



SEED INDUSTRY RESEARCH CENTRE

Annual report 2023-2024



Preface

The Seed industry Research Centre (SIRC) is a partnership between the Foundation for Arable Research (FAR) and major seed companies, farmer and research organisations listed below. Established in 2017, this funding model enables greater investment into education and development of new capability while delivering applied research to growers and industry. SIRC also receives funding from government and private research funds and contributes to wider industry programmes such as the work on herbicide resistance. This booklet is a compendium of the research reports on projects conducted by SIRC in its collaboration with FAR and other research and education entities. While results of these projects have been previously delivered in part through events and media, these are the full peer reviewed reports for the period.

SIRC would like to acknowledge the work of researchers, growers, agronomist and technicians from the partner organisations involved directly in these projects, as well as the input that the technical team representatives provide us to prioritise the projects.

Ivan Lawrie Manager, Seed Industry Research Centre.

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Evaluation of fungicides for white blister and *Alternaria* control in radish seed crops

Project code	B21-02-00
Duration	Year 5 of 5 (2023-24 season)
Authors	Nicholas Davies (AgResearch)
Location	Southbridge, Canterbury
Funding	Seed Industry Research Centre (SIRC)

Acknowledgements Arron Lill (host farmer), NZ Arable (trial operator), James Taylor (South Pacific Seeds Agronomist).

Key points

- Ranman[®] and Ridomil[®]Gold MZ WG, are a good backbone to a white blister fungicide programme. Treatments with applications of both Ranman[®] and Ridomil[®]Gold MZ WG produced higher seed yields than the control.
- Pristine[®] and Amistar[®] were also included in the fungicide treatments with the highest seed yields and the lowest white blister symptoms.
- None of the products in the trial had a significant effect on the *Alternaria* score.

Background

Canterbury arable growers produce approximately 60% of the world's radish (*Raphanus sativus*) seed, and the major disease issue the crops faces is “white blister” (*Albugo candida*), a disease caused by the oomycete (*Albugo candida*). While it is not a true rust it is also referred to as “white rust”. White blister affects several brassica species. The disease leads to leaf spots and hypertrophy (enlarged tissues) in the inflorescence, resulting in “stagheads” that cause economic seed yield loss. *Albugo candida* produces two types of spores—airborne sporangia (asexual) and resilient oospores (sexual), which can survive in soil, plant debris, or contaminated seed for several seasons. Periods of moderate temperatures (10-20°C) and leaf wetness are known to be conducive to infection, while heavy dews, and irrigation late in the day have been suggested as contributing factors.

Being an oomycete, white blister is a hard disease to control. Only a few chemistries are available. Infections, which become systemic within the plant, are especially difficult to remedy. Seed yield losses from the disease have been found to be up to ~40% previously in Canterbury radish seed crops (Braithwaite 2018). Since the last fungicide evaluation trial was conducted in radish seed in 2018, there has been some concern that white blister sensitivity to cyazofamid and/or metalaxyl may have shifted. This trial was a general fungicide evaluation trial, however it had a focus on white blister management due to its importance in radish seed production.

Methods

The fungicide trial was situated in a red round hybrid radish seed crop near Southbridge and all management decisions were made by the host farmer, including the first fungicide application of the season (Cusol[®], Ranman[®], Manco[®]75WG), giving the trial a consistent starting point of disease load. After it was clear several treatments were having limited to no effect on disease scores, Ridomil[®] and Amistar[®] were applied to those treatments on 17/01/2024 to prevent further build-up of white blister, while still retaining the lost seed yield from those treatments. Subsequently desiccation,

harvest date etc. were all aligned with the host farmer’s decisions on the main crops management. The trial was a four replicate randomised complete block design with 12 fungicide treatments (Table 1). Further details about the fungicide chemistries used are presented in Table 2. Male rows were excluded, and each plot was laid across a female bed resulting in plots of 4m across each bed and 3m along each bed.

The two predominant diseases in the trial were white blister and *Alternaria*, both of which were scored regularly on a linear scale of 0 to 10 representing the disease incidence on racemes. A score of 1 indicates 10% of racemes presenting with the disease while a score of 9 represents 90%.

Analysis was conducted in R utilising the agricolae package. Individual effects were analysed using a linear analysis of variance (ANOVA).

Table 1: Applied treatments by date. Details about each chemical and rate are available in Table 2.

Treatment	15/12/2023	27/12/2023	17/01/2024	01/02/2024
1	Negative Control	Negative Control	Negative Control	
2	Zampro®	Zampro®	Ridomil®Gold MZ WG, Amistar®	
3	Foschek®	Foschek®	Ridomil®Gold MZ WG, Amistar®	
4	Ridomil®Gold MZ WG	Ridomil®Gold MZ WG	Ridomil®Gold MZ WG, Amistar®	
5	Phoenix®	Phoenix®	Ridomil®Gold MZ WG, Amistar®	
6	Zorvec®Enicade®	Zorvec®Enicade®	Ridomil®Gold MZ WG, Amistar®	
7	Cusol®	Cusol®	Ridomil®Gold MZ WG, Amistar®	
8	Apex®	Apex®	Ridomil®Gold MZ WG, Amistar®	
9	Ranman®, Foschek®	Apex®, Pristine®	Ridomil®Gold MZ WG, Amistar®	
10	Ranman®, Foschek®	Ranman®, Foschek®, Pristine	Ridomil®Gold MZ WG, Amistar®	Ridomil®Gold MZ WG, Amistar®
11	Ridomil®Gold MZ WG, Foschek®	Ridomil®Gold MZ WG, Pristine	Ranman®, Amistar®	Ranman®, Amistar®
12	Sentinel	Sentinel	Sentinel	Sentinel

Table 2: Breakdown of products and rates used, including active ingredients and fungicide groups.

Product	Active	Rate	Group
Cusol®	92.8 g/L copper	500 ml/ha	M1
Ranman®	400 g/L cyazofamid	200 ml/ha	21
Manco®75WG	750 g/kg mancozeb	2.1 kg/ha	M3
Zampro®	300 g/L ametoctradin + 225 g/L dimethomorph	800 ml/ha	45 + 40
Foschek®	400 g/L phosphorous acid	5 L/ha	33
Ridomil®Gold MZ WG	40 g/kg metalaxyl-M + 640 g/kg mancozeb	2 kg/ha	4 + M3
Phoenix®	500 g/L folpet	1.5 L/ha	M4
Zorvec®Enicade®	100 g/L oxathiapiprolin	350 ml/ha	49
Apex®	200 g/L fluazinam + 320 g/L pyrimethanil	2 L/ha	29 + 9
Sentinel	Trichoderma	200 g/ha	Biological
Pristine®	252 g/kg boscalid + 128 g/kg pyraclostrobin	500 g/ha	7 + 11
Amistar®	250 g/L azoxystrobin	0.75 L/ha	11

Results and Discussion

Radish seed yield and disease scoring results for all treatments are available in Table 3. Treatments with a backbone of Ranman and Ridomil out yielded all other treatments by X%. Treatments 9, 10, 11 and 9 out yielded the control by X, X, and X%, respectively, and were the only treatments which contained both Ranman and Ridomil. The treatments also had significantly lower white blister scores than the control. Treatment 4 outperformed the control which evaluation date? in white blister scoring, however did not have a higher yield than the control. It should be noted that while the p value for yield and the January scoring for white blister are only of marginal significance (between 0.05 and 0.1) this is driven by a large variation between plots in treatment 12 (the biologicals treatment). When treatment 12 is removed from the analysis, the p value drops to 0.0008 for yield and to 0.0158 for the January white blister scoring.

Overall, these results indicate that Ranman and Ridomil still provide protection against white blister and appear to work best when both are used as part of a fungicide regime. It should be kept in mind that oomycetes are known to develop resistance, and the mixture of the three fungicide groups (4, M3 and 21) within these two products within the season will help preserve the chemistries for the future. We did not identify any other fungicide products which have the potential to replace them as the backbone of a white blister program. It should be noted that the higher performing treatments also contained a mixture of Foscheck, Pristine and Amistar, although Foscheck alone did not perform well, Pristine and Amistar should be used in conjunction with other modes of action and were not tested as singular treatments.

Table 3: Yield and disease score results for the differing treatments. Treatments discussions can be found in Table 1. Scores were a linear scale from 1 to 10 based on raceme disease incidence. A score of 1 indicates 10% racemes had disease incidence, while 9 indicates 90% of racemes had disease.

Treatment	Yield (kg/ha)		White blister score 16/01/2024		White blister score 16/02/2024		Alternaria score 16/01/2024		Alternaria score 16/02/2024	
10	882	a	4.25	e	3.75	d	1.75	a	2.00	a
11	780	ab	4.75	de	3.75	d	3.00	a	2.75	a
9	771	ab	5.00	cde	4.75	cd	3.25	a	3.25	a
4	647	abc	5.50	bcde	5	bcd	3.00	a	3.00	a
3	560	bc	6.50	abcde	6.75	abc	2.75	a	3.00	a
6	532	bc	6.75	abcd	6.75	abc	2.75	a	3.00	a
2	522	bc	6.00	abcde	5.75	abcd	2.75	a	3.50	a
1	479	c	7.75	ab	7.25	a	2.50	a	3.50	a
7	434	c	7.75	ab	6.75	abc	3.50	a	3.75	a
5	413	c	7.75	ab	7.25	a	2.75	a	4.50	a
8	403	c	8.25	a	7.00	ab	2.50	a	2.75	a
12	402	c	7.25	abc	7.00	ab	3.00	a	3.50	a
Mean	569		6.46		5.89		2.79		3.21	
p value (model)	0.0635		0.0972		0.0209		0.6046		0.9373	
CV	33				22.58		75.78		84.97	
LSD (p=0.05)	264				2.18		3.01		3.88	

Summary

A fungicide trial was conducted in a radish seed crop, focusing on white blister and Alternaria. Treatments containing applications of both Ranman and Ridomil produced seed yields higher than the control. Pristine and Amistar were also present in the highest yielding and lowest symptomatic white blister treatments. None of the products included reduced Alternaria severity.

References

Braithwaite, M., Chynoweth, R., Gunnarsson, M., Braithwaite, L., Harvey, I., & Rolston, P. (2018). White blister disease control in radish seed crops. *New Zealand Plant Protection*, 71, 325-331.

Fisher, D. J., & Hayes, A. L. (1984). Studies of mechanisms of metalaxyl fungitoxicity and resistance to metalaxyl. *Crop Protection*, 3(2), 177-185.

Seed yield of two white clover cultivars in different row spacings with/without 2,4-D

Project code H19-04-00

Duration Year 2 of 3 (2022-23 Season)

Authors Fiona Anderson, Owen Gibson and Richard Chynoweth (FAR)

Location Yaldhurst, Canterbury (-43.509426, 172.524842)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operators and hosted at Insignis Park).

Key points

- Machine dressed yield was similar between cultivars and row spacings and averaged 913 (\pm 12) kg/ha. However, the application of 2,4-D in early August reduced yield by 58 (\pm 11) kg/ha compared with unapplied treatments ($P=0.04$).
- As row spacing increased from 30 to 60 cm, the number of white flowers/m² at peak flowering was reduced ($P=0.004$).
- Peak flowering on average occurred on 20 December 2022, and was not affected by treatment.

Background

This experiment aimed to continue investigating the effect of row spacing and cultivar on seed yield of white clover (*Trifolium repens* L.). A previous experiment on 'Quartz' (medium leaf) and 'Legacy' (large leaf) cultivars at different row spacings (30, 45 and 60 cm) was completed during the 2021-22 growing season near Lincoln, Canterbury (Ross, 2023). This was a wet harvest year with excess rainfall during February delaying machine harvest. Row spacing had no effect on seed yield, which averaged 340 kg/ha (\pm 29), with no difference between cultivars.

Row spacing is an important management strategy, outside of certification requirements. Stolons grow outward from the crown of the plant into the space between rows. Nodes are produced along the stolon, with a node bearing either vegetative axillary growth (e.g. a branch) or a leaf-flower combination. The more nodes that are produced per stolon, and subsequently per unit area, the greater opportunity for flower production and thereby seed yield. Clifford's work in the 1980s found that with larger leaf size the number of leaves and therefore nodes required to reach canopy closure was reduced, resulting in a reduced opportunity for flower production. In theory, wider row spacing should produce more flowers/m² due to greater distance for stolon proliferation. However, Ross (2023) found no difference in flowers/m² across row spacing or cultivar. This was ultimately due to a consistent number of flowers produced per stolon (1.63 flowers/stolon), despite longer stolons in wider row spacing treatments. Therefore, yield was limited with increasing row spacing due to fewer plants/m² and subsequently stolons/m².

Canopy management is intended to enhance the successful emergence of flower buds by removing shading from upper leaves in the canopy via topping, grazing or herbicide application. Herbicides used for weed control can unintentionally have the same effect due to phytotoxicity. However, removal of photosynthesising canopy results in a reduced supply of resources to developing flowers. In particular, 2,4-D is used to control broadleaf weeds within the clover crop, with its twisting effect known to check clover growth while the plants recover. Previous investigation of the effect of 2,4-D has resulted in lower seed yield (FAR WCGG 2009).

This experiment, conducted during the 2022-23 season, aimed to re-evaluate the cultivar by row spacing treatments tested during 2021-22 season. The experiment also aimed to test the effect of an early spring application of 2,4-D ester on seed yield. This work was completed using the same white clover cultivars, 'Quartz' and 'Legacy', and row spacing treatments.

Methods

The experiment was located in Yaldhurst, Canterbury (-43.509426, 172.524842). The dominant soil type at the site is a Typic Fluvial Recent soil, a Selwyn loam (Lilburne et al., 2012). After full cultivation, plots were sown east to west on 5 April 2022 at 3 kg/ha in 15 cm row spacing using a double-disc plot cone seeder. Each plot was 2.9 m wide by 10 m long and required two passes per plot with the drill. There were twelve treatments (Table 1) replicated four times in a randomised block design. Two white clover cultivars were used; medium-leaf 'Quartz' and large-leaf 'Legacy' (PGG Wrightson Seeds). Three row spacings, 30, 45 and 60 cm were tested. Row spacing treatments were established using Buster® (200 g/L glufosinate-ammonium) on 14/15 July 2022. Unnecessary interceding 15 cm rows were sprayed to create 30, 45 and 60 cm row spacings. On a per plot basis, this resulted in 8 rows in the 30 cm spacing, 6 rows in the 45 cm spacing and 4 rows in the 60 cm spacing. The effect of 2,4-D application was tested on each cultivar by row spacing treatment using an unapplied control and 2,4-D treatment.

The general management of the plots is described in Appendix 1. On 5 August 2022, the 2,4-D treatment plots were sprayed with 1.75 L/ha of Pasture Kleen™ Xtra (680 g/L 2,4-D ester), alongside the general application of Argosy® on that day. Plots were desiccated for harvest on 17 February 2023 with a single application of Reglone® (Appendix 1). Individual plot harvest was completed on 21 February 2023 with a Wintersteiger plot combine. The harvested area was considered to be 2.7 m wide by 10 m long. This removed the 30 cm of inter-plot wheel mark area from the harvested area. Seed was dressed through a stationary seed dresser to determine dressed seed weight per plot.

Flower counts began on 15 November 2022 and were completed weekly from 2 December 2022 until 27 January 2023. The number of white flowers visible in 30 cm of one row (encompassing two half inter-rows either side of drill line) were counted in one randomly selected place per plot. Peak flowering date was taken as the time at which the highest population of white flowers was recorded.

Harvest dry matter (DM%) was assessed on 7 February 2023, ten days prior to desiccation. One quadrat cut of 1 x 0.5 m area was taken per plot. Total fresh biomass was weighed, then a subsample weighed before and after drying at 70°C (for at least 48 hours) to determine DM%. This was then scaled up to a kg DM/ha basis. Harvest index (%) was calculated as the proportion of dressed seed weight in harvest dry matter.

Overall treatment differences were determined using a one-way analysis of variance ($\alpha=0.05$). Individual treatment effect, and any relationship to other treatments, was determined using a two-way ANOVA. As needed, means were separated using the Fisher's unprotected LSD post-hoc test.

Results and discussion

Overall, there was no difference between treatments in the machine dressed seed yield (on average 913 (± 12) kg/ha (Table 1)). However, the application of 2,4-D ester in early spring resulted in 58 (± 11) kg/ha lower ($P=0.04$) seed yield compared with the unsprayed treatments. Prior to harvest desiccation, dry matter was on average 7385 (± 246) kg DM/ha and did not differ between treatments ($P=0.50$). There was a trend ($P=0.08$) that large-leaf Legacy produced 830 kg DM/ha more than medium-leaf Quartz. Dry matter tended to increase with increasing row spacing in Legacy, whereas Quartz decreased with increasing row spacing. This suggested that Quartz was not as successful at proliferating into the inter-row spaces. Quartz produced fewer ($P=0.02$) flowers at peak flowering compared with Legacy, with 206 (± 12) and 172 (± 7) white flowers/m², respectively.

