is dormant and will not germinate at all, this is the key factor driving the long-term persistence of weed seedbanks.

There were significant differences (p<0.01) in weed biomass (dry weight) between the non-FIC inversion treatment and the two non-FIC minimum tillage treatments, with 2.5 to 3.0 times more weed biomass in the no-till and non-inversion tillage treatments compared with full inversion / ploughing (Figure 3). This is typical of the three tillage types with ploughing frequently having lower weed burdens than reduced tillage systems.

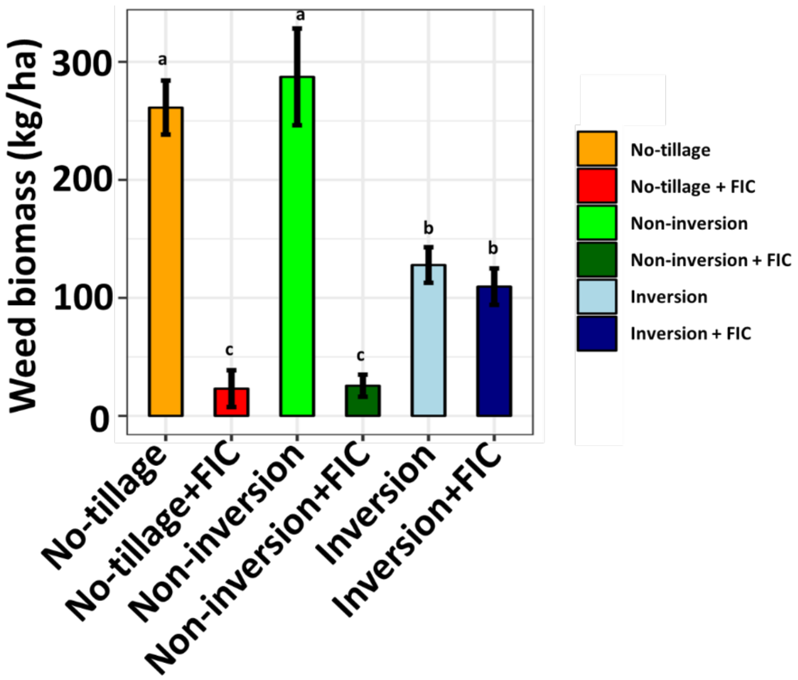


Figure 12. Weed biomass in absence of herbicides in the 2024 wheat crop under three tillage systems (full inversion (ploughing), non-inversion (min-till) and no-till, collected 104 days after sowing in the rotational / strategic ploughing for Integrated Weed Management project utilising the Chertsey long-term establishment trial. FIC = Full Inversion Cultivation / strategic ploughing to 40cm in April 2024. Error bars are the standard error, n=8 for each category. The letters identify significantly different groups (p<0.05)

The strategic ploughing / FIC had a very significant (p<0.001) effect on the weed biomass in the no-till and non-inversion plots reducing from 216 kg and 287 kg to 23 kg and 26 kg per hectare for no and non-inversion tillage respectively, which is less than 10% of biomass in the non-FIC treatments (Figure 3). This is also as expected as the weed seedbank will be concentrated at the soil surface layers due to no or limited mixing by tillage, and then the deep ploughing will have moved most of the seedbank to deeper soil layers where it will inhibit germination and any weeds that do germinate will die before they can reach the soil surface.

Weed biomass in the no-till and non-inversion tillage FIC treatments was also significantly lower ($p<0.05$) than both the inversion and FIC inversion treatments (Figure 3). This is also as expected, as standard ploughing / inversion typically mixes soil layers more than deeply burying the soil surface (as the FIC aimed to do), so with annual ploughing the weed seedbank becomes homogenised (mixed) through the soil profile. This is also why there was no difference between the inversion and FIC inversion treatments at 128 and 109 kg/ha respectively (Figure 3).

