RESEARCH RESULTS 2019/2020

Preface

The Seed industry Research Centre is a partnership between the Foundation for Arable Research (FAR) and major seed companies, farmer and research organisations. Since its creation in July 2017, it has incorporated new partners and has continued to grow, allowing for greater investment into education through scholarships and supporting research positions within partner organisations.

SIRC receives funding from grower levies through FAR, a seed industry levy from partner companies, contributions from research organisations and universities, and government funding through participation in MBIE and MPI SFFF projects.

The body of work in this report is the result of the cooperation between FAR staff, seed company specialists, researchers from other organisations and from growers, who help run trials on their farms and host multiple field days across the regions. We are very grateful to all of those organisations and individuals.

This booklet presents the results of the main projects conducted through SIRC in the 2019-20 season, some of which bring together multiple years of data from ongoing projects.

SIRC welcomes all feedback with respect to the content and layout of this booklet which we hope will provide meaningful information for our industry.

Ivan Lawrie
General Manager
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Managing take-all disease in ryegrass seed crops with Trichoderma

Project code H19-01

Duration Year 1 of 4

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Location Darfield, Mid Canterbury (GPS: 49° 30' 31.65 S; 172° 3' 14.02 E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Hamish Redfern (trial host), Lincoln University Seed Research Centre/BioProtection Research Centre, NZ Arable (trial operators), Agrimm Technologies Ltd (Lincoln), Alice Keir, Justin Inwood and Murray Kelly (PGGWrightson Seeds)

Key points

- The root rhizosphere of ryegrass, either sown with *Trichoderma*-treated seed or established ryegrass with prills direct drilled, was colonized by the *Trichoderma.*
- Root damage from take-all was significantly reduced to less than 50% of the untreated control by the *Trichoderma* treatments.
- Treatment had no significant effect on seed yield.

Background

A number of growers with irrigation have had re-occurring issues of light seed and large dressing losses in perennial ryegrass seed crops. Diagnostic assessments on some of these fields have shown an association with the root-rot pathogen *Gaeumannomyces graminis* var *tritici* (*Ggt*) which causes take-all in grasses and cereals. A pot study by Kandula *et al*. (2014) demonstrated the potential for suppression of *Ggt* by *Trichoderma* spp. and a preliminary pot trial also showed improved seed production of prairie grass grown with *Trichoderma* in soil with *Ggt* (Umar *et al*. 2019). The objectives of this study were to field-test a pasture bio-inoculant (PBI) to determine if: (i) *Trichoderma* seed treatment could reduce light seed and increase seed yield of a 1st year perennial ryegrass crop and (ii) to determine if seed yield and seed quality of a 2nd year ryegrass seed crop, which produced a crop with light seed in Year 1, could be improved with *Trichoderma* prills.

Methods

There were two separate trials established in two nearby growers' fields.

1. 2nd year perennial ryegrass cultivar Request. Prills (15 kg/ha) containing a mixture of four *Trichoderma atroviride* isolates (LU132, LU140, LU584, LU633) were drilled with a John Deere 750a drill at 2.5 cm deep as a +/- comparison in early April, 2019. Plots were 250 m long and 24 m wide with 2 replicates. At harvest, 4 mown strips (8.6 m wide) by the plot length were harvested for yield assessment (0.22 ha/plot).
2. A new sowing with cv. PG One50, a late flowering perennial ryegrass with *Trichoderma atroviride* isolates (LU132, LU140, LU584, LU633) applied as a seed treatment by Agrimm Technologies, with a seed sowing rate of 10 kg ryegrass bare seed weight/ha, with 2 replicates. The crop was drilled in early April, 2019. Plots were 400 m long and 24 m wide. At harvest, two windrowed strips (8.6 m wide) by the plot length were harvested for yield (0.34 ha/plot).

The trials were under the grower's management for all inputs used in the field including irrigation, nitrogen, weed and disease control and plant growth regulator input.

Plots were arbitrarily divided into four blocks with six replicates in each block. Two soil cores (0-10 cm) were collected from each replicate and pooled. *Trichoderma* enumeration was on selective medium (TSM). A 10 g sub-sample of soil was used for dilution plating, 20 root bits for endophytic colonisation and 20 root-bits for take-all disease scoring (roots were assessed microscopically for the presence of *Ggt* runner hyphae and/or hyphodia). Root disease severity was scored based on root deterioration due to rotting and pathogen colonisation using a 0 (clean) to 5 (heavily infected) scale. Growth analysis samples (0.4 sq.m area/plot) were collected on 25 November and 23 December, 2019, from 2nd year and 1st year trials, respectively, to count the number of reproductive and vegetative tillers and crop dry weight.

Ryegrass cv. Request was mown on the 13 January and combine harvested on the 20 January, 2020. Cv. PG 150 was windrowed on the 10 February and combine harvested 17 February, 2020. Harvesting was done by the grower, and the yields were assessed using a weigh wagon. A sub-sample of seed was sieved and the remaining seed separated into three fractions using a Dakota air column separator. The seed loss and seed thousand seed weight (TSW) of each fraction was recorded. Statistical analysis used GenStat v19.

Results and Discussion

Trichoderma colonisation (both colony forming units and endophytic colonisation) was good in both the fields (Tables 1 and 2). Take-all disease severity score in the untreated control increased from 1.5 in August, 2019, to 3.0 (out of 5.0 for dead) by December in the 'Request' compared to the prill treatment that was less than half this score (Table 1). In cv. PG One50, the untreated control averaged 2.1 (out of 5) at both times (Table 2), but was less than half this score in the area sown with *Trichoderma* seed treatment.

Reproductive and vegetative tiller density was higher in the *Trichoderma* prill treatments compared with the control (Table 3), suggesting the reduced *Ggt* damage to roots was associated with better above ground growth.

Table 1. Colonisation of a *Trichoderma* pasture bio-inoculant (PBI) four months after application (prill formulation @ 15kg/ha) and its effect on root disease severity score (Root score) of perennial ryegrass grown in a *Ggt*-infected field (Greendale 2nd year cv. Request).

Treatments	Colony forming units (CFU) / g rhizosphere soil	Root endophytic colonisation (%)	Root score August 2019	Root score December 2019
Control	260	7.5	1.5	3.0
PBI	12840*	28.8*	0.6*	1.3*
LSD (p=0.05)	4618	5.5	0.5	0.3

* indicates significant difference from control in the same column.

Table 2. Colonisation of a *Trichoderma* pasture bio-inoculant (PBI drilled as seed-coat) four months after sowing and its effect on root disease severity score of perennial ryegrass grown in a *Ggt*-infected field (Greendale 1st year cv. PG One50).

Treatments	Colony forming units (CFU) / g rhizosphere soil	Root endophytic colonisation (%)	Root score August 2019	Root score December 2019
Control	390	8.8	2.1	2.21
PBI	15470*	54.6*	1.0*	1.13*
LSD (5%)	4513	6.4	0.4	0.40

* indicates significant difference from control in the same column.

Reproductive and vegetative tiller density was higher in the *Trichoderma* prill treatments compared with the control (Table 3), suggesting the reduced *Ggt* damage to roots was associated with better above ground growth.

Table 3. Reproductive and vegetative tiller number and crop dry weight of perennial ryegrass grown in a *Ggt*-infected field (Greendale 2nd year cv. Request) sampled on 25 November, 2019.

Treatments	Reproductive tiller number/m^2	Vegetative tiller (number/m^2)	Crop DW (g/m^2)
Control	1060	4760	563
PBI	1430*	6770*	645*
LSD (p=0.05)	261	1625	44

* indicates significant difference from control in the same column.

There was no difference in seed yield (LSD p=0.1) for either the prills or the seed coat treatment in comparison with the controls (nil = 2090 kg/ha; treated = 2,180 kg/ha). There was also no difference in TSW (Table 4).

Table 4. Field dressed (FD) and machine dressed (MD) seed yield and thousand seed weight (TSW) for 2nd year ryegrass cv. Request at Greendale 2019/20 following the application of *Trichoderma* prills and in the untreated control.

	Control	Prill	LSD (p=0.1)	F.prob
FD (kg/ha)	1130	1390	483	0.187
MD (kg/ha)	1030	1240	542	0.203
TSW (g)	2.23	2.27	0.33	0.397

Summary

Trichoderma prills were drilled into a second-year ryegrass seed crop, while a new crop was also sown with *Trichoderma* as a seed coat treatment. The trials were established as large plots suitable for evaluation by weigh wagon, but were limited to two replicates and two treatments (nil versus treated). An examination of colonizing of the rhizosphere showed that the *Trichoderma* was present in high numbers compared to the untreated, and root endophytic colonization occurred on 55% of the seed coat treated and 29% of the roots with prill application. However, seed yield was not significantly affected by seed treatments.

For an initial field trial with two replicates the trend in the results have encouraged us to undertake field trials in the 2020-21 growing season. Repeat trials on more sites and with more replicates will be needed to decide if the reductions in *Ggt* translate into seed yield benefits.

References

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Ergot control in ryegrass

Project code H19-02

Duration Year 2 of 2

Author Phil Rolston

Location Tinwald, Mid Canterbury (GPS: 43° 54'22.85" S; 171° 39'58.99" E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Peter Hampton, Tinwald (trial host), NZ Arable (trial operator), Lia Willis, (Barenbrug), Jana Monk (AsureQuality)

Key points

- Common fungicides applied for stem rust control, and applied at similar timings, reduced ergot levels by 50 to 100 %.
- Adding Lorsban® insecticide made no difference to ergot levels, suggesting insect transmission was not important epidemiologically.
- Comet®+Proline® (0.8 + 0.8 L/ha) applied at the appearance of first flowers and again nine days later resulted in nil ergots detected.

Background

Export of New Zealand ryegrass seed to some markets (e.g. South Africa) is possible only if the seed is ergot free. Primary infection of ryegrass by *Claviceps spp.*, the cause of ergot, occurs when flowers are open for pollination. Secondary infection occurs within seed heads, possibly facilitated by flies (Dung *et al*. 2019). Two species of *Claviceps* are now recognized as being in New Zealand; *C. purpurea* and *C. humidiphila*. Visually it is not possible to distinguish between the two species.

Ergot is a problem in mid and late flowering ryegrass (in contrast to blind seed being more severe in early flowering ryegrass). In Oregon, United States, the best control of ergot in ryegrass has been from using pyraclostrobin (Comet® in New Zealand), azoxystrobin (Amistar®), flusilazole (MegaStar™) and azoxystrobin mixed with propiconazole (Amistar® + Tilt®) (Dung *et al*. 2019). In a New Zealand trial in 2018-19 (Rolston *et al*. 2019), treatments with the lowest ergot numbers per head received either Comet® or Amistar® as a split fungicide application at 1st flowering and 10 days later. The 2019-20 trial included an insecticide treatment to determine if insect spread was occurring and repeated some of the more effective fungicide treatments from the previous year.

Methods

A trial was established in a seed crop of perennial ryegrass cultivar Governor, sown with 150 kg/ha Cropmaster 15 in Tinwald, Mid Canterbury in 22 March 2019. All inputs except fungicides were managed by the grower. Spring nitrogen (N) fertiliser applications were: 150 kg/ha ammonium sulphate (20th August), 180 kg/ha urea (11th October) and 200 kg/ha urea (7th November). Plant growth promoter Optimus® (a.i. 175 g/L trinexapac-ethyl) was applied at 1.6 L/ha on 4 November with no fungicide.

Plots were 3.2 m x 7 m, with 4 replicates in a randomized block design. Fungicide treatments were applied on 10 December (T1, the start of flowering) and on 19 (T2) and 30 December 2019 (T3) (Table 1). The treatments included the insecticide Lorsban® (active ingredient (a.i.) 500 g/L chlorpyrifos) and the fungicides carbendazim (a.i. 500 g /kg carbendazim), Comet® (a.i. 250 g/L pyraclostrobin), Megastar™ (a.i. 200 g/kg flusilazole), Proline® (a.i. 250 g/L prothioconazole), Prosaro® (125 g/L prothioconazole and 125 g/L tebuconazole) and Seguris Flexi® (a.i. 125 g/L isopyrazam).

Seed heads were sampled on 21 January 2020, taking four grab samples that were bulked to give 80+ seedheads/plot. The number of ergots on 80 heads (equivalent to 1,500 spikelets) were counted manually. Plots were windrowed on 22 January and combine harvested on 31 January. Ergots were collected and the species of ergots was identified with a DNA probe by the AsureQuality Seed Laboratory, Lincoln.

Results and Discussion

The causal species of ergot present in the Tinwald trial was *Claviceps purpurea*. The level of infection was low, 3-5 spikelets per 80 seed heads or 0.3% of spikelets, in the no fungicide plots, compared with 1.8% of spikelets in 2018-19. The fungicide treatments reduced ergot incidence by between 50 and 100%, but there were no significant differences in control between fungicide treatments (range: 0 to 1.5 ergots/1500 spikelets). Treatments 6 and 9, which both contained Comet® + Proline® (0.8 + 0.8 L/ha) either with or without Lorsban® applied at first flowering and nine days later, produced a crop in which ergot could not be detected. In the previous year's trial, this fungicide treatment reduced ergot sclerotia counts in spikelets by 74%. Lorsban® made no difference to detection rates, suggesting there was no insect transmission of ergot (Table 1).

Summary

Fungicides commonly used for stem rust control in ryegrass reduced the incidence of ergots by between 50 and 100%. Over two trials the combination of Comet® + Proline® (0.8+0.8 L/ha) has given control levels of between 74 and 100%, although other stem rust fungicide combinations were also effective.

References

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Table 1. Fungicide and insecticide treatments, rates and timing of application, machine dressed seed yield and incidence of ergots in a seed crop of perennial ryegrass cultivar Governor, grown in Tinwald, Mid Canterbury in the 2019-20 growing season.