Peak flowers/m² decreased ($P=0.004$) with increasing row spacing, with 218 (± 14) in 30 cm, 186 (± 10) in 45 cm and 164 (± 7) flowers/m² on average per treatment. However, there was no relationship between cultivar and row spacing ($P=0.65$). The application of 2,4-D had no effect on peak flowers/m² ($P=0.89$). Peak flowering was, on average, on 20 December 2022 across all treatments ($P=0.48$). Harvest index averaged 13% (± 0.1), with no difference between treatments ($P=0.81$).

The 2,4-D application had no effect on any measured parameters other than MD seed yield. This would suggest that the main impact of 2,4-D was on flowering components that were not measured. A similar number of flowers had been produced by peak flowering time, which would suggest that the plants had recovered from the checking effect by 20 December. This was demonstrated in the similar harvest dry matter across treatments. However, there may have been limitations in the number of seeds per flower, or seed fill, in 2,4-D treated plots. This potentially resulted in smaller seeds being dressed out, reducing seed yield. A final flower count, including a classification of which flowers were ripe and contributing to harvest, alongside the number of seeds/flower and thousand seed weight, would have clarified any resource limitation effect from 2,4-D application.

As in the previous season (Ross, 2023), there was no difference in seed yield between row spacing treatments. This would suggest that the same number of flowers were initiated between row spacing treatments and the added opportunity for flower-bearing node production, with greater row spacing, was not fulfilled. A FAR trial from the 2008-09 season (data not published) found no difference in stolon length (cm) between 30 and 45 cm row spacing across small, medium and large leaf-size cultivars. Both Ross (2023) and the 2008/09 FAR trial found no difference in the average flowers/stolon across cultivar or row spacing. Both experiments were undertaken in “unusual” seasons, with Ross (2023) having higher than average and 2008/09 lower than average rainfall during flowering. Therefore, the greater space between rows did not change the number of flowers produced per stolon, with vegetative growth favoured by the plants rather than reproductive growth over a greater distance. There was an indication that large-leaf cultivars yielded higher with increasing row spacing (08/09), but this was not seen in either year of this experiment.

Conclusions

This second year of evaluating cultivar and row spacing treatments resulted in no increase in seed yield and was on average 913 (± 12). The application of 2,4-D ester in early spring decreased seed yield by 58 (± 11) kg/ha. The seed yield parameters affected by 2,4-D were unclear as dry matter and peak flower numbers were not changed by 2,4-D application. Increasing row spacing reduced the number of white flowers/m² at peak flowering, but not seed yield. This suggested that unmeasured seed yield components (final flowers/m², seeds/flower, TSW) may have been enhanced with increasing row spacing and resulted in a similar seed yield between treatments.

Table 1. The machine dressed seed yield (kg/ha), dry matter prior to harvest (kg DM/ha), peak flowering date and the number of white flowers/m² at peak flowering. The treatments with the highest mean peak white flowers/m² are highlighted in yellow.

Treatment	Cultivar	Row spacing (cm)	2,4-D application	Machine dressed seed yield (kg/ha)	Harvest dry matter (kg DM/ha)	Peak flowering date	Peak white flowers/m ²
1	Quartz	30	-	994	7354	18/12/2022	192 abc
2	Quartz	30	Yes	914	7190	18/12/2022	197 abcd
3	Legacy	30	-	917	8502	20/12/2022	253 d
4	Legacy	30	Yes	853	6566	22/12/2022	231 cd
5	Quartz	45	-	945	6821	15/12/2022	152 a
6	Quartz	45	Yes	859	7093	23/12/2022	187 abc
7	Legacy	45	-	947	6769	20/12/2022	191 abc
8	Legacy	45	Yes	925	8502	22/12/2022	213 bcd
9	Quartz	60	-	924	7238	22/12/2022	150 a
10	Quartz	60	Yes	853	5946	22/12/2022	157 ab
11	Legacy	60	-	926	8619	22/12/2022	192 abc
12	Legacy	60	Yes	898	8023	21/12/2022	156 ab
<i>p-value</i>				0.764	0.498	0.480	0.03
<i>LSD</i>				150	2500	6	61

Appendix 1. The general management first-year white clover seed crops grown at Yaldhurst, Canterbury during the 2022-23 growing season.

Herbicide	5 April 2022	Roundup Ultra®Max (570 g/L glyphosate) @ 3 L/ha
	10 June 2022	Headstart® (50 g/L flumetsulam) @ 1 L/ha
	29 July 2022	Centurion® Xtra (360 g/L clethodim) @ 500 mL/ha Hasten (704 g/L ethyl- and methyl-esters of vegetable oil, 196 g/L non-ionic surfactants) @ 2 L/ha
	5 August 2022	Argosy® (25 g/L diflufenican, 250 g/L bromoxynil) @ 1.5 L/ha
	17 February 2023	Reglone® (200 g/L diquat) @ 5 L/ha Contact™ Excel (980 g/L linear alcohol ethoxylate) @ 25 mL/L
	Insecticide	5 April 2022
28 November 2022		Mavrik® Aquaflo (240 g/L tau-fluvalinate) @ 150 mL/ha Contact™ Excel (980 g/L linear alcohol ethoxylate) @ 25 mL/L
Irrigation	13 December 2022	40 mm

Lilburne, L. R., Hewitt, A. E., & Webb, T. W. (2012). Soil and informatics science combine to develop S-map: A new generation soil information system for New Zealand. *Geoderma*, 170, 232-238. <https://doi.org/https://doi.org/10.1016/j.geoderma.2011.11.012>

Understanding yield limitations in red clover seed crops

Project code: H23-02-00

Duration: Year 1 of 3 (Season: 2023-24)

Authors: Sean Weith, Fiona Anderson (FAR), Phil Rolston (SIRC) and Richard Chynoweth (Macfarlane Rural Business)

Location: Canterbury

Funding: SIRC (Seed Industry Research Centre)

Acknowledgements: Field-Tek Limited (Sample Collection) and Canterbury red clover survey site hosts

Key points

- 16 commercial red clover paddocks distributed across South, Mid and North Canterbury were surveyed during the 2023–24 growing season.
- Substantial yield potential remains unrealised, with mean realised yield (473 kg/ha) across all sites representing only around 22% of the mean theoretical seed yield (2,184 kg/ha).
- No single yield component strongly explained realised yield, with only weak correlations observed among floral and reproductive traits.
- Pollination success was generally adequate, with ~60% of florets setting seed.
- Late-season insect damage and harvest-related losses are likely underestimated.

Background

Red clover (*Trifolium pratense* L.) is a widely cultivated forage legume valued for both grazing and seed production. It provides high-quality feed for livestock due to its favourable nutritive value and digestibility, while also supporting farming system sustainability through biological nitrogen fixation. Reliable seed production is essential to ensure the continued supply of high-performing cultivars for livestock farmers and the seed industry. In New Zealand, red clover seed production is concentrated in the growing regions of the Wairarapa, Marlborough and Canterbury, with an estimated annual production area of about 1,000 ha (Chynoweth *et al.*, 2018). Crops are generally managed as multi-year stands, with seed harvested for up to three consecutive years.

Seed yields in red clover vary widely across major production regions. In the United Kingdom, one- to two-year-old crops commonly produce 150–300 kg/ha, while average yields in France are around 300 kg/ha, increasing to up to 1,000 kg/ha in irrigated systems where pest pressure is effectively managed. Throughout the rest of Western and Central Europe, diploid red clover cultivars have been reported to typically yield between 400–600 kg/ha (Boller *et al.*, 2010; Karagić *et al.*, 2010). Higher yields have been reported in Oregon, USA, where dryland crops commonly achieve between 400–800 kg/ha and irrigated crops can produce up to 1,400 kg/ha, depending on cultivar and management (Anderson *et al.*, 2018; Anderson *et al.*, 2019; Anderson *et al.*, 2020). Within this international range, red clover seed yields in New Zealand are generally reported between 150 to 500 kg/ha (Clifford & Anderson, 1979), placing New Zealand broadly within the lower to mid-range of yields observed across these established production regions. The comparatively low and inconsistent yields in New Zealand therefore represent a major limitation to the reliability and profitability of seed production.

Seed yield in red clover is a complex trait influenced by both genetic and environmental factors. Despite its economic importance, actual seed yields of red clover seed crops often fall far short of their theoretical or biological potential, revealing there a substantial gap between achievable and realised performance (Dennis & Haas, 1967; Boller *et al.*, 2010). Examining the key yield components that underpin crop performance provides a useful approach for understanding yield variation. Among the main determinants are the number of flower heads per plant, the proportion of functional florets and seed number per head (Herrmann *et al.*, 2006; Jing *et al.*, 2021).

Because red clover is allogamous with strong self-incompatibility, successful cross-pollination by insects, particularly bumblebees (*Bombus* spp.) and honeybees (*Apis mellifera*), is critical with reduced pollinator density causing markedly lower seed yields (Vleugels *et al.*, 2019). Seed production is further constrained by abiotic stresses such as drought and late frosts, as well as biotic pressures including pests and diseases. In New Zealand, below-average yields have recently been linked to increasing pest pressure, particularly from red clover casebearer (*Coleophora deauratella*) and red clover thrips (*Haplothrips niger*) (Chynoweth *et al.*, 2018). These challenges underscore the need to better understand the drivers of seed yield variability across production environments. To examine these factors, a survey of 16 commercial red clover seed paddocks was conducted across South, Mid and North Canterbury during the 2023–24 growing season. The survey aimed to identify the main drivers of seed yield variation in commercial red clover seed production systems.

Methods

A cohort of 16 commercial red clover paddocks was sampled during the 2023–24 growing season. Sites were selected to represent variation in farm size, location, and management history and were distributed across South, Mid, and North Canterbury.

Three random samples were collected 2–14 days prior to desiccation from each site following the methods described by Oliva *et al.* (1994), with modifications. Plant material was cut to ground level from an area spanning two adjacent rows over a 50 cm length (approximately 0.3–0.4 m², depending on row spacing). Each sample was weighed fresh, and a bulk subsample of ~150 g was taken. From each subsample, the mean number of stems, mature flowers per stem, flowerheads and number of florets per flower head (inflorescence) were recorded. Subsamples were oven-dried at 65 °C for ~48 hours in labelled paper bags and dry weights were measured (Anderson *et al.*, 2016).

Reproductive components were assessed following a method described by Oliva *et al.* (1994), with modifications. At each site, 150–300 florets were randomly sampled, and the presence or absence of seed was recorded to determine percentage of florets with seed, assuming a maximum of one seed per floret. Thousand seed weight was estimated by weighing 200 seeds. Derived physiological components including stems per m², flower heads per m², florets per m² and seeds per m² were then calculated. These values were used to estimate seed set potential yield (florets producing harvestable seed) and theoretical seed yield, which represented the biological maximum, assuming all florets successfully produced harvestable seed.

Harvest index was calculated to quantify the efficiency of total above-ground biomass conversion into saleable seed yield as described by Hay (1995). It was calculated as the ratio of realised seed yield (kg/ha) to total above-ground dry matter (kg DM/ha) and is reported as a percentage. This metric provides an integrated measure of biomass partitioning between vegetative growth and reproductive output. Typical values for herbage seed crops like red clover are expected to range between 10 and 30% (Hay & Porter, 2006).

All analyses of data were conducted using R (v 4.5.1) software programming language (R Core Team, 2025). All data was visualised using the ‘ggplot2’ package (Wickham, 2011). Pairwise correlations among measured variables were calculated using the ‘psych’ package in R (Revelle, 2017), with significance ($P \leq 0.05$) tested using the car package (Fox & Weisberg, 2018). The correlation coefficients and P values for each measured variable were used to construct a pairwise correlation matrix which was visualised by generating a correlation plot using the R package ‘corrplot’ (Wei & Simko, 2021).

Results and discussion

A full description of the key calculated physiological and harvest components measured in this study is presented in Appendix Tables 1 and 2. Across all surveyed sites, mean realised seed yield was 473 kg/ha (range: 200–850 kg/ha), compared with a mean seed set potential yield of 1334 kg/ha (range: 236–3,374 kg/ha) (Figure 1). Although realised yields were higher than anticipated, most crops fell well short of their seed set potential, highlighting a substantial yield gap between successful pollination and early seed development and the final harvested yield. This disparity was further emphasised when considering theoretical seed yield, which represents the biological maximum for each crop. Mean theoretical seed yield was 2,184 kg/ha, ranging from 536 kg/ha at the lowest-yielding site to 6,106 kg/ha at the highest-yielding site, underscoring the considerable unrealised yield capacity across sites.

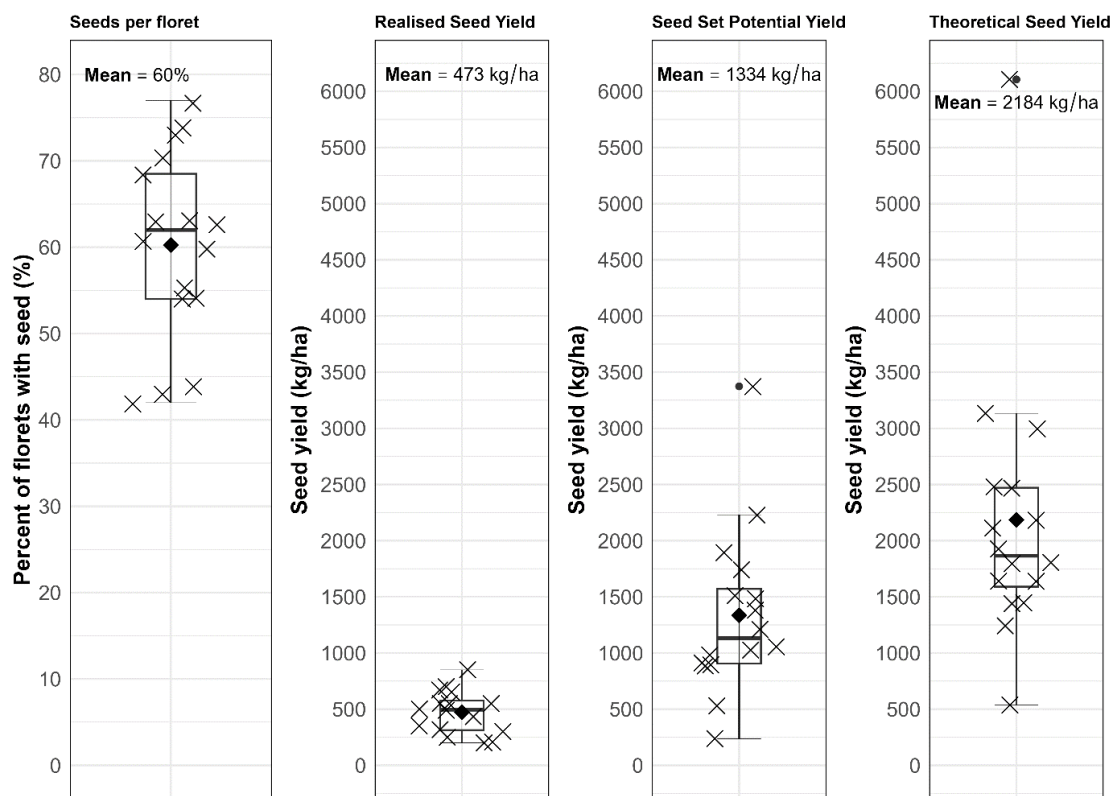


Figure 1. Variability in the percentage of florets containing seed and realised (actual), seed set potential and theoretical seed yield (kg/ha) based on florets with developing seeds from 16 red clover (*Trifolium pratense* L.) crops surveyed across Canterbury, New Zealand during the 2023–24 growing season. In each box, the line represents the median, diamonds show the mean and circles indicate outliers.

Correlation analysis indicated only weak to moderate associations between yield components, with realised seed yield (actual) showing a positive relationship with mature flowers per stem ($r = 0.3$) and a negative relationship with percentage of florets with seed ($r = -0.31$) (data not presented). However, there was no strong relationship between realised seed yield with either florets per m^2 ($r = -0.13$) or seeds per m^2 ($r = -0.19$). Collectively, these correlations indicate that seed yield and its components in red clover are weakly interrelated, with no single factor strongly explaining variation in machine dressed yield. These results suggest that factors beyond the measured yield components are constraining yield, with canopy management, pollination efficiency or insect feeding likely acting as key bottlenecks. A weak positive association between percentage florets with seed and thousand seed weight ($r = 0.2$) suggests that favourable reproductive conditions may marginally support both seed set and seed filling, although the low correlation strength indicates substantial variability. Previous research has highlighted both flowerhead number and seed number per head as important contributors to seed yield (Anderson *et al.*, 2016; Jing *et al.*, 2021). However, unlike the findings of Vleugels *et al.* (2019), which identified flowerhead number as a major determinant of seed yield, this study found only a weak association between flower heads/ m^2 and realised seed yield ($r = -0.13$). This weak relationship may reflect variations in sampling, experimental conditions and unrecorded factors, such as pest damage, irrigation and forage removal, which can influence flowerhead production across sites.