There was significantly ($p<0.05$) more biomass (dry weight) of grasses (monocots) than broadleafs (dicots) in the no-tillage and non-inversion tillage treatments than the inversion (ploughing) treatment (Figure 4). This is a common effect in minimum and no-till systems as burying grass weeds often results in them loosing viability due to their lack of a protective seed coat, before they are brought back to the emergeable zone by further tillage.

Strategic ploughing (FIC treatment) of both the no-till and non-inversion treatment significantly ($p<0.05$) shifted the weed biomass proportion towards dicots, though still less than 50 % (Figure 4). In comparison, while the inversion treatment plots also saw a shift of the weed composition towards monocots from strategic ploughing, however, the shift was only significant at the 10 % level (Figure 4). These results are also as expected, in the no-till and minimum-tillage systems, only dicot weed seeds will maintain viability when buried at depth for long periods so the FIC treatment will bring them up to the emergeable zone. Also, although the FIC aimed to completely invert the soil profile, and bury the surface layers at depth, there will always be some mixing when ploughing, especially when followed by secondary cultivation so, a small proportion of the surface layers, and the grass weed seeds contained there, will have ended up back in the emergeable zone.

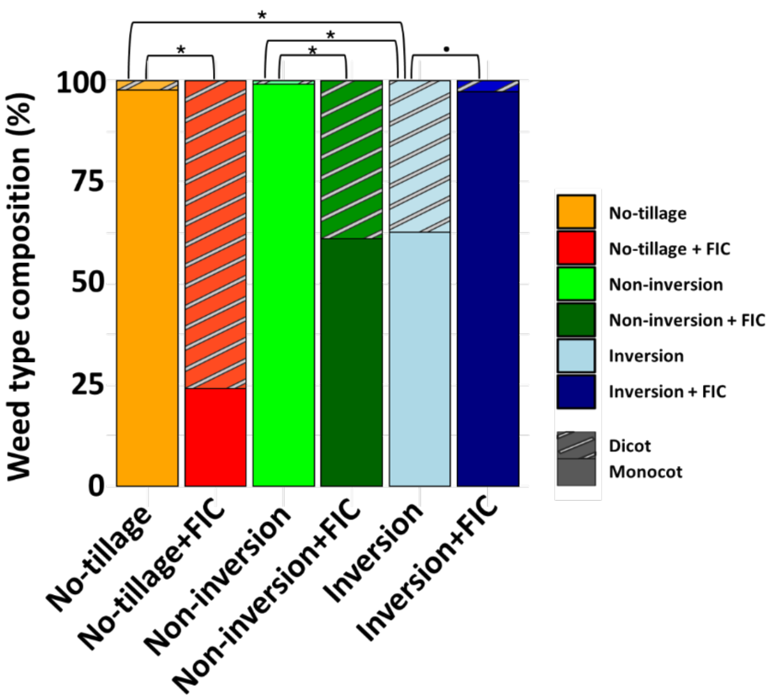


Figure 13. Relative distribution of the above-ground weed biomass in the 2024 wheat crop under three tillage systems (full inversion (ploughing), non-inversion (min-till) and no-till), collected 104 days after sowing in the rotational / strategic ploughing for Integrated Weed Management project utilising the Chertsey long-term establishment trial. FIC = Full Inversion Cultivation / strategic ploughing to 40cm in April 2024. Weeds are separated into monocotyledons (no shape) and dicotyledons (stripes), and the percentage of each family of the whole collected biomass is represented for each of the tillage treatments (n=8). Significance levels: *for $p<0.05$, · p=0.1

These results are in accordance with other long-term tillage research and on-farm experience. Reduced tillage systems typically have larger weed populations with a higher proportion of grasses than inversion / plough systems. Ploughing long term minimum tillage systems will bury the weed seed bank that has accumulated in the surface soil layers beyond the emergeable zone. The soil brought up from depth that now sits in the emergeable zone will be depleted in seeds due to them having lost viability (died) while buried, resulting in much reduced emerged weed biomass in the following crop. As monocot seeds loose viability faster than dicots when buried the weed flora will be shifted towards dicots after strategic ploughing. As weeds produce seeds in the following crops, it is expected that the weed flora will start to return to the state it was in before strategic ploughing. This is another immensely valuable feature of this research in being able to track the changes to the weed seedbanks and emerged weed flora in the strategically ploughed treatments over time, to see how long it takes for them to return to their pre-strategically ploughed status.