Treatment number	Pesticide treatment date and rate			Seed yield (kg/ha)		Ergots/80 seed heads	
	10 December 2019 (T1)	19 December 2019 (T2)	30 December 2019 (T3)				
1	nil	nil		2440	a[1]	3.0	b[1]
2	Lorsban® 50EC (0.4 L/ha)	Lorsban® 50EC (0.4 L/ha)	Lorsban® 50 ED (0.4 L/ha)	2490	a	5.0	b
3	Comet® (0.8 L/ha)	Comet® (0.8 L/ha)		2240	a	0.3	a
4	Proline® (0.8 L/ha)	Proline® (0.8 L/ha)		2710	a	0.5	a
5	Prosaro® (1.0 L/ha)	Prosaro® (1.0 L/ha)		2380	a	1.0	a
6	Comet®+ Proline® (0.8 + 0.8 L/ha)	Comet®+ Proline® (0.8 + 0.8 L/ha)		2420	a	0	a
7	Seguris® Flexi + Proline® (0.6 + 0.8 L/ha)	Seguris® Flexi + Proline® (0.6 + 0.8 L/ha)		2700	a	1.0	a
8	Comet® + Proline®+ Carbendazim (0.8 + 0.8 + 0.5 L/ha)	Comet® + Proline®+ Carbendazim (0.8 + 0.8 + 0.5 L/ha)	Carbendazim (0.5 L/ha)	2610	a	0.5	a
9	Comet® + Proline® + Lorsban® (0.8 + 0.8 + 0.4 L/ha)	Comet® + Proline® + Lorsban® (0.8 + 0.8 + 0.4 L/ha)	Lorsban® 50 ED (0.4 L/ha)	2460	a	0	a
10	MegaStar™ + Proline (80 g/ha + 0.8 L/ha)	MegaStar™ + Proline (80 g/ha + 0.8 L/ha)		2430	a	1.3	a
11	Proline® (0.8 L/ha)	Proline® (0.8 L/ha)	Proline® (0.8 L/ha)	2590	a	1.5	a
			LSD (p=0.05)	NS		2.5	
			P value	NS		0.01	

Note: Yellow indicates the treatments that produced the lowest incidence of seed head with ergot.
[1]Numbers followed by the same letter are not statistically different at LSD (p=0.05)

Stem rust control in turf ryegrass seed crops and development of a prediction model

Project code H19-03

Duration Year 2 of 4

Authors Nick Davies (AgResearch), Richard Chynoweth and Phil Rolston (FAR)

Location Chertsey FAR site and Greendale, Mid Canterbury (Greendale GPS: 43 28’ 45.89” S, 172 04’ 19.04” E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Graeme Marshall, Greendale (trial host), NZ Arable (trial operator)

Key points

- The use of fungicides increased seed yields by between 45 and 115 % under irrigation and by 21% in dryland conditions.
- An early fungicide at Growth Stage 32 increased seed yield under irrigation by between 9 and 14 %. There was also a trend for fungicide treatments applied at GS 32 to increase seed yields in dryland conditions.
- Use of a modified Oregon stem-rust model removed the late application (at flowering) of fungicide without seed yield loss in Canterbury.

Background

Stem rust disease, caused by *Puccinia graminae*, can result in seed yield losses of 20 to 50%. Turf ryegrass and overseas forage ryegrasses for re-multiplication are particularly susceptible to damage. While there are good fungicide options for managing stem rust, these need to be used before the disease becomes symptomatic as the initial infection and damage to vascular tissue occurs under the leaf sheath and is hidden from sight. Research in Oregon, USA, has shown that leaf wetness at sunrise and warm temperatures are major drivers of the disease (Pfender 2003). A prediction model has been developed in Oregon and has provided growers with an early warning of conditions that favour the disease. The model is written in what is now a redundant software language and needed to be modified to run in New Zealand, including changes for it to recognize southern latitude co-ordinates to predict sunrise, linked to leaf wetness.

This report provides an update from Year 2 of a project to validate the Oregon model for New Zealand conditions. Validation of the model requires field trials with nil and typical fungicide treatments to determine the onset of stem rust and help predict when follow up fungicide applications may be required.

Methods

Two trials were established to collect information on the onset of stem rust and the effect of fungicide applications in ryegrass crops in Canterbury during the 2019-20 growing season. The Chertsey trial was also used to assess the ability of the stem rust model to accurately forecast the need for late season fungicide applications.

Greendale trial. The trial evaluated five fungicide treatments applied to an irrigated field of ‘AllSport 4’, a turf perennial ryegrass that was sown in autumn, 2019. The paddock and all inputs except fungicides and plant growth regulator (PGR) were managed by the grower. The plots were 11 x 3.3 m with treatments replicated four times in a randomized block design. Moddus® Evo (active ingredient (a.i.) 250 g/L trinexapac ethyl) PGR was applied at 1.6 L/ha (400 g ai/ha) on 7 November 2019, without fungicide additives. The fungicides evaluated were Amistar®SC (a.i. 250 g/L azoxystrobin), Proline® (a.i. 250 g/L prothioconazole) and Seguris Flexi® (a.i. 125 g/L isopyrazam). Applications were made at Growth Stage GS 32 (20 November), head emergence GS 50 (6 December) and at flowering GS 58 (20 December). Treatments are shown in Table 1. Sampling to assess stem rust occurred four times from 11 November to 15 January. Twenty-five stems per plot (100 stems per treatment) were selected at random from four spots in each plot, and assessed for absence or presence of stem rust; lesions per stem were counted where stem rust was present. The late application dates occurred when a threshold lesion density was reached and so were sprayed on 20 December. The trial was windrowed on 25 January and combine-harvested on 3 February, 2020. The seeds were dressed to a First Generation Seed Certification Standard.

Chertsey trial. The cultivar AllSport 4 was sown on 18 April, 2019, in adjacent blocks that were either dryland or irrigated. Plots were 1.5 x 10 m with four replicates in a randomized block design. There were 10 fungicide treatments with applications at GS 32 (1 November), head emergence (10 December) and at flowering (23 December). The fungicides evaluated were Amistar®SC, Opus®(a.i. 125 g/L epoxiconazole), Proline® and Seguris Flexi® (Table 2). The decision on whether to apply the flowering time fungicide to Treatments 2 and 7 (modelled treatment) were based on reaching a threshold lesion density and on temperature and leaf wetness, recorded at 15-minute intervals with a Campbell Scientific data logger. At approximately 7 to 14-day intervals, sampling of 25 stems, selected at random from four spots in each plot, were assessed for presence and absence of stem rust and the number of lesions per stem. The dryland trial was windrowed on 7 January and combine harvested on 10 January, 2020. The irrigated trial was windrowed on 16 January and combine harvested on 22 January, 2020. The seeds were dressed to a First Generation Seed Certification Standard.

Stem rust prediction model. Managing stem rust in ryegrass is challenging as prior to the stem being fully elongated a proportion of the infection is not visible. The stem rust prediction model is a modified version of the Oregon State University stem rust model, "STEMRUST_G" (Pfender *et al*. 2014), adapted for New Zealand. The modified model uses regular measurements of canopy temperature, rain, humidity, and leaf wetness when available, in this case every 15 minutes. The key weather parameters effecting stem rust infection development are leaf wetness and temperatures for the 2-hour period after sunrise. The model uses thresholds based on observed stem rust pustule density and weather data for the application of triazoles and strobilurins derived from an experiment in Oregon. The effectiveness of the model was evaluated by having the decision for a final fungicide treatment being determined by the model (Trial 2, Treatment 7).

Results and Discussion

Greendale trial. Fungicide treatment increased seed yields by between 98 and 125 % compared with the untreated control, from 1230 to an average 2650 kg/ha (Table 1). There were no differences in seed yields between the two fungicide regimes used (Proline® with Seguris Flexi® followed by either Proline® plus Amistar®SC or Seguris Flexi®) at head emergence and flowering. By harvest, >70 % stems had stem rust lesions and were classified as infected in all treatments, but the lesion numbers at harvest were reduced by 52 to 58% by fungicide treatment (Table 1).

Chertsey trial. Under irrigation, fungicide treatment increased seed yields by 630 kg/ha (45 %) compared with the untreated control (1400 kg/ha) (Table 2). This increase was also observed in dryland conditions, but the average increase was 270 kg/ha (21 %) from the untreated control (1290 kg/ha). The seed yield was reduced by water deficit from an average of 2030 kg/ha to 1560 kg/ha with fungicide treatments (Table 2).

Under irrigation, the severity of disease (lesions/100 stems) was reduced by all fungicide treatments (Table 3). The impact of fungicide treatment on disease incidence was less conclusive, with most showing no effect on the % of stems infected by stem rust. These results suggest that fungicide application may not reduce spread of the pathogen, but may reduce expression of disease. Data for dryland conditions is not presented.

Growth stage 32 fungicide. At Greendale an application of Proline® at GS 32 at PGR timing (20 November) significantly increased seed yield by 220 kg/ha (P value = 0.039) compared with no fungicide at GS 32 (Table 4). At Chertsey, the fungicide treatments applied at GS 32 (1 November) increased seed yields by 260 kg/ha (14%) under irrigation compared with fungicide treatments starting at head emergence (10 December) (Table 4). There was also a trend for fungicide treatments applied at GS 32 (1 November) to increase seed yields in dryland conditions (p=0.081). Despite the apparent advantage afforded by GS 32 fungicide applications, several treatments not including a GS 32 spray (e.g. Treatments 4 and 5) were amongst those producing the greatest seed yield (Table 3).

Model Predictions. The decision on whether to apply the flowering time fungicide to Treatments 2 and 7 used the stem rust prediction model. Treatment 2 had not received an early fungicide application whereas Treatment 7 had received Proline® at GS 32. At the time of flowering, Treatment 7 did not receive a final fungicide application (Table 3) because the model was predicting that pustule numbers were below the threshold. In contrast, modelling in Treatment 2 triggered the application of a fungicide at flowering. This result reiterated that an early GS 32 fungicide application can suppress pathogen pressure. As seed yield in Treatment 7 was not significantly different to treatments that received an extra fungicide application at flowering, these data also identified that the stem rust model could remove the need for late fungicide applications under the right circumstances. This was consistent with the experience in Oregon, which found that the stem rust prediction model can reduce the use of late season fungicide applications without impacting on seed yield if the crop has received good early management and depending on seasonal disease pressure (Pfender *et al*. 2015). The development of stem rust lesions over time for a treatment using the stem rust prediction model compared with that in an untreated control is shown in Figure 1.

The next steps in this project are to develop the stem rust model specifically for New Zealand and develop the software from research code into a useable computer program. A better understanding of how stem rust epidemics develop in Canterbury along with when and what fungicide applications are optimal is needed and can be obtained through future trials. An easy, fast standardised protocol for field estimates of pustule densities needs to be developed to increase the number of locations where the model can be tested and used. Ultimately, a network of monitor weather stations and farms around the region being regularly sampled and the model predicting latent disease levels would be advantageous in determining risk.

Summary

A modified Oregon stem rust prediction model was evaluated. The model uses leaf wetness and temperature data and measured pustule densities to predict if a threshold for fungicide application has been reached. The model saved a late fungicide (flowering GS 58) in irrigated turf ryegrass at Chertsey. Fungicides increased seed yields by 115% in irrigated ryegrass at Greendale and 45% at Chertsey.

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Table 1. Seed yield and stem rust infection at harvest of perennial ryegrass, cultivar Allsport 4, treated with five fungicide programmes and grown under irrigation near Greendale, Canterbury in the 2019-20 growing season.

Treatment number	Fungicide treatments, rates and application dates			Seed Yield (kg/ha)	Stems Infected (%)	Lesions/100 stems
	20 November (GS 32)[1]	6 December	20 December			
1	-	-	-	1230	84	1116
2	Proline® (0.4 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Amistar®SC (0.4 + 0.7 L/ha)	2770	78	517
3	-	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Amistar®SC (0.4 + 0.7 L/ha)	2640	79	495
4	Proline® (0.4 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	2750	71	580
5	-	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	2440	70	465
			LSD (p=0.05)	284	19	378
			P value	<0.001	0.35	0.003

Note: Yellow indicates the treatments that were amongst the treatments that produced the greatest seed yield.
[1]GS = growth stage.

Table 2. Seed yield of perennial ryegrass, cultivar Allsport 4, in the untreated control and following fungicide treatment (mean of nine fungicide treatments) in the dryland and irrigated blocks at Chertsey, Canterbury in the 2019-20 growing season.

Treatment	Seed yield (kg/ha)	
	Dryland	Irrigated
Untreated	1290	1400
Fungicide[1]	1560	2030
LSD (p=0.05)	125	375
Response (%)	21	45
Response (kg/ha)	270	630

Note: Yellow indicates the treatment that produced the greatest seed yield.
[1] mean of all fungicide treatments.

Table 3. Seed yield and stem rust infection at harvest of perennial ryegrass, cultivar Allsport 4, treated with five fungicide programmes and grown under irrigation near Chertsey, Canterbury in the 2019-20 growing season.

Treatment number	Fungicide treatments and rates			Seed Yield (kg/ha)	Stems Infected (%)	Lesions/100 stems
	1 November	10 December	23 December			
1	-	-	-	1400	81	1258
2	-	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Amistar®SC (0.4 + 0.7 L/ha)	1900	63	499
3	-	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	1820	79	819
4	-	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	2000	62	455
5	-	Proline® + Seguris Flexi® + Amistar®SC (0.4 + 0.6 + 0.5) L/ha	Proline® + Amistar®SC (0.4 + 0.7 L/ha)	1940	73	596
6	Proline® (0.4 L/ha)	Seguris Flexi® + Amistar®SC (0.6 + 0.5 L/ha)	Seguris Flexi® + Amistar®SC (0.6 + 0.5 L/ha)	2170	61	393
7	Proline® (0.4 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	-*	2300	50	335
8	Proline® (0.4 L/ha)	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	2040	64	400
9	Proline® (0.4 L/ha)	Proline® + Seguris Flexi® (0.4 + 0.6 L/ha)	Seguris Flexi® + Amistar®SC (0.6 + 0.5 L/ha)	2140	41	205
10	Opus® (0.5 L/ha)	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	Opus® + Amistar®SC (0.5 + 0.5 L/ha)	1950	77	645
			LSD (p=0.05)	375	25	370
			P value	0.005	0.01	<0.001

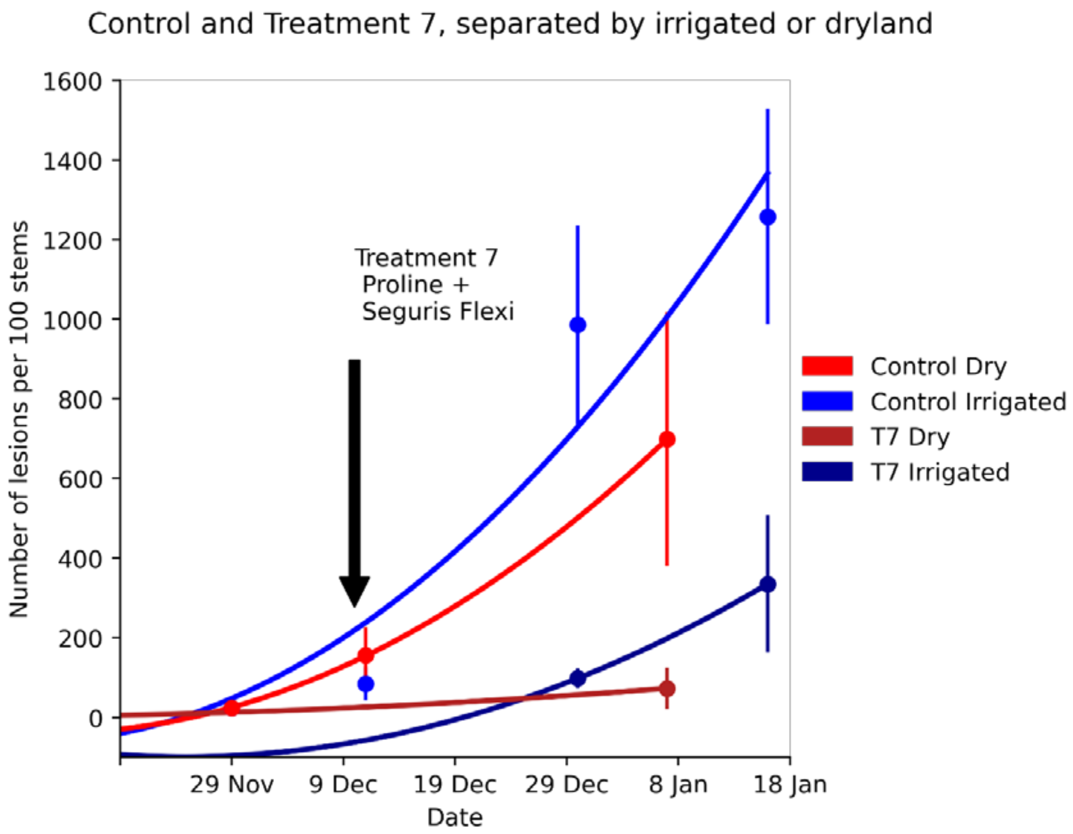
*Treatment modelled & no fungicide required

Table 4. Effect of fungicides at growth stage (GS) 32 on seed yield of perennial ryegrass, cultivar Allsport, 4 in dryland and irrigated treatments at Chertsey and at Greendale, 2019-20.