On average, 60% of florets contained seed (Figure 1), suggesting that pollination is not the primary source of yield loss. However, red clover pollination is complex and influenced by factors not examined in this study, including distance of paddocks from pollinator nesting sites, pollinator species present, the availability of alternative pollen and nectar sources and environmental factors such as temperature (Vleugels *et al.*, 2019). The association between paddock size and key floral components was examined in this study. However, paddock size showed only a weak positive relationship with percentage of florets with seed ($r = 0.18$), suggesting little effect on pollination. In contrast, paddock size had a moderate negative relationship with machine dressed yield ($r = -0.36$), indicating that management complexity, spatial variability, or harvest-related losses may limit yield in larger paddocks. While pollination did not appear to be the main driver of yield loss in this study, improvements could still provide modest gains, but are unlikely to close the gap between potential and realised yield on their own.

Harvest index was used to assess how efficiently the surveyed seed crops partitioned biomass between vegetative growth and seed production (Hay & Porter, 2006). Across all sites, harvest index ranged from 3% to 25%, indicating that most sites were at the lower end of this range, with relatively limited allocation of biomass from the canopy to reproductive structures. This range provides a useful benchmark for future studies and suggests that management of crop bulk density in red clover seed crops may be critical. In wet seasons, excessive non-reproductive biomass may further reduce carbon partitioning to seed and increase seed losses before or after desiccation. These losses are likely to occur through rotting or sprouting when dense canopies impede moisture loss.

The gap between potential and realised seed yield, particularly relative to theoretical yield, suggests that late-season insect damage or losses prior or at harvest in New Zealand red clover seed crops are underestimated and represent a major constraint on achieving maximum yields. The magnitude of the theoretical seed yield values calculated for some of the sites sampled in this study highlights that the species clearly has the capacity to deliver substantially higher yields. Losses at or before harvest

can substantially reduce returns, even where pollination and in-crop management are effective. Closing this gap will require increased emphasis on optimising harvest timing, combine setup, and seed handling, alongside continued improvements in canopy management and pollination efficiency.

Conclusion

This study demonstrates that red clover seed crops in New Zealand possess a substantial but largely unrealised yield potential, with theoretical yields far exceeding both seed set potential and realised seed yields. While pollination was generally adequate, as indicated by high floret seed set, most crops failed to convert this potential into harvested seed, with no single yield component strongly explaining variation in machine dressed yield. Instead, the weak interrelationships among yield components, combined with the negative association between paddock size and realised yield, indicate that yield losses are driven primarily by late-season constraints, including insect damage, management complexity and harvest inefficiencies. These findings suggest that closing the yield gap will require a greater focus on reducing post-flowering and harvest-related losses, alongside continued optimisation of canopy management and pollination efficiency, rather than further improvements in pollination alone.

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Appendix Table 4: Number, size and location relative to closet town of sites and means for harvest components including realised seed yield, seed set potential yield, seed set theoretical seed yield (theoretical seed yield), thousand seed weight (TSW), harvest loss and harvest index from 16 red clover (*Trifolium pratense* L.) crops surveyed across Canterbury, New Zealand during the 2023–24 growing season. **Note:** 0 for harvest loss indicates actual seed yield was higher than calculated seed set potential seed yield.

Site No	Location (closest town)	Paddock Size (ha)	Realised Seed Yield (kg/ha)	Seed Set Potential Yield (kg/ha)	Theoretical Seed Yield (kg/ha)	TSW (g)	Harvest Loss (%)	Harvest Index (%)
1	Hororata	12.5	652	236	536	1.65	0	25
2	Sheffield	5.8	550	897	2112	1.95	39	7
3	Sheffield	5	670	1485	2181	1.75	55	8
4	Springfield	6	318	2230	2995	2.25	86	4
5	Darfield	7	700	1206	1926	2.10	42	9
6	Southbridge	4.5	490	530	1243	1.70	8	10
7	Rakaia	9.3	300	980	1804	2.10	79	4
8	Wakanui	16.6	208	1740	2480	1.85	80	6
9	Lincoln	10	350	886	1638	2.10	51	6
10	Methven	12	433	1025	1640	1.80	51	7
11	Methven	8.4	500	1514	2468	1.90	64	7
12	Lauriston	2.6	549	1891	3133	1.95	87	3
13	Eiffelton	8.4	250	910	1446	2.20	7	9
14	Timaru	12.4	850	3374	6106	2.30	84	7
15	St Andrews	11	550	1057	1439	1.75	72	4
16	Timaru	20	200	1384	1796	2.05	86	3
Mean		9.4	473	1334	2184	1.96	55	7
Median		8.8	495	1131	1865	1.95	59	7

Appendix Table 5: Site number and crop physiological component means for percentage of florets with seed, stems per m², flowers/stem, florets (flowers)/head, florets per flower head, flower heads per m², pollinated florets(flowers) per m² and grams of seeds per m² from 16 red clover (*Trifolium pratense* L.) crops surveyed across Canterbury, New Zealand during the 2023–24 growing season.

Site No	Florets with Seed (%)	Stems/m ²	Mature Flowers/stem	Florets/Flower head	Flower heads/m ²	Pollinated florets/m ²	Seeds/m ² (g)
1	44	208	1.65	86.6	375	14298	24
2	42	714	1.90	74.0	1463	46004	90
3	68	501	2.95	84.3	1478	84872	149
4	74	648	3.30	62.3	2137	99112	223
5	63	285	4.15	70.6	1299	57449	121
6	43	198	4.50	81.0	903	31177	53
7	54	317	3.15	85.9	1000	46678	98
8	70	593	2.55	88.7	1511	94035	174
9	54	332	2.93	71.5	1091	42167	89
10	63	313	3.12	91.6	995	56956	103
11	61	568	3.80	57.2	2271	79675	151
12	60	706	3.20	66.9	2402	96961	189
13	63	148	4.80	92.6	710	41343	91
14	55	680	4.35	89.8	2957	146695	337
15	73	319	3.10	83.1	990	60417	106
16	77	328	2.90	92.2	950	67507	138
Mean	60	429	3.27	79.9	1408	66584	133
Median	62	330	3.13	83.7	1194	58933	113

Small broomrape control in white clover seed crops

Project code: X22-01-11

Duration: Year 1 of 2 (2023-24 season)

Authors: Nicholas Davies (AgResearch)

Location: FAR Chertsey Arable Site, Chertsey

Funding: FAR

Acknowledgements: NZ Arable (trial operator)

Key point

- A single trial has shown imazethapyr to be effective in eliminating small broomrape when spring applied and pre-emergence of Small broomrape 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 infestation 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 a host or "false host" plant to germinate. 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, emphasising 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, 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, though 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 in the previous (and the season of the trial) 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 recorded the number of small broomrape stems in each plot. Data on small broomrape emergence were collected to assess the impact of each herbicide and application timing on small broomrape suppression.

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 6. Small broomrape incidence in white clover after treatment with herbicides in a trial at the FAR Chertsey Arable Site, Chertsey in the 2023-24 season.

Treatment No.	25 September 2023	13 October 2023	16 November 2023	Mean SBR stems
1	Negative Control	-	-	20.6
2	Equate [®] plus Hasten [™] (G2)	-	-	0
3	Imazethapyr (G2)	Imazethapyr (G2)	-	0
4	Imazethapyr (G2)	-	Imazethapyr (G2)	0
5	Preside [™] (G2)	-	-	23

Equate[®] (240 g/L imazethapyr) at 400 mL/ha with Hasten[™] (704 g/L ethyl and methyl esters of canola oil fatty acids and 196 g/L non-ionic surfactants) at 500 mL/ha; Preside[™] (800 g/kg flumetsulam with Uptake[™] Oil) at 1 L/ha. SBR was counted on 14 December 2023.

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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The effect of cutting time on harvested seed yield of perennial ryegrass (*Lolium perenne* L)

Project code: H19-06-00

Duration: Year 5 of 5

Authors Owen Gibson, Richard Chynoweth and Phil Rolston

Location Canterbury

Funding SIRC

Acknowledgements - The NZ Arable team for crop management and harvest; PGG Wrightson Seeds Ltd. for hosting Experiment 3 and Graham Marshall for hosting for Experiment 2.

Key points

- Seed yield was highest when crops were cut between 55% and 41% SMC, averaging 2064 kg/ha.
- Below 41% SMC, yield declined at 25.2 kg/ha per 1% decrease in SMC due to increased losses.
- TSW increased with decreasing SMC until plateauing at 33%.
- Pre-cut irrigation had no significant effect on yield or harvest losses.
- Harvest losses increased below 41% SMC, from <400 kg/ha above 50% SMC to >1100 kg/ha at 29% SMC, equivalent to up to 40% yield loss.

Background

Ryegrass (*Lolium* species *Lolium perenne*, *L. multiflorum* and *L. x boucheanum*) is the most important forage species grown in New Zealand. It contributes \$14.6 billion dollars to GDP and is the foundation of the livestock industry (Nixon 2016). Major challenges in ryegrass seed production are the prolonged flowering period, which can extend over 20 days (Abel et al. 2018) and differing tiller maturity within stands. Determining the optimal cutting time to maximize seed yield can be difficult. Cutting too early, while seed moisture content (SMC) is high (>50%), shortens the seed filling period of later formed tillers. This results in physiologically immature seeds with reduced size, low thousand-seed weight (TSW) and potentially higher dressing losses during processing (Simon et al. 1997). Conversely, delaying cutting until SMC is <40% increases the risk of seed shattering on the earliest formed main stems and higher order tillers (Brown et al. 1990). This can lead to yield losses >20% (Rolston & Chynoweth 2010) before, during, and after seed harvest.

The aim of this study was to provide ryegrass seed growers with recommendations to optimise harvest strategies, improve seed yield and quality, and enhance overall seed production efficiency of perennial ryegrass. The three main objectives were (1) determine the optimal SMC for perennial ryegrass seed crops to maximize seed yield and quality, (2) quantify the effect of seed shattering from environmental factors, losses at cutting and losses at machine harvesting and (3) evaluate the effects of pre-harvest irrigation on machine-dressed seed yield.

Methods

The project consisted of a series of four small plot replicated experiments conducted over three consecutive seasons within Canterbury New Zealand.

Experiment 1 was sown on 27 May 2022 in a paddock of 'Base' tetraploid perennial ryegrass with AR37 endophyte at Lincoln (43°38'14.6"S 172°28'14.8"E) This experiment was established on 5

January 2023 using a randomised complete block design with 17 treatments and four replicates (Table 1). Cutting was initiated at a target seed moisture content (SMC) of 49% and reduced in 3% increments to a final SMC of 29%. From 41% SMC onwards (Table 1), treatments included the presence or absence of 6 mm pre-cutting irrigation. Individual plots measured 3.2 m in width and 8 m in length. The soil type is a Wakanui_3a.1 mottled immature pallic soil (Lilburne et al. 2012). The crop received standard management until the experiment was initiated (Table 2).

Experiment 2 was conducted concurrently with Experiment 3 in the 2023 season in a paddock of 'Array' diploid perennial ryegrass with NEA2 endophyte at Greendale, Mid Canterbury (43°33'02.1"S 172°05'47.6"E). The experiment was established on 4 January 2024 using a doubly resolvable row-column design consisting of 7 treatments and 4 replicates. Treatments began at 53% SMC and reduced in 4% increments down to 29% SMC (Table 1). Individual plots measured 2.5 m in width x 10 m in length. The soil type is predominately a Mayfield_2a.1 argillic pallic soil (Lilburne et al. 2012). The crop received standard management until the experiment was initiated (Table 2).

Experiment 3 was sown on 27 April 2023 in a paddock of 'Three60' diploid perennial ryegrass with AR37 endophyte at Lincoln (43°37'21.8"S 172°29'41.5"E). The experiment was established on 20 December 2023 using a doubly resolvable row-column design consisting of 14 treatments (Table 1) and 4 replicates. Treatments were initiated at a seed moisture content (SMC) of 53% and decreased in 4% increments to a final SMC of 29%. Each treatment was conducted with and without 6 mm irrigation prior to cutting (Table 1). Individual plots measured 2.5 m in width and 10 m in length. The soil type is a Wakanu_6a.1 mottled immature pallic soil (Lilburne et al. 2012). The crop received standard management until the treatments were applied (Table 2).

Experiment 4 was sown on 28 March 2024 in a paddock of 'Three60' diploid perennial ryegrass with AR37 endophyte at Lincoln (43°38'17.9"S 172°28'16.3"E). The experiment was established on 20 December 2023 using a doubly resolvable row-column design consisting of 14 treatments and 4 replicates. Treatments were initiated at a seed moisture content (SMC) of 53% and decreased in 4% increments to a final SMC of 29%. Each treatment was conducted with and without 6 mm irrigation prior to cutting. (Table 1). Individual plots measured 2.5 m in width and 10 m in length. The soil type is a Wakanu_6a.1 mottled immature pallic soil (Lilburne et al. 2012). The crop received standard management until the experiment was initiated (Table 2).

Table 1 - Cutting date and days in windrow of perennial ryegrass seed crops used in four experiments to examine harvest losses of seed in Canterbury 2023-2025.

	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	Base		Array		Three60		Three60	
Target	Cutting	Days in	Cutting	Days in	Cutting	Days in	Cutting	Days in
53			18.1.24	11	19.1.24	10	10.1.25	11
49			21.1.24	8	21.1.24	8	17.1.25	13
47	11.1.23	9						
45			25.1.24	11	26.1.24	10	20.1.25	11
44	13.1.23	7						
41	16.1.23	10	28.1.24	8	28.1.24	8	22.1.25	13
38	20.1.23	6						
37			30.1.24	6	30.1.24	11	24.1.25	11
35	24.1.23	7						
33			2.2.24	8	2.2.24	8	28.1.25	11
32	26.1.23	8						
29	30.1.23	4	5.2.24	5	5.2.24	5	3.2.25	5

Pre-cutting irrigation treatments were applied approximately one hour prior to windrowing. Irrigation was applied by a 2 m handheld boom with 10 x 20-02 Teejet nozzles delivering 6 L water per m²/plot. The boom was powered by a petrol centrifugal water pump connected to a 1000 L intermediate bulk container (IBC). Water was applied at a constant rate by spraying each plot at a walking speed of 1 m/second, water flow was monitored with an inline flow meter with inline ball valve that could be closed once the target water rate was delivered.

SMC was calculated at each experiment at least three times per week starting prior to it reaching the desired level as detailed in the treatment list (Table 1). Seed samples were collected from the experimental area by collecting three grab samples of tillers from multiple areas within each rep and combining them. Approximately 50 randomly selected seed heads were stripped of all seed by hand and collected in aluminium trays. The collected seed was weighed on Vibra HT224 precision scales (0.0001 resolution), and a subsample (~10 g) was oven-dried at 130°C for two hours, following International Seed Testing (2018) protocols. After cooling for approximately one minute, the dried samples were reweighed, and SMC (%) was calculated. The SMC used in statistical analysis (calculated SMC) was derived from a linear regression equation fitted to the observed SMC data against sampling date (Figure 1) using Microsoft® Excel® 2019.

Windrowing was performed using a modified John Deere windrower, cutting a 1.8 m swath per pass. Windrowing commenced at approximately 10:00 AM on the designated treatment dates (Table 1). The windrower was equipped with under-serrated knife sections. Harvest was conducted using a Wintersteiger Classic Plus combine fitted with crop lifters after a drying period of at least five days (Table 1). Total field dressed seed yield per plot was recorded either in the field at time of harvest or within 24 hours of harvest on platform scales. A field-dressed subsample (~400 g) was collected for further processing. The field dressed subsample was machine-dressed on a Westrup air screen cleaner to produce a first-Generation Seed Certification standard (International Seed Testing 2018).

Harvest losses were calculated by vacuuming all seed present within a quadrat of at least 0.074 m² off the ground within each plot after harvest. Samples were collected in the middle of the plot under

the machine harvest residue trail to capture losses at windrowing, during drying and through machine harvest. Harvest loss measurements were conducted in all experiments except Experiment 1 and converted to kg/ha seed loss.

Thousand seed weight (TSW) was determined by weighing 200 machine-dressed seeds using Vibra HT224 precision scales (0.0001 g resolution) and extrapolating to calculate the weight per 1,000 seeds (Figure 3).

Weather data was calculated (Table 3) for each experiment from 1 January to 10 February (last harvest timing) for each experiment from the closest Hortplus weather stations. Total rainfall (mm), mean humidity (%) and total solar radiation ($\text{MJ m}^{-2} \text{d}^{-1}$) was analysed for each experiment. Data was accessed from the FAR Weather platform (FAR 2025).