The soil core results will also be highly valuable to compare with the above results, particularly the proportion of dicots and monocots pre and post strategic ploughing. This will also be a more accurate measure of the vertical distribution and monocot to dicot ratio of the weed seedbank.

Studying the weed flora / biomass and seedbank over the following years will allow for a much deeper understanding of how different tillage approaches in NZ arable cropping systems impacts weed flora. In particular the value of strategic ploughing, once every five or so years, on the weed seedbank, the proportion of broadleaf to grass weeds, the amount of weeds (biomass) and therefore the potential of strategic ploughing as a management tool for grass weeds in min-till and no-till systems and its potential as a herbicide resistance management tool.

Summary

Herbicide resistance (HR) is an ongoing and growing problem in NZ arable systems. Integrated Weed Management (IWM) using as many different weed management tactics as possible is the means of addressing HR. Tillage systems, such as non-inversion / ploughing, minimum-tillage (non-inversion, shallow) and full no-till (direct drilling) are known to drive weed ecology. Ploughing in particular has long been recognised for its role in weed management, not just clearing a paddock of existing vegetation, but also burying surface weed seeds away from the emergeable zone and causing them to lose viability.

While it is well known that tillage systems drive weed ecology, much of this is from practical on farm experience. There is limited research globally on the impacts of contrasting tillage systems, such as regular ploughing, minimum tillage, and no-till, over the long term, on weed flora and seedbanks in arable cropping systems. There is no research in NZ. Globally there are exceptionally few pieces of research studying the impact of once-off deep ploughing / inversion on the weed flora and seedbanks, of long-term tillage treatments. This research, takes advantage of the FAR Chertsey Long Term Establishment trial to study these effects.

After running for 20 years, the Chertsey Long Term trial, has been comparing annual ploughing, min-till and no-till cultivation / establishment techniques, on a wide range of soil measurements. In April 2024 each of the main treatments were split into sub-plots, and half once-off, deep ploughed to 40 cm to bury surface accumulated soil organic carbon (SOC), to study the impact of burying SOC and study how fast surface SOC reaccumulates. This presents a unique opportunity study the effects of long-term tillage treatments on weeds in a NZ arable system, and globally a unique opportunity to study the effect of once-off deep ploughing on the weeds in the three tillage systems.

The research is only part way through the first season so only weed biomass (flora) data is available, i.e. this is an interim report. Only weed biomass measurements are currently available.

There were clear differences among the three tillage regimes, with no-till and min-till having similar weed biomass and both more than twice the weed biomass of ploughing.

Deep ploughing caused approximately a 90 % reduction in weed biomass in the no-till and min-till, but no change in the regular ploughing.

The no-till and min-till were completely dominated by grass weeds, while the ploughing treatment was about two thirds grass weeds. Deep ploughing changed this with broadleaf weeds becoming a much larger proportion, especially for the no-till treatment. This is in the context of a large reduction in emerged weeds (biomass) post the deep ploughing in the min-till and no-till.

Studying the weed flora / biomass and seedbank over the following years will allow for a much deeper understanding of how different tillage approaches in NZ arable cropping systems impacts weed flora. In particular the value of strategic ploughing, once every five or so years, on the weed seedbank, the proportion of broadleaf to grass weeds, the amount of weeds (biomass) and therefore the potential of strategic ploughing as a management tool for grass weeds in min-till and no-till systems and its potential as a herbicide resistance management tool.