GS 32 Treatment	Seed yield (kg/ha)		
	Greendale	Chertsey Irrigated	Chertsey Dryland
Nil	2540	1900	1470
Fungicide	2760	2160	1565
LSD (p=0.05)	207	141	
LSD (p=0.1)			85
P value	0.039	0.039	0.081

Note: Yellow indicates the treatment showed the greatest seed yields (p<0.05 or p=0.10).

Figure 1. Number of lesions per 100 stems on 'AllSport 4', a turf perennial ryegrass, grown in dryland and irrigated trials at Chertsey in the 2019-20 growing season following application of fungicide (Treatment 7) or in a no fungicide control (standard deviations (bars)). The fungicide schedule was created using the modified Oregon STEMRUST_G model adapted for Canterbury. Fungicides were applied as recommended by the model defaults.



Tall fescue tolerance to herbicides with potential for ryegrass control

Project code H19-05

Duration Year 1 of 3

Authors Phil Rolston (FAR)

Location Southbridge, Mid Canterbury (GPS: 43°47' 58.58" S; 172°12' 50.90" E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Ian Lowery (trial host) Shane King (Luisetti Seeds), PastureFirst, NZ Arable (trial operator)

Key points

- Second year tall fescue had moderate to excellent tolerance to the Group H herbicide glufosinate (Buster®) and Group K1 herbicide propyzamide (Kerb™).
- Tall fescue has little tolerance to the Group B herbicide iodosulfuron (Hussar®).
- Ryegrass weed pressure was not sufficient to evaluate ryegrass control efficacy.

Background

Grass weeds in tall fescue crops can be difficult to manage. This is particularly true for volunteer ryegrass, which has a similar sized seed to tall fescue and so cannot be removed during seed dressing. The usual herbicide options in second year crops include the soil active triazine and urea group C herbicides (e.g. Atranex® WG) (active ingredient (a.i.) 900 g/L atrazine/kg) and Karmex® DF (a.i. 800 g/kg diuron), often in combination. The efficacy of both herbicides mostly relies on tall fescue having a deeper root mass than ryegrass to provide selective control. These herbicides can cause a problem in subsequent crops because of residues in soil. Their effectiveness is also variable between years depending on crop residues, soil moisture and soil type.

In Oregon, United States, a range of other herbicide mixes including the Group H herbicide glufosinate (Buster® a.i. 200 g/L glufosinate) are being evaluated for control of grass weeds in tall fescue crops (Curtis *et al*. 2019). In this trial, we evaluated crop tolerance to Buster® and two additional herbicides (Hussar® a.i. 50 g/kg iodosulfuron (Group B) and Kerb™ 500F a.i. 500 g/L propyzamide (Group K1)) used in cocksfoot for ryegrass control (2019 Annual Report).

Methods

A trial was established in the headland area of an irrigated second-year tall fescue cultivar RAD-50 crop sown in March 2018 (ex-peas) in 30 cm wide rows. Ryegrass contamination was considered too high for the trial to be included in the main seed harvest. Inputs for the trial were managed by the grower except the late winter/early spring applied herbicide treatments. The crop was sprayed with the herbicides Karmex® 900 (diuron) at 1.0 kg/ha and Atranex® WG (atrazine) at 0.4 kg/ha on the 10 May, and Foxtrot® 750 mL/ha (a.i. 69 g/litre fenoxaprop-P-ethyl) on 17 August 2019. The fertiliser inputs were 38 kg nitrogen (N)/ha as Crop 15 on 23rd May, 54 kg N/ha as Ammo 36 on 1 September and 124 kg N/ha as urea split between mid and late October. Moddus® Evo was applied as a split application of 1.0 + 1.0 L/ha on the 20 and 30 September. The fungicide Proline® (a.i. 250 g/L prothioconazole) was applied on the 24 October and Proline® + Amistar® (a.i. 250 g/L azoxystrobin) (0.5 + 0.5 L/ha) was applied on 16 November, 2019 to manage disease in the crop.

There were four experimental herbicide treatments and a nil control in the trial (Table 1). These treatments were applied on 23 August 2019, with three replicates in a randomized block design where plots were 3 x 10 m. The herbicides used were Nu-Trazine™ 900DF (a.i. 900 g/kg atrazine), Buster® (200 g/L glufosinate), Hussar® (50 g/kg iodosulfuron-methyl-sodium), Karmex®900 (900 g/kg diuron) and Kerb™500F (500 g/L propyzamide).

Crop damage was assessed on 15 November 2019 and there was not enough ryegrass to score for ryegrass control. Tall fescue seed head density was assessed from quadrats (1 m x 0.3 m) on 13

December. The plots were windrowed using a modified John Deere windrower on 24 December taking a 1.8 m wide cut from the centre of each plot. Plots were harvested with a Wintersteiger Elite Nursery Master combine on 3 January 2020. Seed was cleaned to a First Generation Seed Certification Standard.

Results and Discussion

The trial was located in a crop headland where ryegrass appeared to be more prevalent, which may have contributed to the high coefficient of variation (CV 28%) for seed yield and the large Least Significant Difference (LSD) for the trial. Nevertheless, seed yield was closely related to seed head density (R^2=0.90).

Treatment of the second-year tall fescue with iodosulfuron (Hussar®) caused severe leaf burning, resulting in a failure of seed heads to form and a 98% reduction in seed yield (Table 1). Application of the Group H herbicides, Buster® and Kerb™, resulted in similar seed yields to both the untreated control and the yield produced by treatment with Nu-Trazine™ + Karmex®, the industry's standard practice (Table 1), while the seed yield following treatment with Nu-Trazine™ + Karmex® was lower than the untreated control. The Nu-Trazine™ + Karmex® application was the second with both products as the grower had applied this combination during the autumn, resulting in a combined total application rate of 2.4 L/ha atrazine and 2.5 kg/ha diuron. The cumulative application of these herbicides may have been too high for this cultivar and follow up trials will be needed to confirm the tolerance of second-year tall fescue to Buster® and Kerb® and to verify their efficacy in controlling ryegrass in this crop.

Table 1. Seed head density and seed yield for a second-year tall fescue cultivar RAD-50 crop grown near Southbridge, Canterbury in the 2019-20 growing season following treatment with one of five herbicide treatments applied on 23 August, 2019.

Treatment number	Herbicide application[2]	Application rate (L or kg/ha)	Seed head no. (m^2)		Seed yield (kg/ha)	
1	Control	0	660	a[1]	2360	a[1]
2	Hussar®	0.2	2	c	50	c
3	Buster®	1.7	700	a	1720	ab
4	Nu-Trazine™ + Karmex®	2.0+1.5	430	b	1420	b
5	Kerb™	0.5	630	a	2190	ab
		LSD (p=0.05)	280		840	
		P value	0.002		<0.002	

Note: Yellow indicates the treatment was amongst the treatments showing the greatest seed head number or the greatest seed yields (p<0.05).

[1] Data followed by different alphabetical letters are significantly different.

[2] Trial area previously sprayed with Karmex® 900 at 1.0 kg/ha and Atranex® at 0.4 kg/ha on 10 May 2019.

Summary

The trial was a preliminary screening trial to evaluate the tolerance of tall fescue to herbicides, especially the Group H herbicide glufosinate (Buster®), used for ryegrass control in Oregon, USA. The trial confirmed this grass has tolerance to this herbicide in New Zealand as well. Similar tolerance to a Group K1 herbicide - Kerb® was observed too, but further work is required to both evaluate ryegrass control efficacy and to confirm crop safety.

References

Curtis, DW.; Roerig, KC.; Hulting, AG.; Mallory–Smith, CA.; Anderson, NP. 2019. Management of annual ryegrass contamination in tall fescue and orchard grass grown for seed. *In*: 2018 Seed Production Research at Oregon State University USDA-ARS Cooperating. Department of Crop and Soil Science Ext/CrS 160, 4/19. *Eds*: Nicole Anderson, Andrew Hulting, and Darrin Walenta. pp 5-8

Ryegrass harvest: a comparison of windrowing and cutting

Project code H19-06

Duration Year 1 of 3

Authors Phil Rolston and Richard Chynoweth (FAR)

Location Methven, Mid Canterbury (GPS: 43° 36' 21.44" S; 171° 37' 11.89" E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements John McCaw (trial host), Grasshopper, Tim May (May Brothers), NZ Arable (trial operator)

Key points

- Ryegrass seed yield was 520 kg/ha higher in plots cut with the 'Legacy' windrower compared with a traditional disc mower.
- Cutting speeds (14 kph) and area cut per hour (6.5 ha) was faster and larger with the 'Legacy'.
- There was a trend (p=0. 1) towards higher seed yields (200 kg/ha) for night cutting with the 'Grasshopper', compared with cutting during the day time.
- The traditional disc mower had the lowest area cut per hour (2.7 ha).

Background

The 'Legacy' windrower has a disc mowing front that allows cutting at a faster ground speed than the sickle knife cutting in traditional windrowers. In three previous ryegrass harvesting trials (2016-17 and 2017-18), using the 'Legacy' windrower resulted in seed yields that were similar or higher to both auger and draper windrowers and significantly higher than a conventional disc mower (3080 ± 80 v 2650 ± 10 kg/ha). The 'Grasshopper' is a modified windrower utilising a 5.2 m Lely disc mower bar to replace the reciprocating knife cutter bar, without a draper or auger, thus creating a swath that is wider and thinner than a traditional windrow. The trial in 2019-20 compared the 'Legacy', 'Grasshopper' and a conventional disc mower operating in a forage-type perennial ryegrass.

Methods

A trial was established with large plots in a crop of forage-type perennial ryegrass, cultivar Hustle, for evaluation of farm-scale equipment. Plots were 545 m long and 0.55 ha in area, with two replicates of four treatments. The first treatment was cut at night on 4 February, 2020 (between 21.30 and 02.00 hours (h), during which rainfall occurred. Three treatments were cut late afternoon on 5 February between 17.00 and 18.00 h; (i) Grasshopper (ii) Legacy disc windrower (4.65 m wide) and (iii) a 'Claas Disco' disc mower (2.3 m wide). The cutting width and speed for each was recorded (Table 1). The temperature and relative humidity (RH%) were recorded at 15-minute intervals with a Hobo datalogger. During the night cut, the average was 9.0°C and 100% RH. The afternoon averaged 14.7 °C and 74% RH. The trial was harvested between 16.00 and 20.00 h on 12 February, eight days later as delayed by rain, with a CR9080 combine at 3 kmph, using a draper pickup. No settings were altered between replicates. The mower plots (Treatment 4) were picked up as double rows, giving a similar volume intake to the combine as the single rows of the other three treatments. Each plot was a return run with the combine giving a total length of 1090 m. The combine was emptied of seed into the weigh wagon for yield determination and a sub-sample collected for machine cleaning and seed moisture content (SMC) assessment. The SMC after harvest was 12% for the Legacy and 11% for the other treatments. All yields were adjusted to 12% SMC.

Results and Discussion

The seed yield of the disc mower was 520 kg/ha less than for the Legacy windrower but similar to that achieved by the Grasshopper (Table 1). The Legacy cutting method produced higher seed yields than the Grasshopper under daytime cutting conditions. This result was consistent with previous ryegrass trials that compared the Legacy with windrowing and disc mowing (FAR project H17-07). In a previous seed loss study, we showed that there was a higher seed loss on the cutting divide than on the cutter bar. In the present study, there were twice as many cutting divides with the disc mower compared with the wider windrowers, which may have contributed to the lower seed yield for disc mowing. There was a trend (LSD p=0.10) for the Grasshopper night cutting to have a 200 kg/ha yield advantage over day cutting.

The cutting speed of the Legacy was faster than the Grasshopper and the mower, as was the area cut/hour (Table 1). The grower commented that the Legacy windrow had more depth, as it was pulled into a narrower windrow. This could be a disadvantage in wet conditions where the swath could take longer to dry, but an advantage in dry conditions or with crops that have less bulk. Loss assessments were not carried out to determine the timing of seed loss.

Table 1. Method and time of cutting interactions on machine productivity and seed yield of perennial ryegrass, cultivar Hustle, grown near Methven, Canterbury in the 2019-20 season.

Harvest treatment	Time of treatment	Seed yield (kg/ha)		Cutting speed (kph)	Area cut (ha/hr)
Grasshopper	Night	2900	ab*	9.5	4.9
Grasshopper	Day	2700	b	9.5	4.9
Legacy	Day	3190	a	14.0	6.5
Disc Mower	Day	2670	b	11.5	2.7
LSD (p=0.05)		318			
LSD (p=0.10)		138			
P Value		0.038			

Note: Yellow indicates the harvest treatments that produced the greatest seed yield.
*Yield numbers with the same alphabetical letter are not significantly different.

Summary

The trial compared crop cutting with three machines; the Legacy windrower, a Grasshopper windrower and a conventional 2.3 m wide disc mower. The seed yield of the area cut with the Legacy windrower (520 kg/ha) was 16% higher when compared with the yield using the mower. The Legacy cuts at a faster ground speed (14 kph) and thus, cuts a greater area per hour (6.5 ha/h) than the disc mower, which cuts at 11.0 kph and 2.7 ha/h.

The Grasshopper, when used at night, gave a similar yield to the Legacy, but the yield was lower when used during the day. These data suggest cutting at night results in less seed loss, and also that the benefits of the Grasshopper may be dependent on the timing of the cut.

The Legacy draws a tighter windrow, that may dry more slowly compared to the Grasshopper and disc mower. Thus, prevailing weather may be important in the yield obtained using the three crop cutting machines.

Desiccation options for white clover seed harvest

Project code H19-07

Duration Year 3 of 5

Authors Richard Chynoweth, Harry Washington, Matilda Gunnarsson, Phil Rolston (FAR)

Location: Lincoln, Mid Canterbury (GPS: 43° 36’ 10.15” S; 172° 25’ 54.66” E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Chris Morrish (trial host), NZ Arable (trial operator), New Zealand SeedLab

Key points

- Desiccants that stop growth (Buster®, Granstar®, Roundup®, Versatill®) may have uses in bulky crops or in wetter than average weather conditions, but post-harvest re-growth for grazing is also compromised.
- GreenMan™ applied at 8% concentration in 500 L/ha has potential as an alternative to Reglone® for desiccation but regreening is rapid and more than one application might be required, making this a costly option.
- Windrowing reduced seed yield by 280 kg/ha in comparison with direct heading.