Table 2 – Standard inputs and application dates following final defloration in perennial ryegrass field experiments investigating seed harvest losses in Canterbury (2023–2025).

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Input type	‘Base’	‘Array’	‘Three60’	‘Three60’
Drilling Date	27 May-8.5 kg/ha	26 Mar-10 kg/ha	27 Apr-15 kg/ha	16 Apr-8 kg/ha
Defoliation Date	25 Oct-Mown	18 Oct-Grazed	31 Oct-Grazed	17 Oct-Mown
Spring Nitrogen	27 Oct-75 kg N	26 Oct-50 kg/ha	25 Oct-70 kg N	24 Oct-70 kg N
Spring Nitrogen	14 Nov-70 kg N	6 Nov-50 kg/ha	21 Nov-70 kg N	13 Nov-75 kg N
Plant growth regulator (PGR)	18 Nov-2.4 L/ha Moddus® Evo	14 Nov-1.6 L/ha Moddus® Evo	10 Nov 1.8 L/ha Moddus® Evo	8 Nov 2.4 L/ha Moddus® Evo
Irrigation	140 mm-4 applications	215 mm Total	¹	155 mm-5 applications

¹ Irrigation data not supplied – No moisture stress recorded.

Table 3 – Summary of weather conditions (total rainfall, mean relative humidity, and total solar radiation) over a 6-week period from 1 January to 10 February 2023-25 for perennial ryegrass seed experiments sourced from FAR (2025).

Season	Experiment	Rainfall (mm)	Mean Relative Humidity (%)	Total Solar Radiation ($\text{MJ m}^{-2} \text{d}^{-1}$)
2023	Experiment 1 ¹	45	77	711
2024	Experiment 2 ²	81	69	712
2024	Experiment 3 ¹	78	74	712
2025	Experiment 4 ¹	100	82	654

¹ Hortplus Kowhai Farm weather station – I25

² Hortplus Greendale weather station – I58

Data were collated in Microsoft Excel and analysed using Genstat version 22. Individual experiments were assessed by restricted maximum likelihood (REML) analysis, while combined data across experiments were evaluated using REML meta-analysis for seed yield, harvest loss, thousand seed weight (TSW), and germination. In Figure 2, seed yield was standardised by expressing values as a percentage of the yield at the first cutting time (29% SMC), which was set to 100%. The mean yield

at this baseline (100%) was 2079 kg/ha. Total seed yields for later times were then calculated by multiplying the percentage values by the grand mean (2079 kg/ha). Similarly, TSW in Figure 3 was standardised to a percentage of the value at the first cutting time. In Experiment 4, data were analysed from the second-lowest SMC level (33%) onwards due to the presence of an outlier at the lowest SMC. Additional statistical analyses were conducted using Python™. Seed yield, TSW, and harvest loss data were evaluated using the “statsmodels” package with linear regression fitted using the Ordinary Least Squares (OLS) method (Seabold & Perktold, 2010). A two-line model was fitted using the curve fit function from the scipy package (Virtanen et al. 2020). Treatment means are presented with standard errors (\pm SE). Means sharing the same letter are not significantly different based on Fisher’s protected least significant difference (LSD) test at $\alpha \leq 0.05$. This means the LSD test was applied only when the overall ANOVA indicated a significant treatment effect. Experiment 3 was excluded from the combined analysis due to an inconsistent trend in seed yield among replicates.

Results and discussion

Seed moisture content is the most reliable indicator of ryegrass seed maturity and provides the best guide for optimal cutting or harvest time. SMC decreased at a constant linear rate (R^2 ranging from 0.93 to 0.99) across four ryegrass experiments (Figure 1). In Experiment 1, ‘Base’ perennial ryegrass exhibited the fastest rate of decline, with SMC decreasing by 1.5% (SE \pm 0.13) per day (Figure 1). In comparison, ‘Array’ (Experiment 2) and ‘Three60’ (Experiments 3 and 4) declined at 1.2% (SE \pm 0.05) to 1.3% (SE \pm 0.09 and 0.07 respectively) per day. The linear trend in SMC decline was maintained regardless of different rainfall patterns (Table 3) during the cutting period. However, measurements taken when dew was present on the crop resulted in artificially elevated SMC values. This linear regression across four experiments over three seasons demonstrates the repeatable nature of SMC decline in perennial ryegrass, which is useful for determining the optimal cutting time to reduce losses.

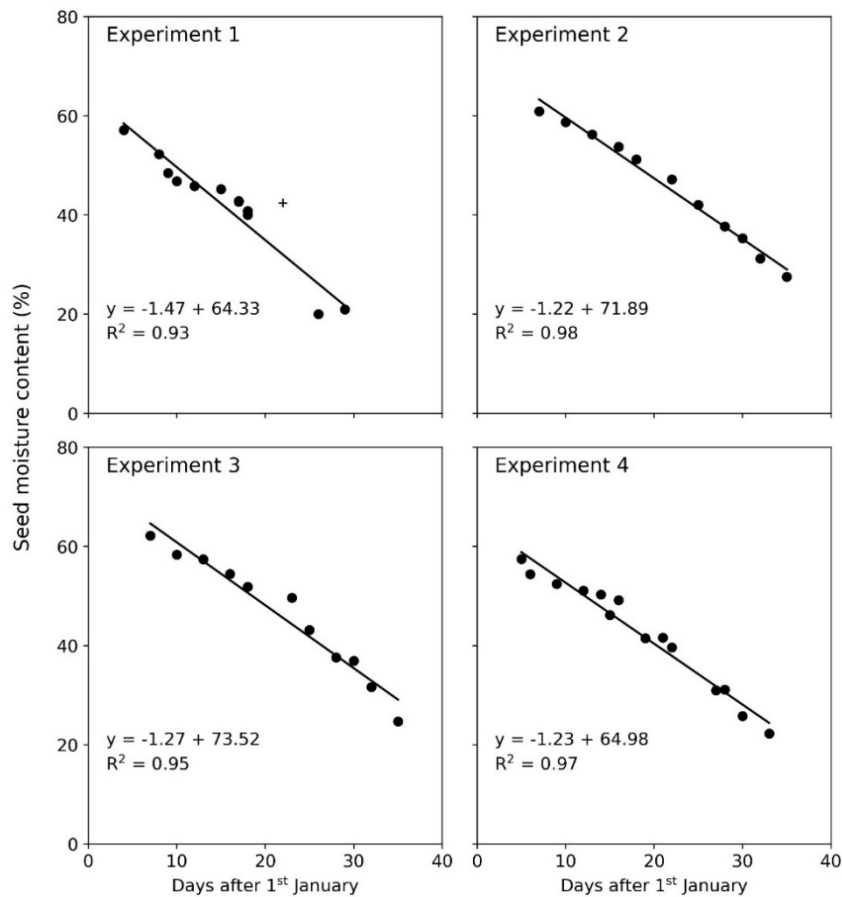


Figure 1. Calculated seed moisture content (SMC) decline of four perennial ryegrass experiments from days after 1 January, Canterbury in the 2022-25 growing seasons. Data from Experiment 1 (23/1/2023 (+)) removed from regression fitting due to residual moisture from overnight dew/rainfall.

Seed yield across the experiments ranged from a maximum of 2572 kg/ha in Experiment 2 (49% SMC, 'Array') to a minimum of 1360 kg/ha in Experiment 4 (29% SMC, 'Three60') (Table 4). Seed yield was greatest between 55–41% SMC (Figure 1). These results show that cutting perennial ryegrass at or above 39% SMC was optimum (41% - the SE 2.40=38.6%). This range encompasses and extends beyond the traditionally recommended optimal cutting range of 35–45% SMC (Brown et al. 1990; Simon et al. 1997; Silberstein et al. 2005; Rolston & Chynoweth 2010). In this study, no negative effects were observed from cutting at SMC above 41% (Figure 1, Table 4). Analysis of Experiments 1, 2, and 4 using a split-line regression model revealed that calculated seed yield remained constant at an average of 2064 kg/ha between 55% and a breakpoint of $41 \pm 2.40\%$ SMC (Figure 2). Below the threshold of 41%, seed yield declined linearly at a rate of 25.5 kg/ha (SE ± 5.12) per percentage reduction in SMC ($R^2 = 0.74$; Figure 2).

At 55% SMC, TSW was <80% of the heaviest seed weights recorded at the lowest SMC cutting time of 29% (Figure 3). Ryegrass continues to partition assimilates into the seed until reaching physiological maturity at ~37-40% SMC (Hyde et al. 1959; Gibson et al. 2023). This is primarily driven by relocation of assimilates from the seed head into the seed (Trethewey & Rolston 2009). In this study TSW stabilised at $\geq 34\%$ (SE ± 3.24) SMC. A split-line regression model demonstrated that TSW increased by 0.9% (SE ± 0.21) per percentage increase in SMC until reaching a breakpoint at 34% SMC, corresponding to 98% of the maximum observed TSW (Figure 3). Beyond this point, TSW plateaued. Seed yields were greatest at SMC levels above 41%. However, the corresponding TSW was only 91% (SE ± 3.24) of the highest measured TSW (Figure 3). TSW was negatively affected by irrigation applied prior to cutting ($p=0.025$; data not shown) reducing the mean TSW from 2.61 g to 2.53 g (SE ± 0.03) across all experiments. As TSW in this series of experiments was measured on machine-dressed samples, the exclusion of immature seed may have skewed results toward larger seed sizes at higher than normal SMC.

Meta-analysis revealed no calculated SMC \times irrigation interaction for seed yield ($p = 0.901$), thousand seed weight (TSW) ($p = 0.337$), harvest loss ($p = 0.604$), or germination ($p = 0.387$) (data not shown). Additionally, the application of pre-cutting irrigation had no effect on seed yield ($p = 0.125$), harvest loss ($p = 0.426$), or germination ($p = 0.367$).

Table 4. Mean seed yield for four experiments when cutting occurred at multiple levels of seed moisture content (SMC) during the 2022-25 seasons in Canterbury.

% SMC	Experiment 1	Experiment 2	Experiment 3	Experiment 4
	Yield	Yield	Yield	Yield
29	1570 ^d	1999 ^c	1751	1360 ^c
32	1794 ^{cd}	*	*	*
33	*	2214 ^{bc}	1733	1551 ^{ab}
35	2014 ^{bc}	*	*	*
37	*	2199 ^{bc}	1756	1496 ^b
38	2001 ^{bc}	*	*	*
41	2270 ^a	2193 ^{bc}	1761	1628 ^a
44	2220 ^{ab}	*	*	*
45	*	2207 ^{bc}	1924	1535 ^{ab}
47	2252 ^{ab}	*	*	*
49	*	2572 ^a	1673	1567 ^{ab}
53	*	2383 ^{ab}	1663	1601 ^a
P value SMC%	< 0.001	0.035	0.226	<0.001
LSD (p=0.05)	228.4	310.9	NS	99.3
SE	114.1	148	101.7	49.33

Note: * indicates no data at the given seed moisture content for the experiment.

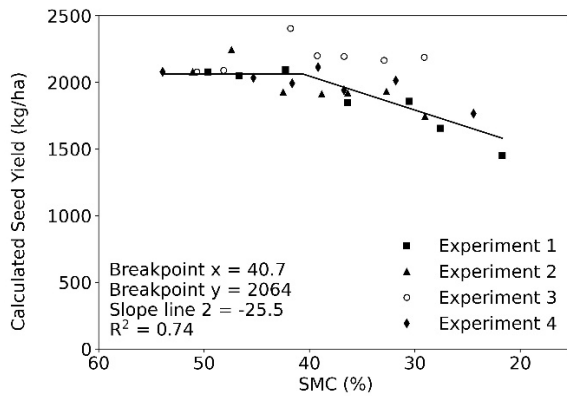


Figure 2. Calculated seed yield from four experiments when cutting occurred at multiple levels of seed moisture content (SMC) grown during the 2022-25 seasons. Experiment 3 (open circles) has been omitted from the regression analysis.

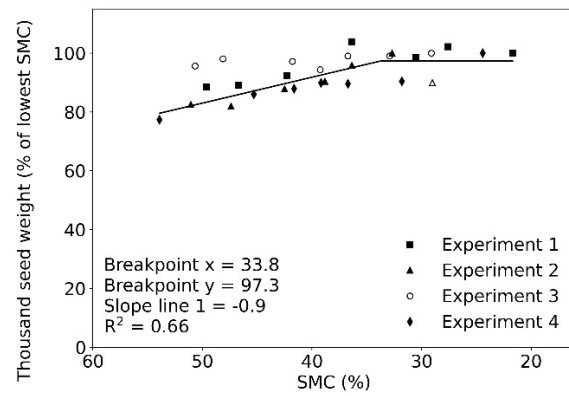


Figure 3. Calculated TSW from four experiments when cutting occurred at multiple levels of seed moisture content (SMC) grown during the 2022-25 seasons. Experiment 3 (open circles) has been omitted from the regression analysis.

High harvest losses were recorded in this study, increasing linearly with declining SMC ($R^2 = 0.93$), at a rate of 31 kg/ha ($SE \pm 3.82$) per percentage change in SMC (Figure 4). Total harvest losses ranged from less than 400 kg/ha (equivalent to 20% of total seed produced) at SMC levels above 50%, to more than 1100 kg/ha (40% of total seed produced) at or below 29% SMC. Equivalent to a \$1260–\$4200 (seed price of \$3.50/kg) loss to the producer. These losses represent a significant economic cost. The rapid loss in seed yield below 41% SMC (Figure 2) was driven by seed shatter (Figure 4), consistent with Anslow (1964), who observed crop yield declined 26–31 days after inflorescence emergence due to seed shatter, despite increasing seed weight. The high degree of diversity of anthesis in perennial ryegrass means the potential for a range in maturity of up to 21 days in a season (Abel et al. 2018).

The application of 6 mm irrigation prior to cutting to simulate dew had no effect on seed yield (Table 1). This contrasts with Silberstein et al. (2005), who reported a 170 kg/ha yield increase when ryegrass was cut with dew present. The implication is that the irrigation was not acting in the same way as the increase in relative humidity that occurs when dew is present.

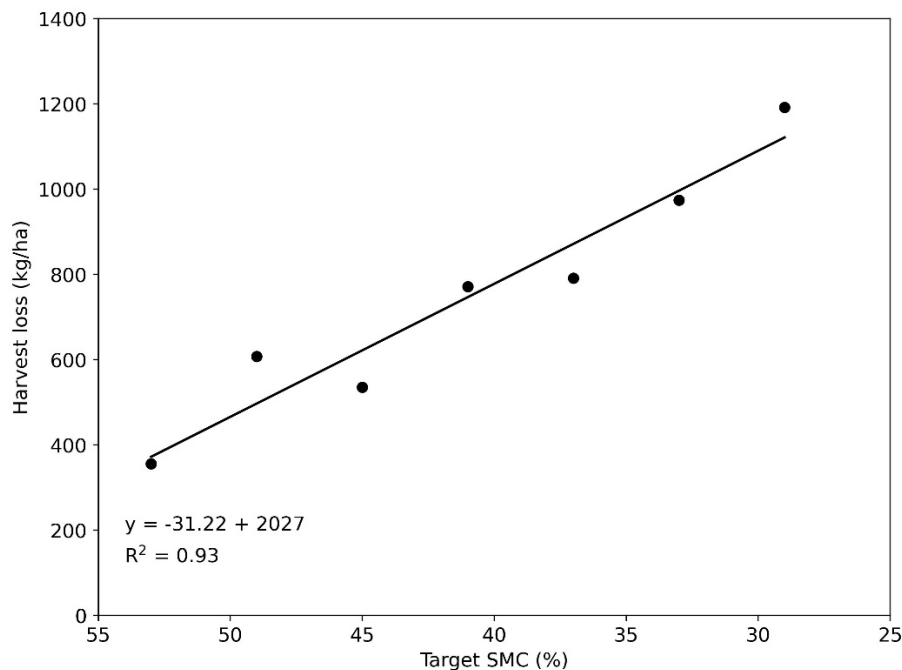


Figure 4. Total harvest loss (kg/ha) compared with target SMC for three experiments grown in the 2023-25 growing seasons. Experiment means averaged across Experiments 2,3 and 4 as calculated harvest loss compared with the grand mean (for the three experiments).

Weather data

Weather conditions varied across the four experiments conducted between 2023 and 2025 (Table 3). Total rainfall over the 6-week period ranged from 45 mm in 2023 (Experiment 1) to 100 mm in 2025 (Experiment 4). Mean relative humidity increased progressively from 69% in 2024 (Experiment 2) to 82% in 2025. Total solar radiation was similar in 2023 and 2024 (711–712 MJ m⁻²), but notably lower in 2025 (654 MJ m⁻²).

Summary

Seed moisture content (SMC) was shown to be a reliable and repeatable indicator of optimal harvest time in perennial ryegrass. Across four experiments, SMC declined linearly, and seed yield was maximised between 55% and 41% SMC. Below 41% SMC, yield declined primarily due to increased seed shatter, while thousand seed weight (TSW) plateaued after 33% SMC, which was taken as indicating the end of seed filling or physiological maturity. Irrigation prior to cutting had no effect on yield or TSW. These findings support cutting perennial ryegrass ≥41% SMC—prior to significant seed loss—as a strategy to optimise yield and reduce harvest losses, without compromising seed quality.

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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)
Authors	Matilda Gunnarsson, Richard Chynoweth and Sean Weith (FAR)
Location	Chertsey FAR Research Site, Lincoln (-43.791915, 171.959236)
Funding	SIRC (Seed Industry Research Centre)
Acknowledgements	NZ Arable (trial operator)

Key points

- *Vulpia* hairgrass (*Vulpia* spp.) is a problematic grass weed in perennial ryegrass seed crops.
- To combat *Vulpia* hairgrass resistance, incorporating herbicides with diverse modes of action is essential.
- Early intervention plays a crucial role in managing *Vulpia* hairgrass infestations in ryegrass seed crops.
- 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.
- 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 Chertsey Research Site (Column 5 - 43.791915, 171.959236) in an irrigated block of perennial ryegrass (cv. Nui) drilled at a rate of 12 kg/ha on the 24th April 2023. *Vulpia* hairgrass seed was hand spread at a rate of 5 kg/ha at the time of perennial ryegrass sowing and incorporated via Cambridge roller. The trial had 17 herbicide treatments (Table 1) in a complete randomised experimental design with four replicates. 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 27th April 2023 or early post emergence (EPE) when 50% of ryegrass plants had 2 true leaves (GS 12) on the 12th 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 11th 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 25th 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 4th 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 5th January 2024 and harvesting all treatment plots with a Wintersteiger Classic plot harvester on the 10th 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 m² 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 m² (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 m² (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 7. Machine dressed yield, number of perennial ryegrass (*Lolium perenne*) plants and seed heads per square meter 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. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

Treatment No.	Product ¹ , Application Rate and Timing		Machine dressed yield (kg/ha)	Perennial ryegrass plants/m ² (11 th Aug 2023)	Perennial ryegrass seed heads/m ² (4 th Jan 2023)	TSW (g)	
	Pre-emergence (GS 00-07) 27 th April 2023	Early post-emerge 2-leaf (GS 12) 12 th 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) + Atraflo™ (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 ($P \leq 0.05$)	301	30	520	NS
			P value	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.01$	0.20

NS = No significant difference.

¹ Asulox® (a.i. 400 g/L asulam, Group 18 Herbicide); Atraflo™ (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 8. 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. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

Treatment No.	Product ¹ , Application Rate and Timing		Estimated <i>Vulpia</i> hairgrass control score (0-100%) (25 th Aug 2023)	<i>Vulpia</i> hairgrass seed heads/m ² (4 th Jan 2024)	<i>Vulpia</i> hairgrass control (Abbott) (%) (seed heads) (4 th Jan 2023)	% <i>Vulpia</i> hairgrass relative to total sample weight (3 g)	
	Pre-emergence (GS 00-07) 27 th April 2023	Early post-emerge 2-leaf (GS 12) 12 th 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 ($P \leq 0.05$)	12	889	39	4.0
			P value	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$

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).

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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 separate passes
Rolling	18 Aug	Site rolled using a Cambridge roller

Evaluating the efficacy and selectivity of Kerb™ herbicide in cocksfoot seed crops

Project code	H19-11-00
Duration	Year 3 of 3 (Season 2023-24)
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

- Grass weed presence was minimal, hindering specific data collection on grass weed control efficacy in both trials.
- Herbicide effects on seed yield varied by location, with treatment-related differences in machine-dressed yield observed only at Methven.
- At Wakanui, herbicide treatments including Karmex®900 with Atraflo™ increased seed heads per m², but their effects on seed yield were inconsistent.
- Herbicide treatments like Stratos®, Puma® S, and Jive® caused crop damage and seed yield reductions up to 29.5%.
- 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 m²) in the Wakanui trial and 10.7 m (35.3 m²) 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 treatments were applied onto mature winter dormant cocksfoot plants with some tiller post-harvest regrowth before normal plant growth regulator application timings treatments. For the trial located at Wakanui, treatments were applied at two timings, either on the 21st July 2023 or the 4th October 2023. For the Methven trial, treatments were applied on either the 20th July 2023 or the 4th October 2023. Conditions at the timing of first application on 21st 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 20th July 2023 whilst conditions were clear and dry with moderate wind during the 4th October 2023 application timing. All treatments were applied at the first application timing using either 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 at both sites, 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 the application of timing 1 treatments using a scale of 0% to 100%, where 0% = no damage and 100% = all plants dead with no green leaf. These assessments were conducted fortnightly 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 9th and 24th 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 1st February 2024 for the Methven trial and for the Wakanui trial on 9th January 2024. Both trials were harvested using a Sampo 2010 plot harvester, with the Methven trial harvested on 15th February 2024 and the Wakanui trial on 17th 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 issues. 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 was 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, seed yields varied between trials, and the untreated controls (Treatment 1) performed similarly to many herbicide treatments, indicating limited response as a result 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 ($P \leq 0.01$) MDY than some treatments and showed a modest 9.6% increase in seed yield compared with the untreated control. Conversely, Sakura®850 WG (a.i. 850 g/kg pyroxasulfone, Group 15) (-5.9%) and Kerb™500F (1 L/ha) tank mixed with 1.5 L/ha Atracrow™ (a.i. 500 g/L atrazine, Group 5) (-7.4%) exhibited notable reductions in seed yield compared with the untreated control. 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 Atracrow™ 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 (Atracrow™) 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 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) report, 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 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 profitability of seed yield (as measured by (MoC) of most herbicide treatments) resulted in negative economic responses with differences ($P \leq 0.001$) between treatments, 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. The treatment where Kerb™500F was applied at highest rate by itself (1.4 L/ha) (treatment 9) achieved the highest MoC (\$363/ha), while treatments where Kerb™500F was applied at 1 L/ha followed by either Stratos® (-\$940/ha), Puma® S (-\$619/ha), or Jive® (-\$525/ha) had the lowest economic responses.

Table 9: Cocksfoot seed head density, machine dressed seed yield, percentage dressing yield, thousand seed weight (TSW) and margin-over-cost (MoC) from cocksfoot (*Dactylis glomerata*) (cv. Lazily) plots treated with 14 different chemical treatments in a herbicide trial conducted at Methven, Mid Canterbury during the 2023-24 season. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

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 th July 2023	4 th October 2023					
1	Untreated	Untreated	433	697	12.5	1.2	-
2	Karmex [®] 900 (0.5 kg/ha) + Atracflow [™] (1.5 L/ha)		556	709	12.6	1.2	-4.4
3	Kerb [™] 500F (0.6 L/ha) + Atracflow [™] (1.5 L/ha)		525	691	11.5	1.2	-111
4	Kerb [™] 500F (1 L/ha) + Atracflow [™] (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 ($P \leq 0.05$)			NS	98	NS	NS	934
CV			23.2	13.4	31	5.5	-204
P value			0.26	<0.01	0.25	0.10	<0.001

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 10: Cocksfoot seed head density, machine dressed seed yield, percentage dressing yield, thousand seed weight (TSW) and margin-over-cost (MoC) from cocksfoot (*Dactylis glomerata*) (cv. Shawnee) plots treated with 14 different chemical treatments in a herbicide trial conducted at Wakanui, Mid Canterbury during the 2023-24 season. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

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)
	21 st July 2023	4 th October 2023					
1	Untreated	Untreated	485	836	11.0	1.1	-
2	Karmex [®] 900 (0.5 kg/ha) + Atraflo [™] (1.5 L/ha)		605	868	14.6	1.1	100
3	Kerb [™] 500F (0.6 L/ha) + Atraflo [™] (1.5 L/ha)		566	891	9.6	1.1	209
4	Kerb [™] 500F (1 L/ha) + Atraflo [™] (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 ($P \leq 0.05$)			111	NS	3.9	NS	NS
CV			19.8	12.0	21.2	6.1	-
P value			<0.001	0.11	<0.05	0.24	0.33

NS = No significant difference.

¹ Alion[®] (500 g/L indaziflam, Group 29 Herbicide); Atrflow[™] (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, Atrflow[™] 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.

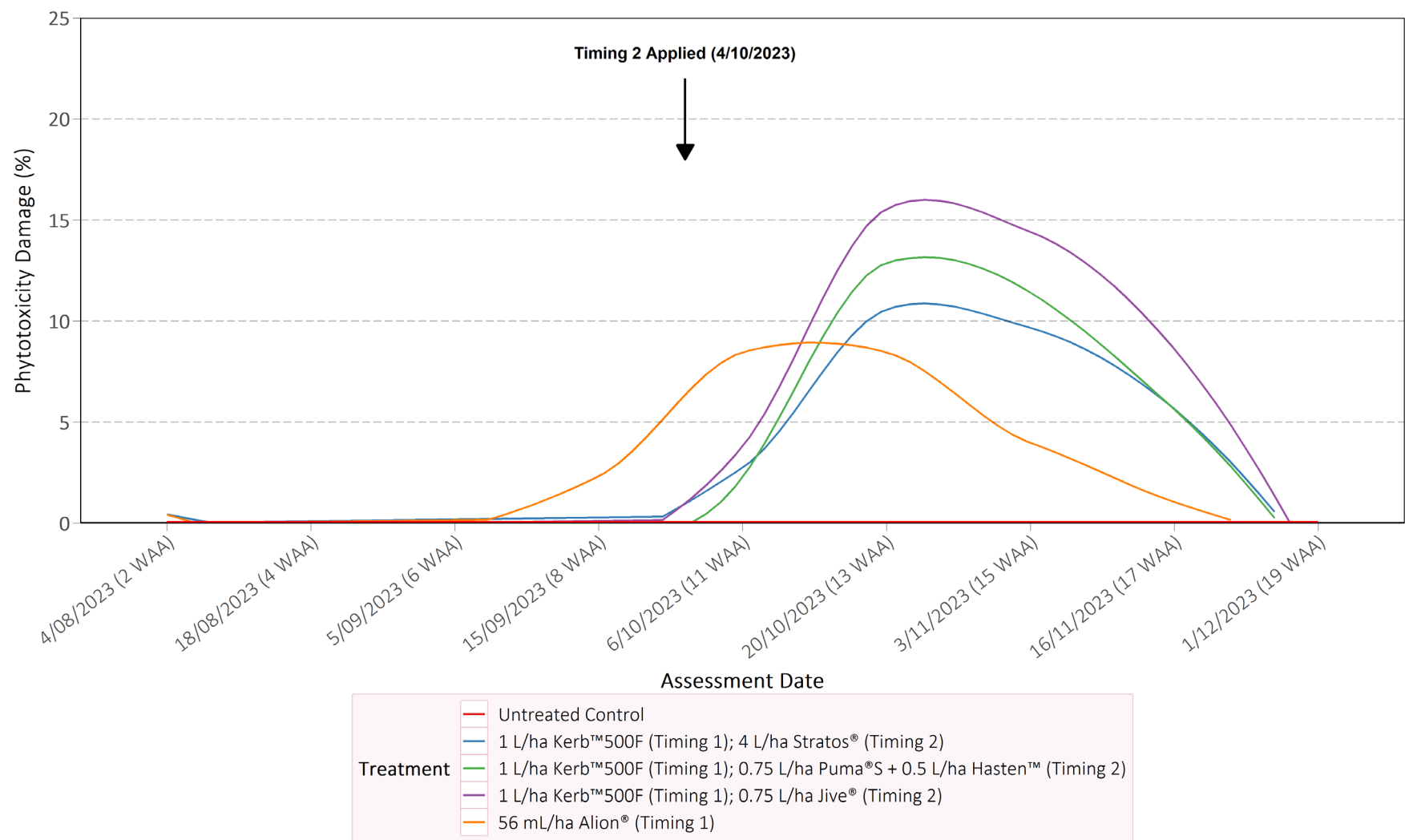


Figure 1: Phytotoxicity scores ranked on a scale of 0–100% in cocksfoot (*Dactylis glomerata*) (cv. Shawnee) plots from a herbicide trial conducted at Wakanui, Mid Canterbury, during the 2023–24 season. Only treatments exhibiting visible phytotoxicity damage are presented. Weeks after application (WAA) are relative to Timing 1, which was applied on 21st 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 efficacy. In Methven, Kerb™500F at 1.2 L/ha increased MDY compared to untreated plots, while Sakura®850 WG and Kerb™500F (1 L/ha) followed by 1.5 L/ha of Atraflo™ showed seed yield reductions. At Wakanui, Karmex®900 with Atraflo™ notably increased cocksfoot seed head density but other treatments like Stratos®, Puma® S, and Jive® caused moderate crop damage, leading to MDY reductions. 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 1

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. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

Treatment	Product, Application Rate and Timing ¹		\$/ha Chemical	\$/Application*	Cost/ha (\$/ha)	MoC** (\$/ha)
	20 th July 2023	4 th 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 ($P \leq 0.05$)	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		

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 st July 2023	4 th 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
Product Name		Cost per Litre or gram (\$) ***			LSD (P≤0.05)	NS
Alion [®]		1491			P value	0.33
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 21st July 2023 and 17th January 2024 at FAR Methven weather station (Station ID: H81; -43.645920, 171.613800) located about 10 km away from the trial site. Data was retrieved from the FAR MetWatch weather portal (<https://far.metwatch.nz/stations?station=H81>) managed by HortPlus on the 9th January 2025.

Day	Month						
	July 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 21st July 2023 and 17th January 2024 at FAR Wakanui weather station (Station ID: I17, -44.009380, 171.874530) located 4.8 km away from trial site. Data was retrieved from the FAR MetWatch weather portal (<https://far.metwatch.nz/stations?station=I17>) managed by HortPlus on the 9th January 2025.

Day	Month						
	July 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

Autumn management of multi-year grass seed crops

Project code	H19-15-03
Authors	Richard Chynoweth
Location	FAR Chertsey Arable Research Site, Mid Canterbury
Funding	Seed Industry Research Centre (SIRC)

Key points

- Early opportunities for tiller appearance by autumn management are critical for seed head formation in tall fescue and cocksfoot. They are less critical in other grass species.
- To stimulate tiller emergence, light is required at the base of last year's tillers, following which, tillers must reach a certain size to be vernalized before the end of winter.
- Autumn management that removes the previous seasons residue, promotes tiller growth and maximises the number of reproductive tillers.
- Residue management, soil fertility and monitoring soil moisture status will combine to influence autumn tiller production.

Background

For all grass seed crops, the number of seedheads/m² is the primary yield component that sets the potential seed yield. The optimum number seed head numbers range from ~400 in tall fescue through to 1800 in perennial ryegrass. Seed head number is determined by the number of tillers, or in some cases buds, that are exposed to the winter environmental cues for reproductive development. Winter requirements range from nil in some *Poa*, and *Phleum* species, to intermediate for cocksfoot and perennial ryegrass (*Lolium perenne*) to strong requirements for tall fescue.

Where winter requirements are greater, management of crop residue post-harvest is crucial to attain optimal seed yield in the subsequent season e.g. tall and fine fescue. The seed heads which will form the basis of the subsequent harvest begin their growth cycle during the previous summer and autumn as vegetative tillers. In tall fescue, it is generally accepted that tillers have a juvenile phase and must reach a certain size before they can be vernalised. In grasses, tillers begin life as a bud located under a leaf sheath. In order for buds to grow into tillers, they must receive a light stimulus. When crop canopies are dense and capturing all the sunlight e.g. during summer when a seed crop has good seed head numbers, the buds located near the base of the crop are shaded and dormant. At harvest, the crop is swathed and harvested, potentially allowing light to the base where new tillers can be released. However, if crop residue or a large canopy remains on or near the soil surface, this may intercept sunlight and restrict tiller emergence, and subsequent growth rates.

Current tall fescue trial

Tall fescue, cultivars Quantica and Temora, were sown during the summer of 2021/22 and managed as a seed crop during the 2022/23 growing season. Plots were direct harvested in mid December. Following harvest, all plots were cut to 15 cm using a windrower and the foliage removed by hand raking. On 23 Jan 2023, treatments with a 7 cm cutting height were cut using a plot windrower and foliage removed approximately 14 days later. Subsequently plots were kept trimmed to their respective heights until the end of June. All plots received 50 kg N applied as Sustain applied 29 March.

In June, all treatments had ~4000 vegetative tillers/m² (data not shown). Seed head number was assessed 9 November by counting the number of seed heads on 30 cm of row at two locations in each plot. The seed head number was influenced by cultivar only, no differences in seed head numbers were observed between treatments. Note: ‘Temora’ in later heading than ‘Quantica’ and that seed heads were still emerging in many treatments.