Background

The desiccants currently used for direct-headed white clover are based on a single or double application of Reglone® (active ingredient (a.i.) 200 g/l diquat) or the phenoxy herbicide MCPA (2-methyl-4-chlorophenoxyacetic acid) as a pre-desiccant to fold leaves. In crops that are not bulky and in rain-free harvest conditions, these desiccation treatments are very effective. However, when crops are bulky and /or it rains after the desiccant is applied, crop re-growth can occur. In bulky crops, the collapsing petioles can drag flower heads into a wet-decaying leaf mat that is hard to get dry for harvest. MCPA also stops the seed from filling, so if applied too early it can reduce seed yield and thousand seed weight (TSW). Diquat has been banned in parts of Europe, and is amongst the chemicals under consideration for review by the Environmental Protection Agency in New Zealand Therefore, there is a need to identify alternative crop desiccants for direct harvesting and to find alternative options that can be used when environmental conditions are less favourable. A further factor to consider is that diquat alternatives that reduce re-growth post-harvest will be a constraint for growers with an integrated crop-livestock programme where post-harvest white clover used for finishing lambs.

This trial is the fourth in a series of trials examining desiccation options for white clover seed crops, with previous trials (project codes H18-23 and H17-06) focused on alternatives to MCPA as a pre-desiccant and the use of a fatty-acid organic desiccant Greenman™ as an alternative to diquat. Pre-desiccant alternatives to MCPA that were effective in the earlier trials were clorpyralid, glufosinate, glyphosate, and tribenuron. The GreenMan™ bioherbicide was not an effective desiccant at the recommended 2-4 % dilution rates on clover, possibly limited by the water volume sprayed and coverage. The 2019-20 trial investigated the effectiveness of higher concentrations of Greenman™ as well as management of post-harvest clover re-growth.

Methods

A trial was established in a paddock of white clover, cultivar Grasslands Huia, near Lincoln, with 11 treatments in a randomized block design with four replicates. The plots were 8 m long and 1.5 m wide. The products evaluated as desiccants or pre-desiccants were: Buster® (active ingredient (a.i.) 200 g/L glufosinate-ammonium); Granstar® (a.i. 750 g/kg tribenuron-methyl); GreenMan™ (a.i. 650 g/L fatty acids in the form of an emulsifiable concentrate derived from oil seed rape) plus 'Expedient' oil (2 L/ha applied in 500 L/ha water); Agritone® (a.i. 750 g/L MCPA); Reglone® (a.i. 200 g/L diquat) with Contact™ Xcel surfactant (25 mL/ 100 L water); Roundup® 360 (a.i. 360g/L glyphosate) plus organosilicone Pulse® Penetrant (1 mL/L of water); Versatill® (a.i. 300 g/L clopyralid).

The herbicide desiccants (except GreenMan™) were applied with 250 L water/ha, using Teejet XR standard flat fan 110 015 at 250kpA spray nozzles, creating a very fine droplet size. GreenMan was applied at 40 L/ha in 500 L of water (an 8% solution). Treatment 13 (3 L/ha Reglone® followed by 2 L/ha Reglone® seven and three days before harvest, respectively), was the same as that applied to the remainder of the crop by the grower.

Crop brown-off was visually assessed at 2 to 3-day intervals and from a 0.25 m^2 quadrat dry matter cut from each plot on the day of harvesting. The windrow plots were cut with a modified John Deere plot windrower on 29 February, 2020. All plots were direct harvested with a plot combine on 2 March, 2020. The combine operator scored each plot for ease or difficulty of harvest (1= very difficult, 10 = easy). The seed was machine dressed to a First Generation Seed Certification standard. Seed germination was tested on six treatments by New Zealand SeedLab, using 200 seeds from each plot.

On 9 March, 2020, the paddock was irrigated and sheep were introduced to the field. The trial was fenced off from the sheep and re-growth was assessed visually at three scoring times (10, 17 and 21 days after irrigation) as well as on the 28 April. Dry matter regrowth was assessed from 0.25 m^2 quadrat cuts.

Results and Discussion

The seed yields of white clover in the nine direct-headed treatments averaged 805 kg/ha, with no significant differences between them (Table 1). The average seed yield of the four windrowed treatments was significantly lower at 525 kg/ha (Table 1). During the windrow process there was an obvious build-up of shattered seed on the cutter bar. There was a trend towards a higher seed yield (average 620 kg/ha) for earlier windrowing without a pre-desiccation treatment (24 February) compared with those treatments windrowed on the 29 February (average 495 kg/ha; Table 1). It is possible that seed shattering was associated with the particular plot windrower used in the trial. However, the grower's windrowed yields from the remainder of the paddock were similar to those in the windrowed treatments in the trial.

GreenMan™ at 8% (Treatments 4 and 10), caused rapid desiccation of the crop but the crop began to re-green 8 days post application (Table 2). The rapid desiccation contrasted with the previous year when GreenMan™ diluted to a 4% mixture was not an effective desiccant (applied in 250 L water/ha). Both the early windrow (Treatment 12) and the early GreenMan™ (Treatment 4) were more difficult to harvest than other treatments because of the green material present. However, the GreenMan™ treatment still produced a high seed yield.

The use of Agritone® as a pre-desiccant increased the rate of Reglone® brown-off (Treatment 2 versus Treatment 1), but the DM% and the seed yield of the crop at harvest were similar in these treatments (Tables 1 and 2).

Re-growth of white clover for grazing was measured 56 days after harvest and averaged 23 kg DM/ha/day. There was almost no re-growth following Buster® (Treatments 3 and 11) and Versatill® (Treatment 6) (Table 2). Treatment with Granstar® and GreenMan™ (Treatment 5) or Roundup® 360 (Treatment 7) reduced re-growth by 40% compared with the average of the eight remaining treatments (Table 2).

Seed germination tests following desiccant application showed that none of the translocated treatments (e.g. Agritone®, Roundup® 360 and Versatill®), had any negative effects on germination (Table 1). Testing by NZ SeedLab on 12-month old seed from the previous year's trial, also showed there were no detrimental effects on germination with the nil, Versatill 0.35 L/ha and Roundup 3 L/ha treatments all having >95% germination.

Summary

The trial showed that there are various options for pre-desiccant treatments but none improved seed yield above Reglone® alone this season. GreenMan™ offers promise as an alternative option to Reglone® for both conventional and organic white clover seed production, but requires high rates and water volumes to achieve desiccation. At 8% dilution, viscosity of the product is a limitation and the cost at >$1,000/ha is an uneconomic option. In addition, regrowth is rapid meaning that Treatment applications will need to be made 3 to 5 days before harvest.

If lamb finishing on post-harvest re-growth is important, some treatments, especially Buster® and Versatill® should not be used. Granstar® and Roundup® were less damaging to post-harvest re-growth.

Table 1. Seed yield of white clover, ease of harvest score and germination for the cultivar Huia following various methods of crop dry down when grown near Lincoln in the 2019-20 growing season.

Treatment number	Product, rate and timing of application				Seed yield (kg/ha)	Harvest score[2]	Germination[3] (%)
	18 February	24 February	28 February	29 February			
1	-	Reglone® (4 L/ha)	-	-	790 a*	5 b*	-
2	Agritone® (2 L/ha)	Reglone® (4 L/ha)	-	-	850 a	6 ab	97
3	Buster® (5 L/ha)	Reglone® (4 L/ha)	-	-	770 a	8 a	98
4	GreenMan™ [1]	-	-	-	840 a	3 bc	98
5	Granstar® (40 g/ha)	GreenMan™	-	-	760 a	6 ab	98
6	Versatill (350 mL/ha)	Reglone® (4 L/ha)	-	-	810 a	7 a	-
7	Roundup® 360 (3 L/ha) + Pulse	Reglone® (4 L/ha)	-	-	830 a	6 ab	99
8	Reglone® (2 L/ha)	Reglone® (4 L/ha)	-	-	840 a	6 ab	-
9	-	Reglone® (3 L/ha)	-	Windrow	510 b	5 b	-
10	GreenMan™	-	-	Windrow	490 b	6 ab	-
11	Buster® (5 L/ha)	-	-	Windrow	480 b	6 ab	-
12	-	Windrow	-	-	620 b	4 b	-
13	-	Reglone® (3L/ha)	Reglone® (2 L/ha)	-	760 a	5 b	98
			LSD (p=0.05)		131	2	1.8 (NS)
			P value		<0.001	<0.01	0.65

Note: Yellow indicates the treatments that were among the treatments that produced the greatest seed yield.
*Numbers followed by the same letter are not statistically different at LSD (p=0.05)
[1]GreenmanTM applied at 8% v/v in 500 L of water/ha
[2]Difficulty of harvest score; 1 = very difficult, 10 = easy
[3]Germination % =germinated + hard seed; with hard seed average 16%

Table 2. Brown-off visual scores (100 = complete brown-off; 0 = no brown-off) at five scoring dates, the dry matter percent of the crop at harvest and the re-growth dry matter production for white clover cultivar Huia at Lincoln in 2019-20.

Treatment number	Brown off (%) on date of scoring					Crop dry matter (DM% on 2 March)	Regrowth dry matter (kg DM/ha on 28 April)
	19 February	22 February	24 February	26 February	28 February		
1	-	-	-	48	59	67	1530 a
2	4	9	18	68	84	65	1280 a
3	0	24	84	80	96	67	140c
4	45	83	86	48	30	52	1360 a
5	0	1	56	69	70	62	820 b
6	3	12	26	70	92	63	160 c
7	0	2	15	50	79	68	750 b
8	33	79	86	84	73	65	1110 ab
9	-	-	-	38	45	77	1250 a
10	48	85	90	54	38	76	1240 a
11	0	23	86	80	85	80	90 c
12	-	-	*	*	*	80	1170 ab
13	-	-	1	40	68	61	1390 a
LSD (p=0.05)	7	7	16	18	12	7	470
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Yellow indicates the treatments that produced the greatest brown off after 10 days or the lowest amount of dry matter yield.
[1]Numbers followed by the same letter are not statistically different at LSD (p=0.05)
- treatment not applied at assessment, *Windrowed on 24 February

Herbicide tolerance of second-year cocksfoot cultivars

Project code H19-11

Authors Phil Rolston and Richard Chynoweth (FAR)

Duration Year 2 of 3

Location Chertsey, Mid Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Pasture First (trial operator)

Key points

- No differences in herbicide susceptibility were detected in 11 cocksfoot cultivars grown as 2nd year crops.
- The widely used herbicides Karmex® (a.i. 800 g/kg diuron, group C2 herbicide) and Nu-Trazine™ 900DF (a.i. 900 g/L atrazine, group C1 herbicide) increased seed head number when compared with the no herbicide control.
- Kerb™ (a.i. 500 g/L propyzamide, Group K) offers an option for mid-winter grass weed control and belongs to a different herbicide group.
- Foxtrot® could be used in conjunction with the primary herbicides if wild oat control is needed in spring.

Background

The area of cocksfoot seed production in New Zealand has increased over the past five years with many new cultivars now being multiplied for re-export. Weeds in established cocksfoot seed crops include volunteer seedling cocksfoot, annual or perennial ryegrass, annual poa, hairgrass and wild oats. A trial was conducted last year in 1st year cocksfoot to identify cultivar differences in tolerance to herbicides that could potentially be applied to control hairgrass, annual poa and perennial ryegrass. Results demonstrated that the Karmex® (a.i. 800 g/kg diuron, group C2 herbicide) and Kerb™ (a.i. 500 g/L propyzamide, Group K) showed the greatest promise for problem grass weed species in seedling cocksfoot, providing good weed control with minimal impact on the crop (Rolston *et al*. 2019). Hussar® (a.i. 50g /kg iodosulfuron-methyl-sodium, Group B) gave broadleaf weed control with no or a small reduction in cocksfoot head numbers.

In second-year crops, growers commonly use atrazine (active ingredient (a.i.) 900 g/L atrazine, Group C1) and Karmex® herbicides to control or suppress weed grasses. However, there is little information available to growers on crop safety of these and other herbicides for the range of cultivars now being grown. The aim of the trial was to evaluate tolerance across a range of cultivars from both continental (standard) and Mediterranean (which are more winter active) backgrounds to a number of herbicides used for grass weed, broadleaf and wild oat control.

Methods

Eleven cocksfoot cultivars, including three Mediterranean types (‘Kasbah’, ‘GK281’ and ‘Howlong’; Table 1), were sown as individual rows on 2 March 2018, with 50 cm between rows. The trial involved three replicates in a split plot design. Plots were 3 m wide and 7 m long. In January 2019, the residue remaining after the first year’s trial was removed.

The trial was irrigated when required, based on soil moisture neutron probe monitoring. Fertiliser nitrogen (N) was applied as urea in autumn (50 kg N/ha on 23 May) and spring (68 kg N/ha on 10 September followed by 32 kg N/ha on 19 November). The plant growth regulator Moddus® Evo (a.i. 250 g/L trinexapac ethyl) was applied at 0.8 L/ha on 19 November. Seed head numbers were assessed by cutting 1 m of row from each plot and counting the number present on 15 December 2019. No weed pressure was present in the plots, removing this as a variable in the trial.

Twelve herbicide treatments were evaluated with timings depending on herbicide type, with the application dates and rates shown in Table 2. The herbicides were Nu-Trazine™ 900DF (a.i. 900 g/L atrazine), Karmex® 800 DF, Hussar®, Kerb™, Stratos™ (a.i. 200 g/L flamprop-M-isopropyl, Group Z) and Foxtrot® (a.i. 69 g/L fenoxaprop-p-ethyl, Group A). Stratos™ and Foxtrot® were applied for wild oat control.

Results and Discussion

Seed head density was different between cultivars, ranging from 390 heads/m^2 ('Kainui') to 620 heads/m^2 ('Safin') (Table 1). There was no interaction between cultivar and herbicide treatment.

Table 1. Mean seed head density at mid-seed fill (15 December 2019) for 11 cultivars of cocksfoot treated with 12 herbicide treatments and grown as 2nd year crops near Chertsey in the 2019-20 growing season.

Cultivar	Seed heads/m^2	
Safin	620	a*
Aurus	600	a
Savvy	525	b
Howlong	520	b
Lukir	520	b
GK281	500	b
Vision	490	b
Lazuly	470	bc
DAC428	430	cd
Kasbah	420	cd
Kainui	390	d
LSD (p=0.05)	61	
P value	<0.001	

Note: Yellow indicates the herbicide treatments that produced the greatest number of seed heads (a proxy for seed yield).
*Head numbers with the same alphabetical letter are not significantly different.

2nd year cocksfoot treated with up to 2.5 kg/ha Karmex®, shown previously to control grass weeds and to have only limited impact on seed head density in 1st year cocksfoot, was again amongst the treatments with the greatest seed head density (500-540 heads/m^2) (Table 2). The seed head density was significantly higher than the no herbicide control, suggesting this chemistry has potential to increase seed yield.

Cocksfoot treated with a single application of atrazine (up to 3L/ha) in April was also amongst the treatments with the greatest seed head density (Table 2). As atrazine causes significant damage to 1st year crops (Rolston *et al.* 2019), these data confirmed the benefits of selective use of atrazine depending on crop age.