Thus, post harvest management must allow tillers to grow during autumn and early winter. The presence of straw, debris, or standing stubble can reduce tiller growth, ultimately reducing potential seed yield.

Table 1. Seed head number per m² for two cultivars of tall fescue assessed on 9 November 2023 following autumn trimming at two heights and winter inter-row spraying as post-harvest management options when grown at the FAR Chertsey Arable Research Site, Mid Canterbury during the 2023/24 growing season.

Cultivar or treatment	Topping height (cm)			Cultivar mean
	7 cm	7 cm	15 cm	
Interrow sprayed	No	Yes	No	
‘Quantica’	313	264	279	280 a
‘Temora’	219	195	226	212 b
Trt mean	266	230	253	
	P value	LSD _{0.05}		
Cultivar	<0.001	45.3		
Height	0.577	NS*		
Interrow spraying	0.125	NS		
All interactions	>0.326	NS		
* = Not significant				

Disease control in plantain seed production

Project code	H19-16-00
Duration	Year 5 of 5 (2023-24 season)
Authors	Owen Gibson, Richard Chynoweth (FAR)
Location	Southbridge, Mid Canterbury (43°47'31.7"S 172°15'14.4"E)
Funding	Seed Industry Research Centre (SIRC)
Acknowledgements	Aaron Lill (trial host) and NZ Arable (trial operator)

Key points

- The 2023-24 season resulted in above average plantain seed yields.
- Fungicide treatments averaged 18% increase in yield over the untreated.
- There were no significant differences in disease incidence among fungicide programmes.
- Yield response closely mirrored *Phomopsis* infection levels.

Background

Phomopsis stalk disease, caused by the fungal pathogen *Phomopsis subordinaria*, is a significant threat to the productivity of plantain (*Plantago lanceolata*) seed crops. The disease is characterised by a brown to black discoloration of the stem immediately below the seed head, which subsequently bends downward. This stem collapse results in the death of the seed head, halting seed development at the time of infection. If infection occurs early in the flowering stage, no seed is produced. Infections during seed fill cause seed development to cease prematurely.

Entry of *P. subordinaria* into plantain stems requires a wound, often caused by insect activity in natural populations (Nooij & Aa, 1987). In New Zealand, plantain is typically grown as an annual seed crop; disease severity increases significantly in second-year crops resulting in uneconomic returns. The pathogen overwinters in infected plantain scapes that remain on the ground or within the rosette, providing an inoculum source for reinfection in subsequent seasons. The impact of this was demonstrated by Gibson et al. (2021), who reported infection levels exceeding 80% in second-year, untreated control treatments, compared to less than 15% in the first-year.

Management of *P. subordinaria* in New Zealand relies heavily on the use of prothioconazole, a Group 3 triazolinthione fungicide (DMI – DeMethylation Inhibitor, SBI: Class I), originally registered as Proline®. Prothioconazole plays a critical role in disease control.

Fungicide applications are typically made from early flowering, with two to three treatments applied during the season to protect against infection and reduce disease severity. The effectiveness of disease control depends on the choice of fungicide, timing of application, and crop monitoring.

Previous fungicide trials conducted on 'Boston' plantain have shown that under normal disease pressure, Proline® alone provides effective control and improved seed yields. However, under high disease pressure, such as during the 2020-21 second-year crop season, Proline® alone was insufficient. Under high disease pressure, programmes incorporating Prosaro®, Amistar® or Seguris® Flexi achieved significantly higher yields. The objective of this trial was to evaluate the efficacy of different fungicide programmes for the control of *P. subordinaria* under field conditions and to validate the findings from

the previous fungicide trials to refine recommendations for disease management in plantain seed production.

Methods

A small-plot replicated field trial was established in a commercial irrigated 'Boston' plantain paddock during the 2023-24 growing season at Southbridge, Mid Canterbury (43°47'31.7"S, 172°15'14.4"E). The trial was a randomised complete block design with ten treatments (Table 1) and four replicates. All fungicide applications were applied using a battery-operated backpack sprayer equipped with a 3.0 m boom and 6 × 110 015 AI XR TeeJet nozzles. Applications were made at a water rate of 180 L/ha and pressure of 280 kPa, with a forward speed of 1.0 m/s. To manage plantain moth (*Scopula rubraria* and *Epyaxa rosearia*), Sparta™ (120 g/L spinetoram, Group 5 insecticide) was applied at 200 mL/ha during the first two fungicide timings to all treatments.

Visual disease assessments for *P. subordinaria* were conducted from early seed fill through to harvest. Due to low disease pressure during the season, a single disease assessment was completed on 25 January 2024 (Table 2). All non-fungicide agronomic inputs were managed by the grower following standard commercial practice. For confidentiality reasons, specific details of the management programme are not reported here.

Table 1. Plantain fungicide programme and application timings used in a trial grown near Southbridge, Mid Canterbury in the 2023-24 season.

	16.11.23	7.12.23	19.12.23
Trt	Closing + 2 weeks	+ 3 weeks	+ 3 weeks
1	nil	-	-
2	0.8 L/ha Proline®	0.8 L/ha Proline®	-
3	-	0.8 L/ha Proline®	0.8 L/ha Proline®
4	0.8 L/ha Proline®	0.8 L/ha Proline	0.8 L/ha Proline®
5	0.75 L/ha Amistar® + 0.6 L/ha Seguris® Flexi	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.6 L/ha Seguris® Flexi
6	0.75 L/ha Amistar® + 1.5 L/ha Vimoy® Iblon®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 1.5 L/ha Vimoy® Iblon®
7	-	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 1.5 L/ha Vimoy® Iblon®
8	2 kg/ha Ridomil® Gold + 3 L/ha Tri-Base Blue®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.75 L/ha Amistar®
9	Proline® 0.8 L/ha + Amistar® 0.75 L/ha	0.8 L/ha Proline® + 0.6 L/ha Seguris® Flexi	0.75 L/ha Amistar® + 0.6 L/ha Seguris® Flexi
10	Proline® 0.8 L/ha + Amistar® 0.75 L/ha	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.75 L/ha Amistar®

Chemical active ingredients: Proline® (250 g/L prothioconazole, group 3 fungicide), AMISTAR® (250 g/L azoxystrobin, group 11 fungicide), SEGURIS® Flexi (125 g/L isopyrazam, group 7 fungicide), VIMOY® IBLON® (50 g/L isoflucpyram, group 7 fungicide), Ridomil® Gold MZ WG (40 g/kg metalaxyl-M (mefenoxam) + 640 g/kg mancozeb, group 4 fungicides) and Tri-Base Blue® (190g/L copper as tribasic copper sulphate, group M1 fungicide).

The trial area was windrowed on 17 February 2024 using a modified John Deere windrower cutting a 1.8 m swath. Final harvest was carried out on 24 February using a Wintersteiger Classic plot combine. Field-dressed seed weights were recorded at harvest using platform scales. A 500 g sub-sample from each plot was collected and weighed at harvest, then dried in a warm, ventilated environment to achieve uniform seed moisture of 12%. Samples were machine-dressed using a Westrup seed cleaning machine to meet First-Generation Seed Certification standards. Economic analysis was conducted by calculating the margin over cost (MoC) for each treatment relative to the untreated control. The MoC was based on a seed price of \$4.50/kg, actual fungicide costs, and a standard application cost of \$30/ha per pass.

Results and discussion

All fungicide treatments resulted in a statistically significant increase in seed yield compared to the untreated control ($p = 0.004$) (Table 2). Despite low overall disease pressure in the 2023-24 season, *P. subordinaria* infection was highest in the untreated plots (7.5% of stems affected). In contrast, fungicide-treated plots (Treatments 2–10) exhibited much lower infection rates, ranging from 0.5% to 2.5%.

There were no significant differences in disease incidence among the fungicide treatments; however, all fungicide programmes significantly outperformed the untreated control in disease suppression. These results align with previous findings from Gibson *et. al.* (2022), where Proline® alone provided equivalent control to programmes including Amistar® (250 g/L azoxystrobin, Group 11) and Seguris® Flexi (125 g/L isopyrazam, Group 7).

Under the low disease pressure conditions of this season, no additional yield benefit was observed from tank mixes or extended fungicide programmes beyond Proline® applied twice (7 and 19 December 2023). However, omitting the third application (19 December) and relying on an early two spray program (16 November and 7 December) led to a significant yield reduction in treatment 2 (3.08 t/ha). No benefit was gained by applying a three-spray program (treatments 4,5,8,9 and 10) compared to a two-spray program on 7 and 19 December (treatments 3 and 7) suggesting that the initial fungicide application on 16 November had little effect on *P. subordinaria*.

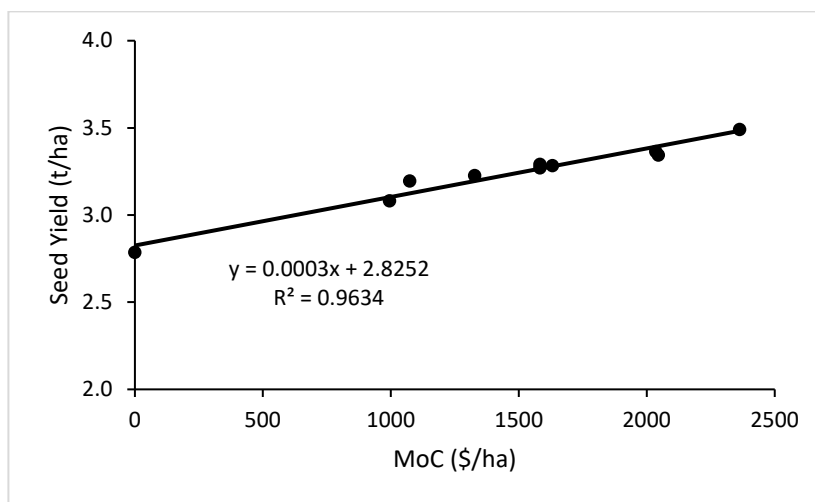


Figure 1. Plantain seed yield compared to Margin-over-Cost for 'Boston' treated with different fungicide programmes grown near Southbridge, Mid Canterbury in the 2023-24 season.

MoC did not differ significantly between treatments due to a high level of variability (coefficient of variation = 49%), the high yielding crop offset the difference in fungicide programme costs. Fungicide programme costs ranged from \$187/ha (Treatments 2 and 3) to \$526/ha (Treatment 6), with corresponding gross margins ranging from \$1,140 to \$2,730/ha. Although statistical differences in MoC were not detected ($p=0.289$), there was a strong positive correlation between seed yield and MoC ($R^2 = 0.9634$) (Figure 1), highlighting the value of yield improvements in driving profitability. In seasons with lower yields, the relative cost of chemical applications may have a greater impact on MoC, underlining the importance of matching input levels to expected disease risk and crop potential.

Summary

The dry conditions experienced during the 2023-24 season resulted in minimal *P. subordinaria* pressure on this plantain seed crop and contributed to above-average seed yields. Under these conditions, Proline® applied alone provided effective disease control, consistent with outcomes from previous seasons. While additional mixing partners did not offer a yield advantage this season, incorporating alternative modes of action remains a key strategy for managing fungicide resistance and safeguarding long-term efficacy. In wetter seasons, when disease pressure is likely to be higher, more robust fungicide programmes are expected to have a greater impact on maintaining yield potential.

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Table 2. Treatment list, Machine dressed yield and diseased head score for ‘Boston’ plantain trial at Southbridge in Mid Canterbury in the 2023-24 growing season.

Trt	16 November 2023	7 December 2023	19 December 2023	Harvest Yield		Diseased Heads		MoC ¹
	Closing + 2 weeks	+ 3 weeks	+ 2 weeks	t/ha		%		\$/ha
1	-	-	-	2.79	c	7.5	b	*
2	0.8 L/ha Proline®	0.8 L/ha Proline®	-	3.08	b	2	a	995
3	-	0.8 L/ha Proline®	0.8 L/ha Proline®	3.34	ab	2.5	a	2045
4	0.8 L/ha Proline®	0.8 L/ha Proline	0.8 L/ha Proline®	3.36	ab	2.5	a	2035
5	0.75 L/ha Amistar® + 0.6 L/ha Seguris® Flexi	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.6 L/ha Seguris® Flexi	3.23	ab	1	a	1328
6	0.75 L/ha Amistar® + 1.5 L/ha Vimoy® Iblon®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 1.5 L/ha Vimoy® Iblon®	3.19	b	1	a	1073
7	-	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 1.5 L/ha Vimoy® Iblon®	3.28	ab	0.5	a	1631
8	2 kg/ha Ridomil® Gold + 3 L/ha Tri-Base Blue®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	3.49	a	1.5	a	2363
9	Proline® 0.8 L/ha + Amistar® 0.75 L	0.8 L/ha Proline® + 0.6 L/ha Seguris® Flexi	0.75 L/ha Amistar® + 0.6 L/ha Seguris® Flexi	3.29	ab	0.5	a	1582
10	Proline® 0.8 L + Amistar® 0.75 L	0.8 L/ha Proline® + 0.75 L/ha Amistar®	0.8 L/ha Proline® + 0.75 L/ha Amistar®	3.27	ab	1	a	1582
			P value	0.004		0.038		0.289
			LSD (p=0.05)	0.29		3.9		NS
			CV%	6.2		133.5		49

¹ Treatment 1 excluded from the MoC analysis due to no value.

¹ Chemical prices for MoC analysis (\$/L): Proline® \$79.20, AMISTAR® \$49.80, SEGURIS® Flexi \$119.50, VIMOY® IBLON® \$78.10, Ridomil® Gold MZ WG \$37.90 and Tri-Base Blue® \$25.40

Fungicide strategies for downy mildew control in cocksfoot seed crops

Project code H23-01-00

Duration Year 1 of 5 (2023-24 season)

Authors Sean Weith and Richard Chynoweth (FAR)

Location Methven, Mid. Canterbury, New Zealand (GPS: -43.571590, 171.676552)

Funding SIRC (Seed Industry Research Centre)

Acknowledgements Mark Braithwaite (Plant Diagnostics Limited), Ian Marr (trial host) and NZ Arable (trial operator)

Key points

- Moderate cocksfoot downy mildew pathogen pressure was observed in this fungicide evaluation trial, influenced by favourable early-season weather conditions and reduced by hot, dry weather during seed filling.
- Fungicides Phoenix[®] (folpet, Group M4) and Foschek[®] (phosphorous acid, Group P07) effectively reduced pathogen symptoms
- Ridomil[®] Gold MZ WG (metalaxyl-M (mefenoxam) + mancozeb, Group 4 + Group M3), Gem[®] Fungicide (fluazinam, Group 29), and Curfew[®] (cymoxanil, Group 27) showed limited efficacy.
- Foschek[®] reduced seed head bleaching and may offer some level of control against the cocksfoot downy mildew pathogen, warranting further research.
- Economic analysis showed no differences in margin-over-cost (MoC) values among fungicide treatments.

Background

Since 2018, downy mildew has emerged as a significant foliar disease affecting cocksfoot (*Dactylis glomerata*) seed crops in New Zealand. The putative pathogen responsible for this disease is believed to be *Sclerophthora cryophila*, a biotrophic oomycete. Prior to 2018, downy mildew had not been reported in New Zealand's cocksfoot seed producing areas suggesting that *S. cryophila* may have been present but undetected for an extended period of time. The earliest documented report of *S. cryophila* affecting cocksfoot dates back to 1948, when Jones (1955) first observed symptoms resembling frost damage in affected field plots in Canada. To date, despite cocksfoot's widespread cultivation and presence in both cultivated and wild grass environments globally, instances of *S. cryophila* infecting cocksfoot have not been reported since its initial detection (Crouch *et al.*, 2022). Although *S. cryophila* is considered the likely pathogen responsible for cocksfoot downy mildew in New Zealand, definitive identification has not yet been achieved, pending further validation through molecular sequencing. Therefore, throughout this report, the term "cocksfoot downy mildew pathogen" will be used to refer to this pathogen.

Cocksfoot downy mildew pathogen primarily infects susceptible cocksfoot plants via the leaves, leaf sheath and stems, with the resulting damage causing seed yield losses, especially when conditions are cool (<15°C) and moist (Jones, 1955). Generally, downy mildew has presented on susceptible cocksfoot plants with light yellow to tan lesions which can appear as bands on leaves and reproductive stems (peduncles) a few days after flowering (GS 60- 69) (Harvey & Braithwaite, 2022). Over time, these lesions expand, eventually causing the upper stem and seed heads to bleach, leading to reduction in the size of seeds or total seed loss (Jones, 1955).

Downy mildew has primary and secondary infection stages, which are disseminated by infection structures called sporangia (spores) that are spread via rain splash and release motile zoospores that can infect host tissue via the stomata when in the presence of free water. Provided conditions are

conducive, these sporangia will be produced on sporangiophores nocturnally (under darkness) for a just a few hours in the early morning (Crouch *et al.*, 2022). The primary infection is expected to occur each year, but the secondary infection, which can cause significant damage, typically takes hold during the spring and summer months when the weather is wet.