The use of a mix of Karmex® and atrazine either as a single application in April or as a second application in July after an initial application of atrazine also produced similar seed head densities. An application of up to 1.0 L/ha Kerb™ in winter (5 July) did not reduce seed head density, despite some growers observing potential yield losses in the field when using Kerb™ at the higher 1.5L/ha label rate for use on clover. Kerb™ is registered in Oregon for use on cocksfoot and being in a different herbicide group, offers an alternative option to the Group C triazines and urea herbicide families if a second herbicide treatment is required.

Table 2. Mean seed head density for 11 cocksfoot cultivars following treatment with 12 herbicide programmes when grown as 2^{nd} year crops near Chertsey, Canterbury in the 2019-20 growing season.

Herbicide, rate and application date			Seed heads (m^2)	
4 April	5 July	18 September		
No herbicide control			460	bc*
Atrazine[1] (1.5 L/ha)	Kerb™ (0.75 L/ha)		550	a
Atrazine (1. 5 L/ha)	Atrazine+ Karmex® (1.5 L/ha + 1.5 kg/ha)		550	a
Karmex® (1.5 kg/ha)			540	a
Atrazine (3.0 L/ha)			530	a
Atrazine (1.5 L/ha)			520	a
Atrazine (1.5 L/ha)	Atrazine (1.5 L/ha)	Foxtrot® (0.75 L/ha)	510	ab
Atrazine (1.5 L/ha)	Kerb™ (1.0 L/ha)		500	ab
Atrazine + Karmex® (1.5 L/ha +1.5 kg/ha)			500	ab
Karmex® (2.5 kg/ha)			500	ab
Atrazine (1.5 L/ha)	Hussar® (0.2 L/ha)		450	bc
Atrazine (1.5 L/ha)	Atrazine (1.5 L/ha)	Stratos® (4 L/ha)	400	c
		LSD (p=0.05)	63	
		P Value	<0.001	

Note: Yellow indicates the herbicide treatments that produced the greatest number of seed heads.
*Head numbers with the same alphabetical letter are not significantly different.
[1] Atrazine applied as Nu-TrazineTM 900DF (a.i. 900 g/L atrazine).

Treatment with Hussar® produced seed head numbers similar to those observed when no herbicide was applied. Our previous data showed it provided little or no control of grasses in 1^{st} year crops, despite Hussar® being commonly used for ryegrass/ annual poa control in commercial cocksfoot seed crops. Thus, the lack of control in these trials may have been because of the timing of application.

The treatment with applications of atrazine in April and July followed by an application of Stratos® in September produced similar seed head numbers to the untreated control and a seed head density significantly below that of a similar treatment that had two identical sprays in April and July, but then had a Foxtrot® spray in September. This data suggests an application of Stratos® in spring at the rate tested causes significant damage to the crop. Foxtrot® showed a slight increase in seed head density in crops already treated with Atrazine when applied at a rate of 0.75 L/ha. This suggested Foxtrot® could be used in conjunction with this herbicide if wild oat control was needed.

Summary

The 11 cocksfoot cultivars tested in this trial showed no differences in their susceptibility to a range of herbicides applied primarily for grass weed control in 2^{nd} year crops. The two primary herbicides used commercially, Karmex® and atrazine, performed well when applied to these cultivars, increasing seed head density significantly over the non-herbicide treated control. Kerb™, used commonly in cocksfoot in the United States, also showed potential as an alternative to Group C triazine and urea herbicides for the control of weedy grasses in cocksfoot while Foxtrot® could also be used in conjunction with the primary herbicides if wild oat control is needed in spring. Future work will aim to confirm the suitability of these chemistries for use in cocksfoot production.

Reference

Rolston, P, Vreugdenhil, S, and Chynoweth, R (2019). Herbicide tolerance of first year cocksfoot cultivars. *FAR Research Results 2018/19.* Pp 88-91.

Cocksfoot seed yield response to irrigation

Project code H19-12

Duration Year 2 of 3

Authors Richard Chynoweth and Phil Rolston (FAR)

Location FAR Arable Site Chertsey, Mid Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator), Hydroservices, Jean-Baptiste Fevrier (Massey University)

Key points

- Irrigation of cocksfoot should aim to provide access to adequate soil moisture throughout the lifecycle of the crop.
- Drought stress of the same duration and intensity resulted in similar yield reductions regardless of whether the stress occurred before head emergence in November or after flowering in December.
- Yield reductions were associated with a lower seed head density and less seeds harvested per head.

Background

Water stress occurs most summers throughout the seed producing areas of the east cost of New Zealand as evapotranspiration usually exceeds rainfall during the key growing months October, November and December. If the stored soil supply cannot provide the short fall, plant growth becomes limited with symptoms such as wilting, leaf death, tiller death and crop dormancy. In grasses grown for seed, early spring droughts tend to reduce the number of tillers that produce seed heads while late season drought reduces seed size and thus the number of saleable seeds harvested. This trial was established to investigate the response of cocksfoot seed crops to drought and quantify the effects of early or late season drought.

Methods

The trial was set up in a 4th year stand of cocksfoot cultivar Savvy that was established in February of 2016 in 30 cm wide rows. In the 2018-19 season, the area was used for a time of cutting/windrowing experiment what was reported by Rolston *et al*. 2019. Following harvest, the straw was removed from the trial. Volunteer cocksfoot seedings and ryegrass were controlled using a combination of Hussar® (active ingredient (a.i.) 50 g/kg iodosulfuron) applied 16 May 2019 and two applications of Atranex® WG (a.i. 900 g/L atrazine/kg) and Karmex® DF (a.i. 800 g/kg diuron) applied 4 April and 16 July. Autumn nitrogen (N) application was 80 kg N/ha split between 50 kg N/ha applied as SustaiN® on 4 April and 30 kg N applied as Ammonium sulphate on 20 May. Spring N application consisted of 170 kg N/ha applied over four applications of SustaiN® between August and November. A single application of 1.5 L/ha of Cycocel™750 (a.i. 750 g/L chlormequat-chloride) and 0.4 L/ha of Moddus® Evo (a.i. 250 g/L trinexapac ethyl) was applied to all plots on 25 October. Two applications of the fungicides Proline® (0.4 L/ha) and Seguris® Flexi (0.6 L/ha) were applied 1 November and 5 December.

The soil type was a Chertsey Silt Loam with ~55 cm of topsoil above free draining gravel. The water holding capacity is ~120 mm of which half is freely plant available. Irrigation was applied to the in-between row space of each plot via an above ground trickle tape system with drippers spaced approximately 33 cm apart. A single application was applied weekly, based on measured soil moisture levels at an application rate of ~8 mm/hr. Soil moisture was measured in all plots at hourly intervals in the 0-20 cm layer using Campbell Scientific CS650 reflectometers. At weekly intervals, the day prior to irrigation application, soil moisture between 20 and 50 cm was measured by neutron probes to give the weekly measured soil water deficit. Rainfall was measured on site.

On 7 January 2020, a 0.3 m^2 quadrant was cut from each plot to assess total dry matter production and the number of seed heads produced. All plots were windrowed on 7 January using a modified John Deere windrower and were harvested on 15 January using a 'Sampo' plot combine. A sub sample was machine dressed to a 1st generation seed certification standard.

Results and Discussion

Seed yield was increased by 1.4 kg/mm of applied irrigation from 600 kg/ha in the untreated control to 960 kg/ha in the fully irrigated treatment where 263 mm of irrigation was applied (Figure 1, Table 1). Maximum seed yields were obtained from treatments where irrigation replaced measured water use until mid-seed filling (approx. 10 December) and where measured deficits were no greater than 54 mm. However, 40 mm rain was received over a two-day period between 17 and 18 December that provided nine days water and reduced the expected time under water stress for late drought treatments. Thus, the late drought treatment that was irrigated until mid-seed fill did not experience any water stress. Similar levels of drought stress reduced seed yield by a similar amount regardless of whether the stress occurred mid-season (e.g. November as per treatment 2) or after anthesis (e.g. in December as per Treatment 3).

Table 1. Seed yield of cocksfoot, cultivar Savvy, following the application of seven irrigation treatments based on replacing measured water use (MWU) when grown on a Chertsey silt loam soil type with a readily available water content of approximately 60 mm near Chertsey, Mid Canterbury in the 2019-20 growing season.

Treatment		Applied water (mm)	Maximum measured deficit (mm)	Seed yield (kg/ha)		MoC[1] ($/ha)	
1	No irrigation	0	108	600	e	0	c
2	Mid drought f.b. MWU	148	97	710	d	79	c
3	Replace MWU until anthesis	115	96	730	cd	283	c
4	Replace MWU until early seed fill	138	94	820	bc	762	ab
5	Replace MWU until mid seed fill	198	54	890	ab	784	ab
6	Replace MWU	263	50	960	a	936	a
7	50% of MWU	141	77	780	cd	423	bc
			P value	<0.001		0.005	
			LSD (p=0.05)	103		462	

Note: Yellow indicates the irrigation treatments that produced the greatest seed yield or MoC.
[1]Margin over cost relative to the control.
f.b.: followed by.

Total dry matter production increased as applied irrigation increased (Table 2) and thus harvest index, the proportion of dry matter as seed, was unaffected by irrigation treatment. The number of seed heads produced increased as applied irrigation was applied, predominantly related to the continued production of smaller, later season heads that were not considered when making harvest decisions (data not presented). Thousand seed weight was consistent across treatments suggesting head numbers and harvested seed number/m^2 were the main drivers of the seed yield response.

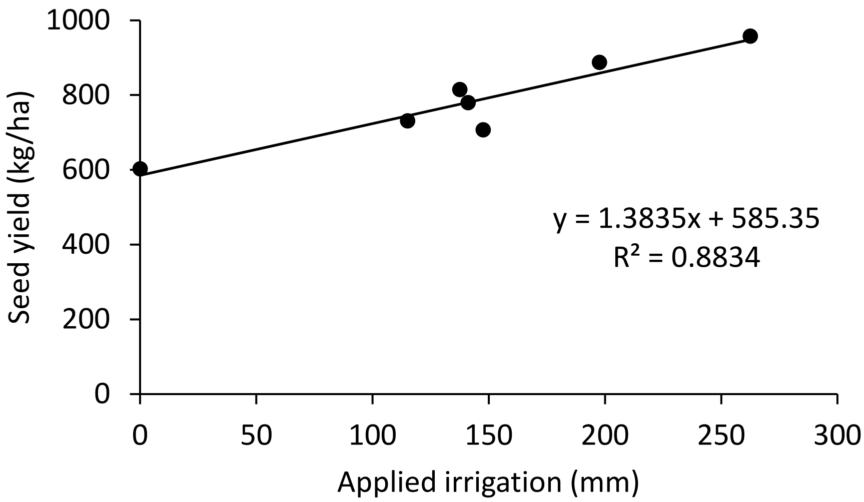


Figure 1. Seed yield of cocksfoot, cultivar Savvy, following the application of seven irrigation treatments when grown near Chertsey, Mid Canterbury in the 2019-20 growing season.

Table 2. Harvest components of cocksfoot, cultivar Savvy, following the application of seven irrigation treatments based on replacing measured water use (MWU) when grown near Chertsey, Mid Canterbury in the 2019-20 growing season.

Treatment	Applied water (mm)	Dry matter (kg/ha)	Heads/m2	TSW (g)	Harvest index (%)
1 No irrigation	0	8780	460	1.16	5.7
2 Mid drought f.b. MWU	148	12650	680	1.04	5.3
3 Replace MWU until anthesis	115	10170	600	1.09	6.0
4 Replace MWU until early seed fill	138	12280	700	1.07	6.2
5 Replace MWU until mid seed fill	198	15160	800	1.08	5.5
6 Replace MWU	263	14500	810	1.07	6.2
7 50% of MWU	141	15220	760	1.06	4.9
	Pvalue	<0.001	0.014	0.214	0.092
	LSD (p=0.05)	2224.3	159	NS	NS

Note: Yellow indicates the irrigation treatments that produced the greatest dry matter, seed heads/m^2 or harvest index.

Summary

Irrigation of cocksfoot should provide access to adequate soil moisture throughout the season. Yield reductions were associated with a lower seed head density and less seeds harvested per head.

References

Rolston, P, Chynoweth, R and Gunnarsson, M (2019). Optimising the time of harvest in cocksfoot. *FAR Research Results 2018/19*. Pg 95-97.

Cocksfoot response to plant growth regulators and effect of leaf burn on seed yield

Project code H19-13

Authors Ashley Harrison, Richard Chynoweth, Phil Rolston (FAR)

Location FAR Chertsey Arable Research Site, Mid Canterbury

Duration Year 2 of 2

Funding Seed Industry Research Centre (SIRC)

Acknowledgements New Zealand Arable (trial operator)

Key points

- Irrigated yields averaged 1030 kg/ha compared to dryland at 600 kg/ha.
- A mixture of chlormequat-chloride (Cycocel® 750) (CCC) and trinexapac-ethyl (Moddus® Evo) (TE) increased seed yield by 240% (dryland) and 210% (irrigated) compared to the untreated control.
- The CCC and TE mixture was more effective than either component applied alone.
- While some leaf burn occurred when CCC and TE were applied, it was not severe and the yield response to PGR in dryland crops was similar to irrigated crops.
- The margin over cost was $1840/ha in dryland and $3050/ha under irrigation.
- Reduced height from PGR was more important than lodging reduction for yield response.

Background

Plant growth regulators (PGRs) are commonly used in cocksfoot seed production. In previous trials, both Cycocel® 750 (active ingredient (a.i.) 750 g/L chlormequat-chloride) (CCC) and trinexapac-ethyl (Moddus® Evo) (TE) separately or in mixes increased seed yield (Rolston et al., 2014). However, leaf burn can occur, especially with CCC+TE mixes and under dryland conditions. The trial reported here attempted to replicate some grower experiences and assess impact of leaf burn on seed yield. This is the second year of the trial. In 2018-19, the spring was wet and cool and leaf burn was minimal, with large seed yield responses to PGRs associated with stem shortening (Rolston *et al*. 2019).

Methods

This trial was repeated on a cocksfoot crop sown 2 March, 2018 (Rolston *et al*. 2019) located at the FAR Chertsey Arable Research Site, Mid Canterbury. The trial consisted of two cultivars, ‘Savvy’ and ‘Greenly II’, sown in 1.35 x 10 m plots at 30 cm row spacing. Four PGR treatments with combinations of TE (a.i. 250 g/L trinexapac-ethyl) and CCC were used in the trial (Table 1), which was laid out in a randomised complete block design with three irrigated and three dryland replicates. The soil type was a Templeton silt loam with soil analysis (0-15 cm) on 9 May, 2019 (pH 6.4, Olsen P = 22, available K=22 MAF units). The accumulated rainfall from 1 January 2019 to 26 January 2020 was 496 mm.

Autumn nitrogen (N) application was 80 kg N/ha split between 50 kg N/ha applied as SustaiN® on 4 April and 30 kg N applied as Ammonium Sulphate on 20 May, 2019. Spring applied N included 30 kg N as Ammonium sulphate, 50 N kg as urea in early October and 90 kg N as urea at PGR timing. The PGR treatments were applied at growth stage (GS) GS32 and GS37-39 (Table 1). All plots were topped to 10 cm on 8 February, 28 March and 10 May 2019. Fungicides Proline® (0.4 L/ha) and Seguris Flexi® (0.6 L/ha) were applied at head emergence and full flowering.

Weekly visual assessments were conducted from 8 November to 6 December 2019 and on 19 December for leaf burn and lodging, respectively. Leaf burn scores were on a 0 to 10 scale with 0 being no leaf burn and 10 being the leaf burned fully. Lodging scores were on a 0 to 100 scale with 0 being the cocksfoot fully vertical and 100 being the cocksfoot horizontal. Plant height measurements were also conducted weekly from 8 November to 19 December. There were differences in the maturity dates between cultivars, dryland and irrigation and PGR treatments, resulting in 3 windrowing dates 2, 7 and 16 January 2020, and three plot combine harvest dates 6 to 8 days after windrowing. Machine dressed yield was determined after seed cleaning.

Statistical analysis was conducted through two-way analysis of variance with a least significant difference of 5% using GenStat (17th edition, VSN International Ltd., 2014). The Margin over Cost (MOC) analysis included the cost of PGRs and application costs.

Table 1. PGR treatment rates and growth stage (GS) application timing for two cocksfoot cultivars at the FAR Chertsey Arable Research Site in the 2019-20 growing season.

Treatment	Cultivar	PGR	GS32 (14 Oct)	GS37/39 (1 Nov)
1	Savvy	Nil	-	-
2	Savvy	Moddus® Evo	0.8 L/ha	-
3	Savvy	Cycocel® 750	1.5 L/ha	1.5 L/ha
4	Savvy	Moddus® Evo + Cycocel® 750	0.4 + 1.5 L/ha	0.4 + 1.5 L/ha
5	Greenly II	Nil	-	-
6	Greenly II	Moddus® Evo	0.8 L/ha	-
7	Greenly II	Cycocel® 750	1.5 L/ha	1.5 L/ha
8	Greenly II	Moddus® Evo + Cycocel® 750	0.4 + 1.5 L/ha	0.4 + 1.5 L/ha

Results

Seed yield of cocksfoot under irrigation averaged 1030 kg/ha compared with dryland 600 kg/ha (Table 2). The response to PGRs as a percentage of control was similar or slightly higher under dryland (240%) than under irrigation (210%). The mixture of CCC + TE gave a larger yield increase than either CCC or TE applied alone under irrigation, while using either CCC or TE as a solo product was as effective as the mixture under dryland conditions (Table 2). There was no cultivar x PGR interaction.

Table 2. Seed yield (kg/ha) of two cocksfoot cultivars following four PGR treatments under dryland and irrigated conditions at the FAR arable site, Chertsey in the 2019-20 growing season.

PGR Treatment	Dryland			Irrigated		
	'Savvy'	'Greenly II'	PGR mean	'Savvy'	'Greenly II'	PGR mean
Nil	420	210	315	820	440	630
Moddus® Evo	720	550	635	1165	960	1060
Cycocel® 750	680	700	690	1160	990	1080
Moddus® Evo + Cycocel® 750	830	690	760	1490	1200	1350
Cultivar mean	660	540	600	1160	900	1030
P value	0.008		<0.001	<0.001		<0.001
LSD (P=0.05)	86		104	80		124

Note: Yellow indicates the PGR treatments that produced the greatest seed yield.

Leaf burn from the treatments was small, with a score of 2 (out of 10) being the highest score for the CCC + TE mixture in dryland (data not presented).

Reduction in stem length was associated with the seed yield response to the PGR treatments (Figure 1). Under irrigation, every 1 cm reduction in stem length was associated with an increase in seed yield of 21.7 kg/ha, and in dryland of 11.9 kg/ha (Figure 1). The lodging in the trial was moderate, at 50% in the untreated irrigated block and there was no cultivar x PGR interaction (Table 3). In dryland, there was little or no lodging but yields increased with PGR, suggesting stem length reductions are a bigger driver of the seed yield response than lodging control.

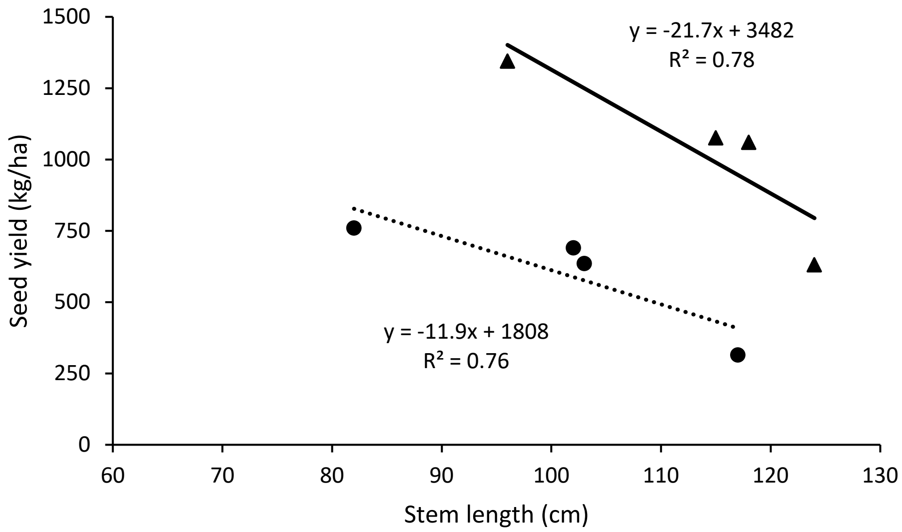


Figure 1. Relationship between reproductive stem length and seed yield for cocksfoot grown under dryland (dotted line) and irrigated (solid line) conditions, with the mean for two cultivars presented following treatment with one of four plant growth regulator programmes grown near Chertsey, mid Canterbury in the 2019-2020 growing season.

Table 3. Lodging percent (0=nil; 100 = horizontal to ground) for the two cultivars grown in dryland or irrigated conditions following treatment with one of four plant growth regulator (PGR) treatments in the 2019-20 growing season at the FAR Arable Research Site, Chertsey, Mid Canterbury.

PGR Treatment	Dryland			Irrigated		
	'Savvy'	'Greenly II'	PGR mean	'Savvy'	'Greenly II'	PGR mean
Nil	33	0	17	57	50	53
Moddus®Evo	17	0	8	33	33	33
Cycocel®750	0	0	0	33	0	17
Moddus®Evo + Cycocel®750	0	0	0	0	0	0
Cultivar mean	13	0	0.6	31	21	26
P value	0.045		0.164	0.34		0.014
LSD (p=0.05)	12		ns	ns		31

Note: Yellow indicates the PGR treatments that produced the greatest crop lodging.

Margin over cost (MoC). There was a very large MoC benefit from the PGR treatments, ranging from a low of $1,360/ha for Moddus®Evo in dryland cocksfoot to $3050/ha in irrigated cocksfoot treated with the Moddus®Evo + Cycocel®750 mix (Table 4).

Table 4. Margin over cost (MoC) of cocksfoot following treatment with one of four plant growth regulators under both dryland and irrigated conditions. Values are the mean of two cultivars grown near Chertsey in the 2019-20 growing season.

Plant growth regulator treatment	Dryland	Irrigated
	MoC ($/ha)	
Nil	0	0
Cycocel®750	1590	1890
Moddus® Evo	1360	1870
Moddus® Evo + Cycocel®750	1840	3050
LSD 0.05	470	468
P value	<0.001	<0.001

Note: Yellow indicates the PGR treatments that produced the greatest margin over cost.

Discussion

In two years of trials, conditions have not resulted in severe leaf burn. The data suggests that under dryland the Moddus® Evo + Cycocel®750 mixtures did cause more leaf burn than either component alone, but the level of leaf burn (score of 2/10), was not severe enough to cause yield loss. The PGR response was a more than doubling in seed yield, both under dryland and irrigated conditions, resulting in large margin over cost benefits. The PGR response is driven by stem shortening rather than reduced lodging, and supports the results of previous trials (Rolston *et al*. 2014). The value of irrigation for cocksfoot is demonstrated with an average yield in the dryland area of 600 kg/ha compared with 1030 kg/ha under irrigation.

Summary

In two cocksfoot cultivars, 'Greenly II' and 'Savvy', large seed yield increases (over 200%) were achieved from using either Moddus®Evo (0.8 L/ha at GS32) or Cycocel®750 (1.5 L/ha twice GS 32 and GS33-37) under dryland conditions. There were similar increases under irrigation, with the best results from a Moddus® Evo + Cycocel®750 mix (0.4 + 1.5 L/ha applied at GS 32 and again at GS33-37). The yield response appears to be driven by stem shortening, more than from reduced lodging.

References

Rolston, P, Vreugdenhil, S and Chynoweth, R (2019). The effect of plant growth regulator-incited leaf-burn on seed yield in cocksfoot. *FAR Annual Research Results 2018/19.* Pp 92-94.

Rolston, P, Chynoweth, R, Kelly, M, McCloy, B, and Trethewey, J (2014). Seed yield response of four cocksfoot (*Dactylis glomerata* L.) cultivars following the application of stem-shortening plant growth regulators. *New Zealand Journal of Agricultural Research, 57*: 332-341.

Cocksfoot disease survey

Project code H19-14

Duration Year 1 of 3

Authors Phil Rolston (FAR) and Mark Braithwaite (Plant Diagnostics Ltd)

Location Various sites in Mid Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Plant Diagnostics Ltd, Murray Kelly (PGGWrightson Seeds)

Key points

- Foliar fungal and bacterial diseases in cocksfoot are common and appear to have the potential to cause severe yield losses in wet spring/early summers like in 2018-19.
- These diseases but can be better managed in drier, average years like 2019-20.
- Take-all occurrence is common and all grass-cereal rotations need broadleaf species as break crops.
- A number of diseases, especially bacterial diseases can be spread by rain and irrigation water splash, and it is recommended that late afternoon-evening irrigation is avoided to reduce this effect.

Background

Spring 2018 was wet with little sunshine during head emergence, especially in the Methven area of Canterbury. Cocksfoot growers reported a number of disease issues, including seed head bleaching and dead patches in crops. Seed yields for many fields, were 50% lower than the seed yields achieved in the previous season, especially around Methven. At a post-harvest meeting with concerned growers, a commitment was made by the Seed Industry Research Centre (SIRC) to examine cocksfoot samples collected by SIRC field reps and growers to ascertain which pathogens were found in cocksfoot fields and which may be associated with these symptoms.

Methods

Diseased plant tissue was collected from 11 cocksfoot seed production paddocks (representing five cultivars) from around Methven and coastal Ashburton in early summer of the 2018-19 season. Samples were also collected from nine cultivars used in an herbicide tolerance trial located at the FAR Arable Research Site near Chertsey, Mid Canterbury. The cultivars did not have fungicide applied and were scored for disease severity (0-nil; 10=high disease presence) on the 6, 13 and 27 December, 2018.

Iin spring/early summer of the 2019-20 season, patches of poor recovery after harvest and dead patches were observed in some grower fields and were tested. Pathogens were also identified from samples with foliar diseases and head bleaching observed in late spring/early summer of 2019-20. All samples were examined by Plant Diagnostics at Templeton and in total the samples collected from December 2018 to December 2019 came from 14 different growers representing 12 cultivars.

Results and Discussion

Diagnostic testing for pathogens in cocksfoot crops showing disease in Canterbury

A range of fungal diseases were detected in the cocksfoot samples collected, especially Ascochyta leaf spot (caused by *Didymella exitialis*), snow mould (caused by *Monographella nivalis*), leaf fleck (caused by *Mastigosporium rubricosum*) (Figure 1), and those caused by *Alternaria* spp. The bacterium *Pseudomonas syringae* was also detected in eight of the first group of 11 samples. At Chertsey, both *M. rubricosum* and *Alternaria* spp. were present on most cultivars.

Post-harvest, 2018-19. During the autumn and into the spring of 2019, patches with poor recovery or with dead plants were selected. Sampling in these patches identified the plant pathogens *Gaeumannomyces graminis* (causal agent of take-all) and *Fusarium graminearum* species complex were present while individual plants with pale/sick leaves and plants easily pulled from the soil had the root pathogens *F. culmorum* or *G. graminis* (Figure 1).

Spring, 2019. Various leaf and stem lesions on cocksfoot from Wakanui and Methven were associated with leaf rust (*Puccinia* species), snow mould and leaf fleck. During late head emergence and flowering, the appearance of pale stem lesions, or stem bleaching and dark girdling on stems was observed on seed heads. The pathogens detected from these samples were: *Xanthomonas translucens*, from stems (cause of wilt disease); *Fusarium* species belonging to the *F. graminearum* species complex, from roots of two samples; *P. syringae* from stems (cause of chocolate spot); and *Fusarium* species (*F. graminearum* species complex), from roots. *X. translucens* was identified by DNA sequence as was *P. syringae*.

Figure 1. Root rot symptoms in cocksfoot associated with take-all and Fusarium (L) and Root rot symptoms (L); and leaf fleck (R).

Summer, 2019. In mid-December 2019, stem bleaching and dark girdling lesions or black heads on seed heads were commonly detected on three farms at Methven. The pathogens detected from symptomatic plant samples were: *P. syringae* (bacterial blast) from dark stem lesions, bleached stem areas and blackened heads; *X. translucens* (wilt disease) from bleached stems; and *Ascochyta* species from bleached stems. *Erwinia rhapontici*, a potential bacterial pathogen, was also identified from a plant sample taken from one farm, which had roots infected with both *G. graminis* (take-all) and *Fusarium* species (foot rot).

The symptoms seen during spring of 2019 were similar to those observed by growers at Methven in the wet spring/early summer of 2018, where seed yields were very poor. In contrast, a dry late spring-early summer in 2019 saw good yields achieved in the 2019-20 harvest.

Cultivar susceptibility to disease

There were significant differences in disease scores between cocksfoot cultivars grown at Chertsey ($p<0.001$), with a low disease incidence in cv.s DAK428 and Lukir (2.3 and 2.6/10, respectively) and a high disease incidence in the Mediterranean type cv. Kasbah and its re-selection GK281 (8.1 and 8.4/10, respectively (now known as Grasslands Kaha) (Table 2).

Table 1. Mean score for foliar disease (0=nil; 10= high disease incidence) in different cultivars of cocksfoot, assessed on three occasions (6, 13 and 27 December, 2018) at Chertsey during the 2018-19 season.

Cultivar	Disease score*
Aurus	6.6
DAC428	2.3
Howlong	5.1
Kainui	3.6
Kasbah	8.1
Grasslands Kaha	8.4
Lazuly	4.6
Lukir	2.6
Safin	6.8
Savvy	5.8
Vision	4.4
LSD (p=0.05)	1.4
Fprob	<0.001

*Pathogens detected were: *Mastigosporium rubricosum* (leaf fleck); *Cercosporidium graminis* (brown leaf spot); *Puccinia* species (rust) and *Alternaria* species

Potential disease management options

Take-all and Fusarium foot rot: use break-crops between cocksfoot crops with non-grasses (e.g. legumes, brassicas or beets) with at least three years out of grass and cereals.

P. syringae and *X. translucens*: If control is going to be undertaken, then an early application (before flowering) with a copper product would be required. Over-use of copper will lead to resistance developing.