The cocksfoot downy mildew pathogen is caused by an oomycete, an organism that is fungal-like, but taxonomically, is not classified as part of the fungal kingdom which contains “true fungi”. Consequently, fungicides effective against true fungal diseases that affect cocksfoot like leaf fleck (*Mastigosporium rubicosum*), brown leaf spot (*Cercosporidium graminis*), and rusts (*Uromyces* and *Puccinia* spp.) are ineffective against this pathogen. While several fungicides have shown efficacy against downy mildew pathogens in crops like grapes, onions, and potatoes (Salcedo *et al.*, 2021), there is limited information on the effectiveness of these active ingredients against gramminicolous downy mildews, including the pathogen responsible for cocksfoot downy mildew.

Over the past three years, The Foundation for Arable Research (FAR)-Seed Industry Research Centre (SIRC) trials (Chynoweth *et al.*, 2022, 2023) have identified several fungicides from different Fungicide Resistance Action Committee (FRAC) mode of action (MOA) groups that can suppress this disease. These include phthalimides (Group M4), such as folpet (Phoenix® Fungicide) and captan (Captan 600 Flo), phenylamides (Group 4), such as metalaxyl-M (mefenoxam) in Ridomil® Gold MZ WG and SL and phosphonates (Group P07), such as phosphorous acid (Foschek®). While these products have been shown to be efficacious against the cocksfoot downy mildew pathogen, there is still a need to further investigate new chemistries specifically targeting oomycetes to enhance control and mitigate resistance development. This report outlines a fungicide evaluation field trial conducted during the 2023-24 growing season, evaluating the efficacy of a range of fungicides targeting oomycetes for managing cocksfoot downy mildew pathogens.

Methods

A small plot trial was established during the 2023-24 season in a six-year-old cocksfoot seed crop (cv. Savvy) in Methven (-43.571590, 171.676552). Table 1 presents the trial's 16 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. Treatment plots within each replicate were 2 m wide and 12 m long (24 m²). All treatments containing Curfew® or coded product FARF2401 were applied with Arma™ (modified alkylamine polymer) at a rate of 1 mL/L or Hasten™ (704 g/L ethyl and methyl esters of canola oil fatty acids with 196 g/L non-ionic surfactants) at a rate of 0.5 L/100 L water. A list of the products included within each treatment is shown in Table 1. Treatments 3-16 were applied in addition to standard fungicide programme applied in Treatment 2 i.e. 1.5 L/ha Phoenix® applied at GS 33 was also applied with 1 L/ha Opus® and 0.75 L/ha of AMISTAR®. All paddock management was as per the host farmer throughout the season with the exclusion of any fungicides being applied to the trial site.

Treatments were applied at four different timings, either at second plant growth regulator (PGR) timing when 50% of tillers with node 3 at least 2 cm above node 2 (Zadocks growth stage (GS) 33) (Zadoks *et al.*, 1974) (T1; 3rd November 2023), 50% of tillers were at end of emergence (GS 59) (T2; 1st December 2023), 50% of tillers at full flowering (GS 65) (T3; 14th December 2023) or 14 days after flowering (GS 69) (T4; 28th December 2023). Conditions at the timing of most applications at both trial sites were damp and calm with no wind. All treatments were applied at all application timings using a backpack type sprayer unit equipped with a 12-volt Flojet pressure pump and 2 m handheld spray boom fitted with 6 x 110 015 AIXR Teejet® nozzles at 33 cm spacing delivering a water rate of 270 L/ha at an operating pressure of 280 kPa.

Assessments of disease incidence and crop greenness were conducted at nine timings during the growing season. The severity of cocksfoot downy mildew pathogen infection on individual cocksfoot plants was determined by completing a quantitative disease severity part assessment at five

different assessment timings. For each diseased part assessment, green leaf area and percentage of top four leaves, stem and head area infected by cocksfoot downy mildew pathogen or leaf fleck lesions (*Mastigosporium rubicosum*) were assessed on a scale of 0 to 100%, where 0% indicated no area was affected by disease and 100% was all of plants affected by disease. The first and third assessments, were conducted on the 1st December 2023 and 4th January 2024, respectively. In these assessments, we evaluated only 20 tillers that were collected randomly from across the whole trial. In the second, fourth and fifth assessments, conducted on the 11th December 2023, 10th and 20th January 2024, respectively, 10 tillers per plot were evaluated.

The progression of disease severity was assessed using a global ordinal scale based on the severity estimation method outlined by Bock *et al.* (2020). This scale evaluated the percentage of plants affected by fungal and oomycete symptoms, as well as the percentage of tillers exhibiting head bleaching. The assessment involved a subjective visual approach, where a rating of 0% indicated no affected plants and 100% indicated all plants were affected by disease. Evaluations were conducted on the 4th January 2024 (7 days after Timing 4 application), 8th January 2024 (11 days after Timing 4), 12th January 2024 (15 days after Timing 4), 16th January 2024 (19 days after Timing 4), and 19th January 2024 (22 days after Timing 4). Treatment plots were assessed for greenness by estimating the greenness of treatment plots using a subjective visual assessment of plant greenness within each treatment plot, where 0% indicated no plants with green leaf area and 100% indicated that all plants had full green leaf area. Greenness assessments were completed on the 4th January 2024 (7 DAA – T4), 8th January 2024 (11 DAA – T4), 10th January 2024 (13 DAA – T4), 12th January 2024 (15 DAA – T4), 16th January 2024 (19 DAA – T4) and 19th January 2024 (22 DAA – T4). Seed yield was obtained by windrowing plots using a modified John Deere plot windrower with a 1.8 m cut width on the 21st January 2024 and harvesting all treatment plots with a Wintersteiger Classic plot harvester on the 30th January 2024. Machine dressed yield and percentage dressing loss were all determined post-harvest.

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. For the analysis of visual estimate scores (including disease, greenness, and seed head bleaching), a two-way linear mixed-effects model was fitted using the residual maximum likelihood (REML) method. Treatment and replicate were included as fixed effects, while row and other random factors, as appropriate for specific variables, were treated as random effects. Disease severity data from quantitative assessments which included all tiller parts were analysed using a two-way linear mixed-effects model with the REML procedure. Treatment and replicate were included as fixed effects, while row, leaf number, and other factors specific to each variable were treated as random effects. Harvest variables (machine dressed yield, dressing loss and margin-over-cost (MoC)) were analysed using a two-way linear model with treatment and replicate as fixed effects. All analyses were carried out using the R packages 'stats' and 'lme4' (Bates *et al.*, 2015).

The adjusted means, least significant difference (LSD), and coefficient of variation (CV) were generated using the R package 'predictmeans' (Luo *et al.*, 2014). The LSD test was not performed for any variables that had a non-significant *P*-value ($P \geq 0.05$) after performing an analysis of variance (ANOVA). To calculate the MoC, the treatment cost per hectare and cost per application were subtracted from the revenue generated per hectare for each plot. This calculated amount was then further subtracted from the cost per hectare of the untreated control. Calculations were based on a grower's cocksfoot seed price of \$5.25/kg.

Overall trial details

The paddock was grazed by sheep through the autumn and winter of 2023. Closing date was 20 May 2023. During the year of the trial (2023-2024) no fungicide products were applied within the trial site. A full description of paddock management details is shown in the table below:

Activity	Date	Product/Rate
Fertiliser	17 Apr 2023	150 kg/ha Sustain [®] (N = 45.9)
	9 Aug 2023	150 kg/ha Cropzeal 16N (NPKS = 15.2-8-10-9.6)
	22 Sep 2023	100 kg/ha Sustain [®] (N = 45.9)
	19 Oct 2023	150 kg/ha Sustain [®] (N = 45.9)
Plant Growth Regulators	18 Oct 2023	1 L/ha Stabilan [®] 750SL (750 g/L chlormequat-chloride)
		0.3 L/ha Trexel [®] (250 g/L trinexapac-ethyl)
	31 Oct 2023	1.5 L/ha Stabilan [®] 750SL (750 g/L chlormequat-chloride) 0.2 L/ha Trexel [®] (250 g/L trinexapac-ethyl)
Herbicides	27 June 2023	1.25 L/ha Atraflo [™] (500 g/L atrazine, Group 5 Herbicide) 0.8 kg/ha Karmex [®] 900 (900 g/kg diuron, Group 5 Herbicide)
	3 Oct 2023	1.5 L/ha Agritone [®] 750 (750 g/L MCPA, Group 4 Herbicide) 3 g/ha Mustang [®] (600 g/kg metsulfuron-methyl, Group 2 Herbicide)
Fungicides	11 Nov 2023	1 L/ha Opus [®] (125 g/L epoxiconazole, Group 3 Fungicide) 1.5 L/ha Phoenix [®] Fungicide (500 g/L folpet, Group M4 Fungicide)
	7 Dec 2023	0.75 L/ha AMISTAR [®] (250 g/L azoxystrobin, Group 11 Fungicide) 1 L/ha Prosaro [®] (125 g/L prothioconazole + 125 g/L tebuconazole, Group 3 Fungicide) 2.5 kg/ha Ridomil [®] Gold MZ WG (40 g/kg metalaxyl-M (mefenoxam), Group 4 Fungicide + 640 g/kg mancozeb, Group M3 Fungicide)
	28 Dec 2023	0.4 L/ha AMISTAR [®] (250 g/L azoxystrobin, Group 11 Fungicide) 1.5 L/ha Phoenix [®] Fungicide (500 g/L folpet, Group M4 Fungicide) 1 L/ha Stellar [®] (125 g/L epoxiconazole, Group 3 Fungicide)
Insecticides	1 May 2023	50 mL/ha Dimilin [®] 2L (240 g/L diflubenzuron, Group 15 Insecticide)
Adjuvant	1 May 2023	50 mL/ha Actiwett [®] (935 g/L alcohol ethoxylate)

Results and discussion

Visually, cocksfoot downy mildew pathogen pressure across this trial was considered to be moderate, with this pressure being lower compared to a similar trial conducted in 2021-22 (Chynoweth *et al.*, 2022) but higher than another trial in 2022-23 (Chynoweth *et al.*, 2023). This fluctuation is likely attributable to weather conditions; specifically, the wet and cool conditions that occurred at the site between November and December 2023, which would have favoured downy mildew. These conditions were followed by dry and hot weather from mid to late January 2024 which would have reduced infection risk during seed filling, potentially limiting pathogen symptom severity as shown in the seed head bleaching scores (Table 1) which do not exceed 50%.

The machine-dressed seed yield (Table 2) of Treatment 2, the commercial standard, did not differ ($P \geq 0.05$) from most treatments using oomycete-targeting products. This outcome indicates that the influence of downy mildew on realised seed yield was less pronounced than previously reported in similar studies (Chynoweth *et al.*, 2022). This finding is further supported by the dressing loss data (Table 2) where the commercial standard did not differ from the values recorded in the untreated control plots (Treatment 1) or in plots treated with products containing active ingredients targeting oomycetes. While the absence of differences among other treatments does not contribute new insights into the optimal timing for controlling cocksfoot downy mildew pathogen, it does support earlier findings from trials conducted during the 2021-22 (Chynoweth *et al.*, 2022) and 2022-23 (Chynoweth *et al.*, 2023) seasons. Specifically, treatments using Phoenix[®] (a.i folpet, Group M4) applied at various growth stages consistently resulted in the severity of cocksfoot downy mildew pathogen symptoms (both quantitative and visual plot-based estimates) being lower compared to most other treatments. This conclusion is supported by the disease severity assessment data presented in Table 1. For example, treatments utilising Phoenix[®] alone at a rate of 1.5 L/ha (Treatments 3, 4 and 5) or in a tank mix with 2 kg/ha of Ridomil[®] Gold MZ WG (Treatment 8) exhibited reduced visual symptoms of the cocksfoot downy mildew pathogen on tiller leaves and stems, accompanied by moderate greenness scores.

There were also some other key products that were identified to have promising levels of activity on cocksfoot downy mildew pathogen. For example, Foschek[®] (phosphorous acid, Group P07) effectively reduced stem and head bleaching symptoms, showing promise for future trials despite plots where this treatment was applied having moderate visual leaf symptom levels throughout the assessment period. Captan 600 Flo (captan, Group M4) also performed well, reducing leaf symptoms and maintaining greenness, further highlighting the potential of the Group M4 fungicides. Conversely, treatments containing Ridomil[®] Gold MZ WG applied solo, Gem[®] Fungicide, or Curfew[®] showed higher levels of leaf and seed head bleaching, indicating limited efficacy of their active ingredients (metalaxyl-M and mancozeb, fluazinam, and cymoxanil, respectively). This effect was evident in Treatments 8 and 9, where the addition of Ridomil[®] Gold MZ WG to Phoenix[®] failed to provide an additive improvement in disease control compared to treatments where Phoenix[®] was applied alone. The lack of enhanced efficacy when tank-mixing Ridomil[®] Gold MZ WG with Phoenix[®] indicates that, in this trial, there was no synergistic benefit from the inclusion of metalaxyl-M or mancozeb, which belong to fungicide mode of action Groups 4 and M3, respectively. These results highlight the importance of selecting effective fungicides and optimising application timing for managing cocksfoot downy mildew pathogen. Further research is required to determine whether the reduced efficacy observed in this trial is due to the intrinsic properties of the active ingredients or environmental factors affecting application timing.

The MoC for fungicide treatments was positive, however, there was no difference observed in MoC values ($P \geq 0.05$), indicating that none of the treatments provided an economic advantage relative to each other (Table 2 & Table A1). Treatment 10 (Foschek, 5 L/ha) applied at ear emergence and flowering, exhibited the highest MoC of \$1800/ha, indicating robust economic performance. This result can likely be attributed to its lower cost per litre (\$12.3/L) and minimal seed head bleaching, likely influenced by the mode of action of phosphorous acid. In contrast, treatments such as Treatment 7 (Ridomil[®] Gold MZ WG, 2 kg/ha) and Treatment 13 (Gem[®], 750 mL/ha), applied twice at ear emergence and flowering, showed lower MoC values of \$546/ha and \$677/ha, respectively. Overall, treatments with higher fungicide application costs did not consistently yield higher MoC, underscoring the importance of selecting cost-effective fungicide strategies based on disease pressure and timing.

Table 1. Mean cocksfoot downy mildew pathogen symptoms on leaves, stems and seed heads as well as leaf greenness per tiller recorded on the 10th January 2024, along with mean visual estimate scores of greenness and overall disease (all fungal and oomycete diseases) recorded on the 12th January 2024, in cocksfoot (*Dactylis glomerata*) (cv. Savvy) plots treated with 15 different fungicide treatments. The trial was conducted near Methven during the 2023-24 season. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

Trt	Fungicide names**, rates (L/ha) and timing				Mean downy mildew leaf symptoms per tiller (0-100%)	Mean downy mildew stem symptoms per tiller (0-100%)	Mean seed head bleaching per tiller (0-100%)	Mean leaf greenness per tiller (0-100%)	Mean estimated disease score (0-100%)	Mean estimated greenness score (0-100%)
	2 nd Growth Reg (GS 33) (3 November 2023)	Ear Emergence (GS 59) (1 December 2023)	Flowering (GS 65) (14 December 2023)	Flowering + 14 days (GS 71-79) (28 December 2023)						
1	Untreated	-	-	-	84	30	45	38	67	37
2	Opus® (1 L/ha) + AMISTAR® (0.75 L/ha)	Proline® (0.8 L/ha) + SEGURIS®Flexi (0.6 L/ha)	Proline® (0.8 L/ha) + SEGURIS®Flexi (0.6 L/ha)		52	19	27	42	50	52
3	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)			30	7	15	64	25	82
4		Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)		43	9	22	50	25	80
5	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)		34	7	16	61	15	90
6			Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)	52	17	24	42	35	65
7		Ridomil®WG (2 kg/ha)	Ridomil®WG (2 kg/ha)		55	15	40	37	35	67
8		Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)		32	10	15	62	22	77
9			Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	40	13	26	53	35	70
10		Foschek® (5 L/ha)	Foschek® (5 L/ha)		49	5	16	44	25	75
11		Curfew® (350 g/ha) + Dithane™ (210 g/ha)	Curfew® (350 g/ha) + Dithane™ (210 g/ha)		47	16	23	46	47	58
12		Captan 600 Flo (4 L/ha)	Captan 600 Flo (4 L/ha)		37	10	20	57	25	77
13		Gem®Fungicide (750 mL/ha)	Gem®Fungicide (750 mL/ha)		45	20	24	50	37	60
14		Sovrin® Flo (360 mL/ha)	Sovrin® Flo (360 mL/ha)		58	18	25	36	35	67
15		FARF2401 Hasten™ (0.5 L/100 L)	FARF2401 Hasten™ (0.5 L/100 L)		37	8	18	56	30	72
16		FARF2402 (149 g/ha)	FARF2402 (149 g/ha)		55	16	26	37	45	57

	Plot value range	0-100	0-80	0-100	0-100	10-80	30-90
	LSD ($P \leq 0.05$)	17	8	10	18	9	9
	<i>P</i> value	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$	$P \leq 0.001$
	CV (%)	72	117	85	76	41	20

* AMISTAR® (a.i. 250 g/L azoxystrobin, Group 11 Fungicide); Captan 600 Flo (a.i. 600 g/L captan, Group M4 Fungicide); Curfew® (a.i. 450 g/kg cymoxanil, Group 27 Fungicide); Dithane™ Rainshield™ Neo Tec™ (a.i. 750 g/ka mancozeb, Group M3 Fungicide); FARF2401 (coded product); FARF2402 (coded product); Foschek® (a.i. 400 g/L phosphorous acid, Group P07 Fungicide); Gem® Fungicide (a.i. 500 g/L fluazinam, Group 29 Fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 Fungicide); Phoenix® Fungicide (a.i. 500 g/L folpet, Group M4 Fungicide); Proline® (a.i. 250 g/L prothioconazole, Group 3 Fungicide); Ridomil® Gold MZ WG (a.i. 40 g/kg metalaxyl-M (mefenoxam) + 640 g/kg mancozeb, Group 4 Fungicide + Group M3 Fungicide); SEGURIS® Flexi (a.i. 125 g/L isopyrazam, Group 7 Fungicide); Sovrin® Flo (a.i. 500 g/L dimethomorph, Group 40 Fungicide).