Bacterial diseases are often spread by water splash from either rain or irrigation. To limit irrigation splash and spread of *P. syringae*, irrigation in late afternoon-evening should be avoided and irrigation events should be less frequent with more water per event rather than little-and-often. *X. translucens* is a seedborne pathogen, so ensuring seed is clean for this pathogen would reduce crop contamination.

Many of the fungal pathogens could be controlled with fungicides used in ryegrass or cereals for leaf disease control.

Summary

A variety of fungal and bacterial pathogens were detected on symptomatic cocksfoot in recent seasons. The economic impact of these pathogens is not currently understood, but the diagnostic testing of samples in the Canterbury region imply that take-all and Fusarium foot rot are underlying diseases that appear to be increasing where cocksfoot is grown in an all-grass rotation (i.e. grass followed by cereals). Break crops between cocksfoot crops with non-grasses (e.g. legumes, brassicas or beets), staying at least three years out of grass and cereals. Bacterial diseases associated with *P. syringae* and *X. translucens* appear to be common in cocksfoot crops and cause seed heads to bleach. Disease expression is linked to wet late spring seasons and probably irrigation events that result in prolonged periods of leaf and stem wetness. Leaf fungal diseases are also common and susceptibility varies between cultivars.

Cocksfoot seed yield response to spring applied nitrogen

Project code H19-15

Duration Year 3 of 4

Authors Phil Rolston, Sonja Vreugdenhil, Richard Chynoweth (FAR)

Location Wakanui, Mid Canterbury (GPS: 43° 58’12.86” S; 171° 47’24.83” E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Eric Watson (trial host), NZ Arable (trial operator)

Key points

- Spring nitrogen (N) requirements for cocksfoot measured in this and five previous trials ranged from 90 to 150 kg applied N/ha.
- Total N [applied + soil mineral N] to a achieve seed yields not limited by N was 125 kg/ha in this this trial;
- Using a nitrogen nutrition index model with a critical N value of 1.0, predicted an N input of 91 kg N/ha without compromising seed yield.

Background

This trial is part of a series to define the spring nitrogen (N) requirements for cocksfoot seed crops. Cocksfoot tillers that become reproductive are formed in autumn and winter. Spring N is used to ensure reproductive tillers are not nutrient limited during their development. The previous trials undertaken between 2016 and 2018 indicated that with the typical grower autumn-winter management, the spring N requirement for cocksfoot is less than ryegrass with an optimum spring N being 129 ±10 kg N/ha. Nitrogen Nutrition Index (NNI) is used to guide N decision making in some crops. The NNI is based on the dilution curve of increasing biomass against declining foliar N% (Gislum & Boelt 2009). When the NNI is below the critical N (usually 1.0), the crop will respond to additional N. The trial reported here adds to datasets on N responses in cocksfoot and provides more species-specific data for improving the Overseer model and its reliance on ‘proxy’ crops.

Methods

The trial was established in a second year, irrigated, cocksfoot cv. Safin crop on a Wakanui silt loam in Wakanui. All inputs except spring N were managed by the grower. The crop received 72 kg N/ha (2 April 2019), 400 kg/ha superphosphate (15 April) and 50 kg potash (KCl) (20 September). The crop was closed on 25 May by cutting and removing as baleage. Fungicides applied were Prosaro® (active ingredient (a.i.) 125 g/L prothioconazole and 125 g/L tebuconazole) at 0.8 L/ha on 24 August and Prosaro® + Amistar® (a.i. 250 g/L azoxystrobin) at 0.8 and 0.5 L/ha on 30 October, 27 November and 12 December. Tri Base Blue® (a.i. 190 g/L tribasic copper sulphate) was applied on 24 August (2 L/ha) and 27 November (1.5 L/ha). Plant growth regulators (PGR) Cycocel™ 750 and Moddus® Evo (1.0 + 0.5 L/ha) were applied twice, on 13 and again on 30 October.

The trial evaluated nine N treatments. Soil mineral N (NO_3 + NH_4) (0-30 and 30-60 cm) was assessed on 21 August at the time of trial setup and averaged 36 kg N/ha. Treatments with a total N [mineral N + applied N] input covered from 36 to 250 kg N/ha, with fertiliser applied as SustaiN (46% N) (Table 1). One treatment used the NNI (Nitrogen Nutrition Index) developed for ryegrass (Gislum and Boelt 2009) to estimate the final N required based on the plant herbage N% and the biomass. These were 2.7% N and 7,030 kg DM/ha, respectively on 8th October, when all treatments were assessed. An average NNI value of 0.99, gave an estimated 9 kg N/ha to achieve a critical N of 1.0. Treatments were replicated four times in a randomised block design. Plots were 3.3 m wide and 12 m long. The greenness of treatments was assessed as a colour score on 22 November with 1= yellow and 10 = dark green. Crop dry matter and head density was assessed on 30 December by cutting a 0.3 m^2 quadrat (2 rows x 50 cm), and oven drying a subsample at 70° C for 48 hours.

The trial was windrowed on 11 January, cutting a 1.8 m width from the centre of each plot and harvested on 24 January with a plot combine. The seed was dressed to a 1st Generation seed certification standard and machine dressed (MD) seed yield calculated. The margin over cost (MOC) analysis used a cocksfoot grower price of $4.50/kg, SustaiN at $1.36/kg N, and application costs at $20/ha/application. Statistical analysis used GenStat v19 ANOVA and for split line regression to define a linear plateau seed yield response. A Mirtscherlisch response curve was not fitted to the seed yield data because the highest N rate did not depress seed yield.

Results and Discussion

Seed yield increased from 900 kg/ha (control) with increasing rates of N to 125 kg N [applied + mineral N] producing a yield of 1210 kg/ha (Figure 1). A split-line regression indicated no increase in yield with higher spring N application. In this trial, with 36 kg mineral N/ha, the top response was achieved with 89 kg applied N/ha. The NNI based treatment (Treatment 9), had a seed yield that was similar to treatments receiving higher N rates (Table 1). The MoC also increased with increasing rates of N to 125 kg total N/ha, returning an additional $1,480 margin over cost of N (Table 1).

Table 1. Machine dressed seed yield and Margin over Cost for cocksfoot, cv. Safin, when grown near Wakanui, Mid Canterbury in the 2019-20 growing season following the application of one of nine spring nitrogen (N) treatments.

Treatment number	Applied N (kg/ha)			Total Applied N (kg/ha)	Total N (kg/ha)	Seed yield (kg/ha)		MOC[2] ($/ha)
	3-Sep	1-Oct	22-Oct					
1	0	0	0	0	36	900	d	0
2	16	0	0	16	50	1030	cd	510
3	32	32	0	64	100	1110	bc	800
4	45	44	0	89	125	1260	ab	1430
5	57	57	0	114	150	1250	ab	1380
6	70	69	0	139	175	1150	bc	900
7	82	82	0	164	200	1330	a	1680
8	107	107	0	214	250	1140	bc	760
9[1]	82	0	9	91	127	1170	abc	1030
					LSD (p=0.05)	174		630
					P value	<0.001		<0.001

Note: Yellow indicates the nitrogen programmes that produced the greatest seed yield and MoC.
[1] NNI = treatment, [2] MoC = margin over cost where cocksfoot seed price = $4.50/kg; SustaiN = $1.36/kg N, application costs = $20/ha/application.

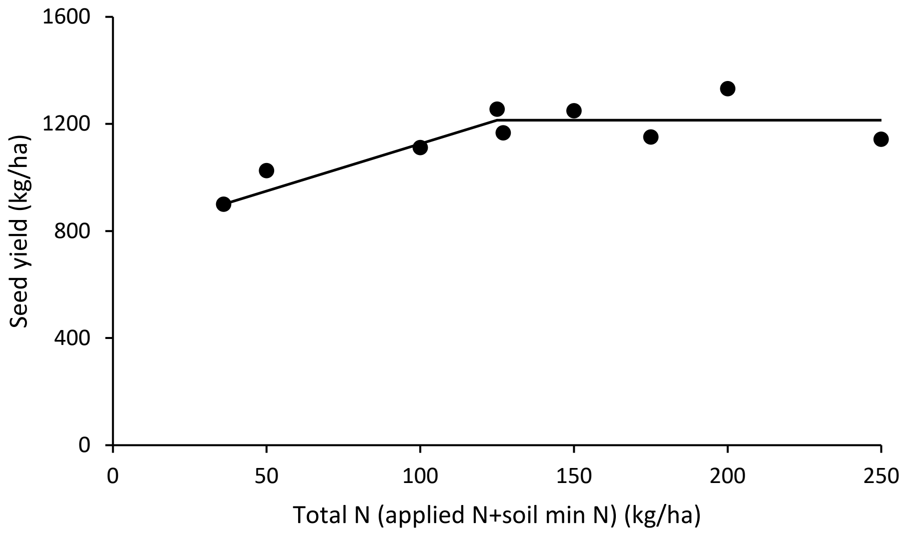


Figure 1. Seed yield response of cocksfoot cv. Safin grown near Wakanui, Mid Canterbury in the 2019-20 growing season following the application of one of nine nitrogen (N) treatments. The breakpoint defined by linear plateau regression = 125 kg N/ha.

Nitrogen increased the greenness colour score from 4 (untreated) to 10 (the maximum score) at 200 and 250 kg N/ha (Figure 2). The darkest green plots were no higher in seed yield than the treatments receiving 125 kg N/ha (Figure 1), which had a colour score of between 6.6 and 7.5. This is similar to data collected from ryegrass trials, where the highest yielding plots were not visually the greenest coloured plots.

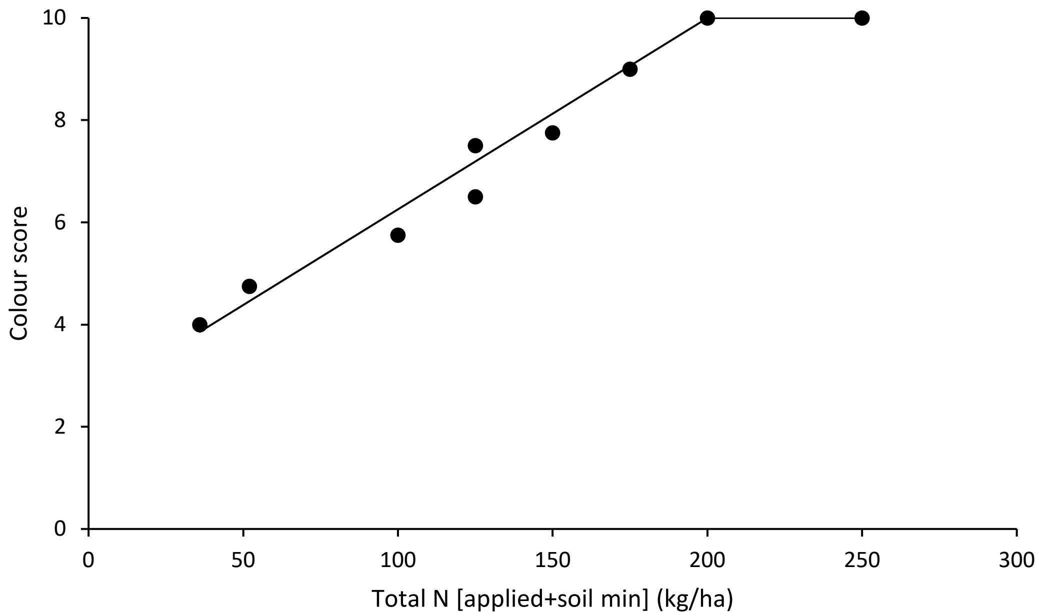


Figure 2. Relationship between colour score on 22nd November 2019 and total N [mineral+applied] kg N/ha in cocksfoot cv. Safin grown near Wakanui, Mid Canterbury in the 2019-20 growing season.

N increased the crop dry matter at harvest from 11,700 to 14,860 kg DM/ha at 200 kg N/ha. Seed head numbers were increased from 590 to 830 heads/m^2 with increasing N applied (data not presented).

The data from this trial is consistent with five previous cocksfoot N rate trials undertaken by FAR and SIRC. Combined data from six cocksfoot N rate trials estimates the spring applied N rate at 105 kg N/ha.

Summary

The seed yield response of cocksfoot to nitrogen was measured using both applied N response and total available N, including soil mineral N (0-60 cm) at the end of August. The application rate for maximum seed yield and minimum risk of N loss was 89 kg N/ha applied or 125 kg total N/ha [mineral+applied]. One treatment evaluated a Nitrogen Nutrition Index (NNI) approach that was based on measuring biomass and foliar N level in spring. The NNI approach used 91 kg applied N/ha, similar to the overall most effective treatments.

Reference

Gislum R and Boelt B (2009). Validity of accessible critical nitrogen dilution curves in perennial ryegrass for seed production. *Field Crops Research 111*: 152-156.

Control of Phomopsis stalk disease on two plantain cultivars grown for seed

Project code H19-16

Author Owen Gibson, Phil Rolston and Richard Chynoweth (FAR)

Duration Year 2 of 5

Location FAR Kowhai Research Site, Lincoln (GPS: 43° 28' 24" S; 172° 28' 14" E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator), Allan Lill (Norwest Seeds Ltd)

Key points

- The seed yield of the two cultivars were similar. Seed yield was increased by all fungicide treatments.
- The later flowering cultivar Boston had more Phomopsis stalk disease in untreated plots than the earlier flowering cv. AgriTonic.
- Triazole-based fungicides with Proline® (0.8 L/ha) alone had seed yields that were as good as mixtures of Proline® with strobilurin or SDHI partners.

Background

Phomopsis stalk disease, caused by *Phomopsis subordinaria* (Figure 1), results in the collapse of stems below the seed head of plantain (*Plantago lanceolate*) and in empty seed heads. Disease control by growers typically relies on prothioconazole (Proline®). This project was developed to understand the impact of Phomopsis stalk disease on seed yield of plantain and to develop additional management options. Two cultivars, Agritonic and Boston, with different head emergence dates were assessed. Cultivar AgriTonic flowers four weeks earlier than cv. Boston.

Figure 1. Phomopsis stalk disease in plantain. The seed head on the left is at an early infection stage whereas the seed head on the right is collapsing with Phomopsis stalk disease.

Methods

An irrigated trial was established at FAR Kowhai Research Site to evaluate the effect of five fungicide treatments on the production of two plantain cultivars (Table 1), AgriTonic (PGG Wrightson) and Boston (SeedForce/Norwest Seed). Treatments were in a randomised complete block design with three replicates. The trial was on a Wakanui silt loam. The previous crop (in the 2018-2019 season) was faba beans for seed. The trial was drilled with a disc plot drill on 25 March, 2019, in 10 x 3 m plots with a row spacing of 15 cm. Weedmaster® TS540 (active ingredient (a.i.) 540 g/L glyphosate) at 3 L/ha + Pulse® penetrant (a.i. >800 g/L organomodified polydimethylsiloxane), and 1.2 kg/ha Karmex® DF (a.i. 800 g/ka diuron) was applied pre-emerge on 22 March, 2019.