Note: Treatments 3-16 were applied in addition to standard fungicide programme applied in treatment 2 i.e. 1.5 L/ha Phoenix® applied at 2nd growth regulator timing was also applied with 1 L/ha Opus® and AMISTAR® (0.75 L/ha).

Table 2. Machine dressed seed yield, dressing loss and margin-over-cost (MoC) from cocksfoot (*Dactylis glomerata*) (cv. Savvy) plots treated with 15 different fungicide treatments in a trial conducted near Methven during the 2023-24 season. Cells highlighted yellow show the top statistical group (most effective treatments) based on least significant difference (LSD) ($P \leq 0.05$) for each presented variable.

Trt	Fungicide names**, rates (L/ha) and timing				Machine dressed seed yield (kg/ha)	Dressing loss (%)	MoC (\$/ha)	
	2 nd Growth Reg (GS 33) (3 rd November 2023)	Ear Emergence (GS 59) (1 st December 2023)	Flowering (GS 65) (14 th December 2023)	Flowering + 14 days (GS 71-79) (28 th December 2023)				
1	Untreated	-	-	-	911	25	-	
2	Opus® (1 L/ha) + AMISTAR® (0.75 L/ha)	Proline® (0.8 L/ha) + SEGURIS® Flexi (0.6 L/ha)	Proline® (0.8 L/ha) + SEGURIS® Flexi (0.6 L/ha)		1260	18	1391	
3	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)			1295	17	1429	
4		Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)		1244	19	1161	
5	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)		1351	19	1650	
6			Phoenix® (1.5 L/ha)	Phoenix® (1.5 L/ha)	1279	19	1346	
7		Ridomil®WG (2 kg/ha)	Ridomil®WG (2 kg/ha)		1139	18	546	
8		Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)		1362	15	1630	
9			Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	Phoenix® (1.5 L/ha) + Ridomil®WG (2 kg/ha)	1336	17	1494	
10		Foschek® (5 L/ha)	Foschek® (5 L/ha)		1372	16	1800	
11		Curfew® (350 g/ha) + Dithane™ (210 g/ha)	Curfew® (350 g/ha) + Dithane™ (210 g/ha)		1242	19	1207	
12		Captan 600 Flo (4 L/ha)	Captan 600 Flo (4 L/ha)		1281	18	1283	
13		Gem®Fungicide (750 mL/ha)	Gem®Fungicide (750 mL/ha)		1154	18	677	
14		Sovrin® Flo (360 mL/ha)	Sovrin® Flo (360 mL/ha)		1201	20	982	
15		FARF2401 Hasten™ (0.5 L/100 L)	FARF2401 Hasten™ (0.5 L/100 L)		1188	18	Not Available	
16		FARF2402 (149 g/ha)	FARF2402 (149 g/ha)		1238	17	Not Available	
					Plot value range	790-1554	11-35	-244-2891
					LSD ($P \leq 0.05$)	167	NS	NS
					P value	$P \leq 0.001$	0.54	0.23
					CV (%)	12	23	64

NS = No significant difference.

* AMISTAR® (a.i. 250 g/L azoxystrobin, Group 11 Fungicide); Captan 600 Flo (a.i. 600 g/L captan, Group M4 Fungicide); Curfew® (a.i. 450 g/kg cymoxanil, Group 27 Fungicide); Dithane™ Rainshield™ Neo Tec™ (a.i. 750 g/ka mancozeb, Group M3 Fungicide); FARF2401 (coded product); FARF2402 (coded product); Foschek® (a.i. 400 g/L phosphorous acid, Group P07 Fungicide); Gem® Fungicide (a.i. 500 g/L fluazinam, Group 29 Fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 Fungicide); Phoenix® Fungicide (a.i. 500 g/L folpet, Group M4 Fungicide); Proline® (a.i. 250 g/L prothioconazole, Group 3 Fungicide); Ridomil® Gold MZ WG (a.i. 40 g/kg metalaxyl-M (mefenoxam) + 640 g/kg mancozeb, Group 4 Fungicide + Group M3 Fungicide); SEGURIS® Flexi (a.i. 125 g/L isopyrazam, Group 7 Fungicide); Sovrin® Flo (a.i. 500 g/L dimethomorph, Group 40 Fungicide). Note: Treatments 3-16 were applied in addition to standard fungicide programme applied in treatment 2 i.e. 1.5 L/ha Phoenix® applied at GS 33 was also applied with 1 L/ha Opus® and AMISTAR® (0.75 L/ha).

Summary

Downy mildew pressure in this trial was moderate compared to higher levels observed in the 2021-22 season and lower levels in 2022-23. This variability was influenced by wet, cool conditions during early crop development, which favoured disease onset, followed by dry, hot weather later in the season that reduced infection risk. Fungicide treatments showed varying efficacy, with Phoenix[®] (folpet, Group M4) and Foschek[®] (phosphorous acid, Group P07) reducing disease symptoms and seed head bleaching, while treatments like Ridomil[®] Gold MZ WG, Gem[®] and Curfew[®] were less effective. Economic analysis revealed no significant differences in margin-over-cost (MoC) among treatments. These findings underscore the need for targeted fungicide selection and precise application timing to manage cocksfoot downy mildew efficiently.

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Appendix

Table A1: Cost per hectare per chemical (\$/ha Chem), cost per application (\$/app), cost per hectare (\$/ha) and margin-over-fungicide cost (MoC) for 15 different fungicide treatments applied to control cocksfoot downy mildew in a trial conducted in a cocksfoot seed crop (cv. Savvy) near Methven during the 2023-24 season.

Tr t	Fungicide names, rates (L/ha) and timing				\$/ha Chem	\$/app**	Cost/ha (\$/ha)	MoC *, *** (\$/ha)
	2 nd Growth Reg (GS 33) (3 November 2023)	Ear Emergence (GS 59) (1 December 2023)	Flowering (GS 65) (14 December 2023)	Flowering + 14 days (GS 71-79) (28 December 2024)				
1	Untreated	-	-	-	-	-	-	-
2	Opus [®] (1 L/ha) + AMISTAR [®] (0.75 L/ha)	Proline [®] (0.8 L/ha) + SEGURIS [®] Flexi (0.6 L/ha)	Proline [®] (0.8 L/ha) + SEGURIS [®] Flexi (0.6 L/ha)		352	90	442	1391
3	Phoenix [®] (1.5 L/ha)	Phoenix [®] (1.5 L/ha)			89	60	149	1429
4		Phoenix [®] (1.5 L/ha)	Phoenix [®] (1.5 L/ha)		89	60	149	1161
5	Phoenix [®] (1.5 L/ha)	Phoenix [®] (1.5 L/ha)	Phoenix [®] (1.5 L/ha)		133	90	223	1650
6			Phoenix [®] (1.5 L/ha)	Phoenix [®] (1.5 L/ha)	89	60	149	1346
7		Ridomil [®] WG (2 kg/ha)	Ridomil [®] WG (2 kg/ha)		152	60	212	546
8		Phoenix [®] (1.5 L/ha) + Ridomil [®] WG (2 kg/ha)	Phoenix [®] (1.5 L/ha) + Ridomil [®] WG (2 kg/ha)		240	60	300	1630
9			Phoenix [®] (1.5 L/ha) + Ridomil [®] WG (2 kg/ha)	Phoenix [®] (1.5 L/ha) + Ridomil [®] WG (2 kg/ha)	240	60	300	1494
10		Foschek [®] (5 L/ha)	Foschek [®] (5 L/ha)		123	60	183	1800
11		Curfew [®] (350 g/ha) + Dithane [™] (210 g/ha)	Curfew [®] (350 g/ha) + Dithane [™] (210 g/ha)		30	60	90	1207
12		Captan 600 Flo (4 L/ha)	Captan 600 Flo (4 L/ha)		163	60	223	1283
13		Gem [®] Fungicide (750 mL/ha)	Gem [®] Fungicide (750 mL/ha)		100	60	160	677
14		Sovrin [®] Flo (360 mL/ha)	Sovrin [®] Flo (360 mL/ha)		42	60	102	982
15		FARF2401 Hasten [™] (0.5 L/100 L)	FARF2401 Hasten [™] (0.5 L/100 L)		167	60	227	Not Available
16		FARF2402 (149 g/ha)	FARF2402 (149 g/ha)		77	60	137	Not Available
							LSD (P≤0.05)	NS
							P value	0.23

Note: Treatments 3-16 were applied in addition to standard fungicide programme applied in treatment 2 i.e. 1.5 L/ha Phoenix[®] applied at GS 33 was also applied with 1 L/ha Opus[®] and AMISTAR[®] (0.75 L/ha).

* MoC for treatments were calculated based on product price per litre or gram with treatments 3-16 including the cost the standard fungicide programme applied in treatment 2 based on: AMISTAR[®] (a.i. 250 g/L azoxystrobin, Group 11 Fungicide, \$49.7/L); Captan 600 Flo (a.i. 600 g/L captan, Group M4 Fungicide, \$20.3/L); Curfew[®] (a.i. 450 g/kg cymoxanil, Group 27 Fungicide,

\$0.031/g); Dithane™ Rainshield™ Neo Tec™ (a.i. 750 g/ka mancozeb, Group M3 Fungicide, \$0.018/g); FARF2401 (coded product, price not available); FARF2402 (coded product, price not available); Foschek® (a.i. 400 g/L phosphorous acid, Group P07 Fungicide, \$12.3/L); Gem® Fungicide (a.i. 500 g/L fluazinam, Group 29 Fungicide, \$66.5/L); Opus® (a.i. 125 g/L epoxiconazole, Group 3 Fungicide, \$35.3/L); Phoenix® Fungicide (a.i. 500 g/L folpet, Group M4 Fungicide, \$29.5/L); Proline® (a.i. 250 g/L prothioconazole, Group 3 Fungicide, \$84.9/L); Ridomil® Gold MZ WG (a.i. 40 g/kg metalaxyl-M (mefenoxam) + 640 g/kg mancozeb, Group 4 Fungicide + Group M3 Fungicide, \$0.037/g); SEGURIS® Flexi (a.i. 125 g/L isopyrazam, Group 7 Fungicide, \$119.5/L); Sovrin® Flo (a.i. 500 g/L dimethomorph, Group 40 Fungicide, \$58.7/L).

** Price per application is based on standard FAR operating costs

*** MoC, margin-over-fungicide cost was calculated based on average cocksfoot seed price at harvest of \$5.25 per kg (effective May 2024).

Herbicides to control chitted seed in tall fescue seed crops

Project code	H19-05-03
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	SIRC
Acknowledgements	NZ Arable (trial operator)

Key points

- 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.
- Based on visual seedling counts, herbicide treatments utilising pre-emergence herbicides such as Sakura® were effective at controlling volunteer grass seedlings, with or without post-emergence herbicides.
- 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 to 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	Pre-emergence 21/2/2023	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 dates were different 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, numbers would have been negligible 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 (Continental-type are more winter-hardy, while Mediterranean-type 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 had no 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. Interestingly, 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.

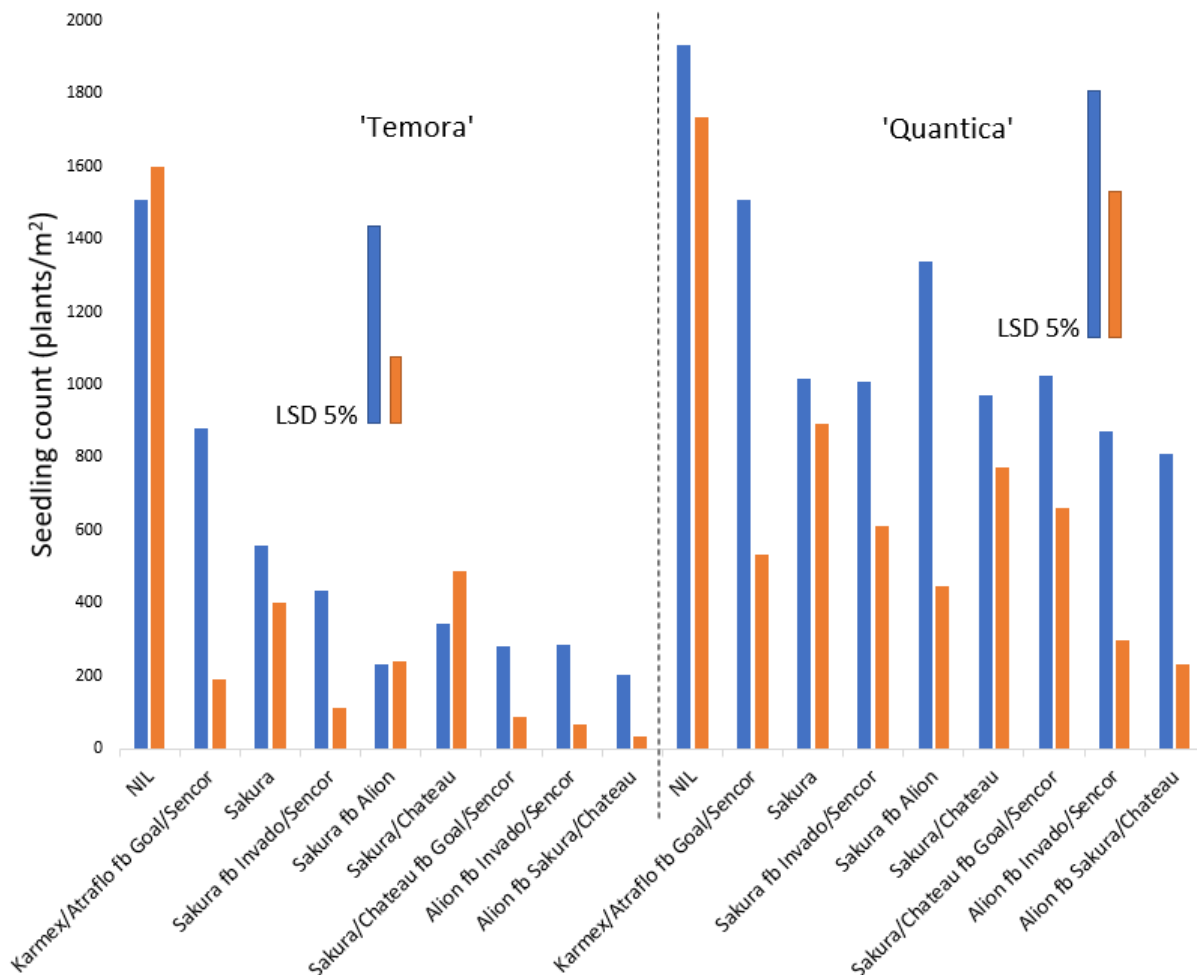


Figure 2: Visual image of the tall fescue herbicide trial at Lincoln, Canterbury, taken on 24/5/2023. The slightly lighter plots correspond to the plots containing the 'Temora' cultivar, but no treatment differences could be detected. (Note: this trial had no buffer plots.)



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
	F Pr.	0.823	0.144	0.116	
	cv%	5.2	6.9	6.1	
	L.S.D. 5%	275	219	283	

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 tall fescue crop health, seed head numbers or seed yield.

References

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Appendix 2 – 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
F Pr.	0.001	0.041
cv%	23.9	15.9
L.S.D. 5%	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
	F Pr.	<0.001	<0.001
	cv%	11.3	21.0
	L.S.D. 5%	186	397