Kamba® 500 DF (a.i. 500 g/L Dicamba) 1 L/ha was applied on 25 May, 2019, to control seedling faba beans. Gramoxone® 250 (a.i. 250 g/L paraquat) 2 L/ha was applied on 8 August 2019 and 16 September 2019. Lorsban™ (a.i. 500 g/L chlorpyrifos) at 1 L/ha was applied to all plots on 25 October 2019. A follow up application of Lorsban™ was applied with a mid-flowering fungicide application on both varieties (cv. AgriTonic – 28 November 2019 and cv. Boston – 11 December 2019). All plots received two nitrogen (N) applications, each of 75 kg N/ha in the form of SustaiN® on 16 October, 2019, and 11 November, 2019, prior to an irrigation or rain event.

All fungicide applications were made with a battery operated 2.8 m hand held plot boom with 6, 110 015xr AI tee jet nozzles at a working pressure of 250 kpa delivering 165 L/ha water at a walk speed of 3.6 kph. The fungicides evaluated were Amistar® - (a.i. 250 g/L azoxystrobin), Proline® (a.i. 250 g/L prothioconazole), Prosaro® – (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole), and Seguris® flexi - (a.i. 125 g/L isopyrazam) applied twice either alone or in mixtures at mid-flowering (28 November (cv. AgriTonic) and 11 December (cv. Boston) and repeated 14 days later (Table 1). Disease assessments were made by sampling 90 heads per plot at harvest, and separating into those with disease, non-diseased and immature heads. The data presented on percent diseased heads excluded the immature heads.

Windrowing occurred for the cv. AgriTonic plots on 3 January, 2020, and the cv. Boston plots on 5 February, 2020, with a modified 1.8 m John Deere windrower. Cv. AgriTonic plots were harvested on 20 January, 2020, and cv. Boston plots on 18 February, 2020, with a Wintersteiger Elite Nursery master combine. Results were analysed using Genstat®19th Edition (VSN 2019).

Margin over cost (MoC) relative to the untreated was calculated for each treatment, based on a grower's price of $4.00/kg for seed, the fungicide costs and application at $20/ha per application.

Results and Discussion

Seed yield was similar for both plantain cultivars; 2,300 kg/ha for cv. AgriTonic and 2,410 kg/ha for cv. Boston (Table 1). Seed yield was increased by all fungicide treatments (Table 1). There was a cultivar by fungicide interaction where the later heading cv. Boston had more Phomopsis stalk disease in the untreated control (24% of stems) than in the earlier flowering cv. AgriTonic (7%) (Table 2). When fungicide was applied the amount of Phomopsis stalk disease observed was similar in both cultivars and all fungicide treatments.

The Proline® fungicide treatment produced the highest MoC relative to the control in cv. Boston ($3,200/ha) and in cv. AgriTonic ($1,530/ha) (data not shown). The higher MOC for fungicides applied to cv. Boston was a result of lower seed yield in untreated plots caused by an increased presence of stalk disease.

Summary

Seed yield was similar between the two cultivars. There was greater stalk disease in the untreated cv. Boston than cv. Agritonic, probably associated with its four-week later heading date. Proline®, applied twice, at mid-flowering and 14 days later, was as effective as adding a strobilurin fungicide (Amistar®) or a succinate dehydrogenase inhibitor (SDHI) (Seguris® Flexi). However, as part of an anti-resistance strategy, fungicide families should not be applied alone. The trial will be repeated in 2020-21.

Table 1. Seed yield of two plantain cultivars following treatment with five fungicide programmes when grown near Lincoln, Canterbury in the 2019-20 season.

	Fungicide treatment applied mid flowering + 14 days [1]	Seed yield (kg/ha)		Fungicide mean (kg/ha)
		cv. AgriTonic	cv. Boston	
1	nil	2090	1840	1970 b
2	Prosaro® (1 L/ha) + Amistar® (0.5 L/ha)	2360	2480	2420 a
3	Proline® (0.8 L/ha)	2470	2650	2560 a
4	Proline® (0.8 L/ha) + Seguris® Flexi (0.6L/ha)	2340	2460	2385 a
5	Proline® (0.8 L/ha) + Amistar® (0.5 L/ha)	2240	2650	2440 a
	Cultivar mean	2300	2410	
			LSD (p=0.05)	284
			P value – fungicide trt[2]	<0.01

Note: Yellow indicates the treatments with the greatest mean seed yields.
[1]cv. AgriTonic application dates – 28 November and 11 December, 2019, cv. Boston application dates – 11 December and 23 December, 2019.
[2]P value interaction = 0.204, P Value cultivar =0.149

Table 2. Average percentage of heads infected with Phomopsis stalk disease following the application of five fungicide treatments on two cultivars of plantain when grown at Lincoln, Canterbury in the 2019/2020 growing season.

Treatment number	Mid Flowering + 14 after Application[1]	disease heads (%)	
		cv. AgriTonic	cv. Boston
1	nil	6.2	24.0
2	1 L/ha Prosaro® + 0.5 L/ha Amistar®	5.0	3.5
3	0.8 L/ha Proline®	1.9	4.1
4	0.8 L/ha Proline® + 0.6 L/ha Seguris Flexi®	4.9	1.7
5	0.8 L/ha Proline® + 0.5 L/ha Amistar®	2.1	2.7
	LSD(p=0.05)	4.2	
	P value, cultivar * fungicide	<0.001	

[1]'AgriTonic' application dates – 28 November 2019 + 11 December 2019, 'Boston' application dates – 11 December 2019 + 23 December 2019

Herbicides for weed control in plantain seed crops

Project Code H19-17

Duration Year 1 of 1

Author Owen Gibson, Phil Rolston, Richard Chynoweth (FAR)

Location FAR Kowhai Lincoln Site, Mid Canterbury (GPS: 43° 28' 24" S; 172° 28' 14" E).

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator)

Key points

- In a trial site where speedwell and fumitory were the main weeds present, combinations of Karmex®DF (diuron) pre-emergence, Gramoxone® 250 (paraquat) or Nortron® (ethofumesate) plus Gramoxone® 250 reduced weed populations by 45% and increased seed yield by 85%.
- T Max™ (aminopyralid) or Argosy® (diflufenican plus bromoxynil) applied in mid-winter caused some leaf burn, but produced yields similar to the highest yielding groups.
- Firebird® (Flufenacet plus diflufenican) and Stomp® (pendimethalin) both killed plantain.

Background

Plantain (*Plantago lancelata*) seed production is approximately 300 t/year, with a range of cultivars grown. Currently, there is no publicly available information on weed management of plantain as a seed crop. This project was developed to understand the impact of weed competition on seed yield and the use of early spring herbicides in plantain seed crops in order to identify effective weed control/herbicide options.

Methods

The trial evaluated 10 herbicide treatments (Table 1) on the plantain cultivar AgriTonic in a randomised complete block design with four replicates. Plots were 3.2 x 10 m, the soil type was a Wakanui silt loam, and the trial was irrigated. Weedmaster® TS540 (active ingredient (a.i.) 540 g/L glyphosate) at 3 L/ha + Pulse® penetrant (a.i. >800 g/L organomodified polydimethylsiloxane) was applied pre-plant on 22 March 2019. The trial was drilled with a disc-plot drill on 25 March 2019 with 15 cm row spacings.

All herbicide applications were made with a battery operated, 2.8 m hand held plot boom with 6, 110 02xr TeeJet® nozzles at a working pressure of 250 kpa delivering 200 L/ha water at a walk speed of 3.6 kmph. An application of 1 L/ha Kamba® 500 DF (a.i. 500 g/L dicamba) was applied to all plots on 25 May 2019 to control volunteers from a previous crop of faba beans. Herbicide efficacy was evaluated from 24 May 2019 at weekly intervals until 9 October 2019.

The proportion of dry matter (DM) as weeds, or plantain, was assessed by hand sorting leaf tissue and oven drying for 48 hours at 70°C on 21 October 2019. The main weeds in order of occurrence were speedwell (*Veronica persica*), fumitory (*Fumaria* sp.), shepherd's purse (*Çapsella bursa-pastoris*), groundsel (*Senecio vulgaris*).

The plots were windrowed on 3 January 2020 with a modified 1.8 m John Deere windrower. All plots were harvested with a Wintersteiger Elite Nursery Master combine on 20 January 2020 and a sub-sample cleaned to a 99% purity using a Dakota screen separator for calculation of seed yield per hectare. Data analysis used the GenStat v19 ANOVA package.

Margin over Cost (MoC), relative to the control, were calculated using a grower seed price of $4.00/kg, the herbicide cost and an application cost of $20/ha for each application.

Results and Discussion

Seed yield was increased over the control by all herbicide treatments where plantain was not killed. The top six herbicide treatments were similar to each other with seed yields in the range of 1,620 to 1,800 kg/ha (Table 1). When Stomp® (a.i. 330 g/L pendimethalin) and Firebird® (a.i. 400 g/L flufenacet + 200 g/L diflufenican) were applied pre-emergence, complete loss of plantain occurred. Agrosy® (a.i. 25 g/L diflufenican and 250 g/L bromoxynil) and T-Max™ (a.i. 30 g/L aminopyralid) applied late-winter (8 August 2019), resulted in severe chlorosis. However, the plantain recovered and produce adequate head numbers and seed yield was not affected. Bromitril® (a.i. 400 g/L bromoxynil) applied in early-spring depressed seed yield.

All plots were sprayed with Kamba® 500 DF (dicamba) in May for volunteer faba beans. Broadleaf weeds were still abundant; the common weeds were speedwell and fumitory (data not presented). In the control, half the biomass present was that of weeds, indicating substantial competition for limited resources.

The MoC value closely followed the yield trend with three treatments generating a MoC of greater than $3,000/ha compared with the control.

Summary

All herbicides applications reduced weed levels to below 7% of total biomass in late spring and increased seed yield above the control unless they killed the plantain crop. Treatments with Karmex®DF (diuron) pre-emergence, and Nortron® (ethofumesate) and Gramoxone® (paraquat) post-emergence, were effective where the primary broadleaf weeds were speedwell and fumitory. Stomp® and Firebird® pre-emergence killed plantain.

Table 1. Herbicide treatments and dates of herbicide application in a plantain, cultivar AgriTonic, crop at Lincoln in the 2019-20 growing season, as well as average of percentage dry matter (DM percentage 21 October), seed yields (kg/ha) and Margin over Costs (MoC).

Treatment number	28.3.19 Pre-emerge[1]	17.04.19 Post-emerge	8.8.19 Late winter	19.8.19 Late winter + 2 weeks	19.9.19 Spring	Seed Yield (Kg/ha)	Weed load (% of total DM)	MoC[2] ($)
	Timing of herbicide application							
1	Control	-	-	-	-	960	51	0
2	Karmex®DF (1.2 kg/ha)	-	T Max™ (1 L/ha)	-	Gramoxone® (2 L/ha)	1710	0	2800
3	Stomp® (1 L/ha)	-	-	-	-	0	-	-
4	Firebird® (0.3 L/ha)	-	-	-	-	0	-	-
5	-	Nortron® (3L/ha)	Gramoxone® (2 L/ha)	-	Argosy® (1 L/ha)	1780	1.5	3110
6	-	-	Gramoxone® (2 L/ha)	Karmex®DF (1.2 L/ha)	-	1640	4.0	2620
7	Karmex®DF (1.2 kg/ha)	-	Gramoxone® (2 L) + Quantum® (0.2 L/ha)	-	Basagran® (2 L/ha) + Hammer® Force (0.07 L/ha)	1620	6.5	2440
8	-	Nortron® (3L/ha)	Argosy® (1 L/ha)	-	Gramoxone® (2 L/ha)	1790	0.8	3140
9	Karmex®DF (1.2 kg/ha)	-	Gramoxone® (2 L) + Karmex®DF (1.2 kg/ha)	-	Bromotril® (0.62 L/ha)	1460	4.7	1840
10	Karmex®DF (1.2 kg/ha)	-	Gramoxone® (2 L/ha)	-	Gramoxone® (2 L/ha)	1800	1.3	3210
					LSD (p=0.05)	324	4.9	1310
					P value	< 0.001	<0.001	<0.001

Note: Yellow indicates the treatments which had the greatest seed yield and MoC[2].

[1] Karmex®DF (a.i. 800 g/kg diuron), Stomp® (a.i. 330 g/L pendimethalin), Firebird® (a.i. 400 g/L flufenacet + 200 g/L diflufenican), Nortron® (a.i. 500 g/L ethofumesate), T-Max™ (a.i. 30 g/L aminopyralid), Gramoxone® 250 (a.i. 250 g/L paraquat), Quantum® (a.i. 500g/L diflufenican), Argosy® (a.i. 25 g/L diflufenican and 250 g/L bromoxynil), Basagran® (a.i. 480 g/L bentozone), Hammer® Force (a.i. 240 g/L carfentrazone-ethyl) and Bromotril® (a.i. 400 g/L bromoxynil).

[2]Margin over cost relative to the control: Seed price = $4/kg, Application price = $20 per herbicide application.

Sow thistle control options in white clover

Project code H19-18

Authors Owen Gibson, Richard Chynoweth (FAR)

Duration Year 2 of 3

Location Barrhill, Mid Canterbury (GPS: -43.670436,171.821209)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Les and Grant Maw (trial hosts), NZ Arable (trial operator)

Key points

- Replacement herbicide treatments containing diflufenican and bromoxynil such as Argosy® provided similar weed control and produced similar seed yields when compared with Jaguar® (a.i. 25 g/L diflufenican and 250 g/L bromoxynil).
- Once crop flowering begins, application of Tropotox® Plus (a.i. MCPB 375 g/L and MCPA 25 g/L), reduces seed yield of white clover.
- Treatments with a mixture of 2,4-D ester, with diflufenican and bromoxynil applied in late July resulted in high seed yields (790 to 860 kg/ha) and a low sow thistle density.
- Unless there is high weed pressure, herbicide application might not increase yield, but will reduce seed returned to the soil seedbank.

Background

In white clover seed crops, sow thistle (*Sonchus* spp.) can be difficult weeds to control. Three subspecies, *Sonchus arvensis* (perennial sow thistle), *Sonchus asper* (spiny leaved sow thistle) and *Sonchus olerceus* (annual sow thistle) can be present at the same time. Generally, spiny and annual sow thistle are more problematic in Canterbury farming systems than perennial sow thistle.

For the past ten years, the most commonly used control strategy for sow thistle has been the application of a combination of Jaguar® (active ingredient (a.i.) 25 g/L diflufenican and 250 g/L bromoxynil) and 2, 4-D Ester (e.g. Relay® Super S (a.i. 680 g/L 2,4-D as the ethylhexyl ester)) during later winter when clover is dormant but 'about to' start growing. Alternative control options are late autumn application of herbicides to 'hold' the sow thistle and slow growth before these late winter applications. However, bare ground and aggressive growth regulation of clover can allow spring germination of thistles which can be detrimental to clover seed yield where clover was late established or growth was reduced by pest pressure.

As Jaguar® has been removed from the market, the aim of this trial was to evaluate alternatives to Jaguar® and to assess herbicides for use in poorly-established, weaker or dryland crop scenarios. An additional trial was included to investigate late season use of Tropotox® Plus on white clover seed yield (no weed control data was collected). In a previous trial in 2018-19, alternatives herbicides to Jaguar® demonstrated good sow thistle control, including Paraquat or Quantum® and Bromotril®, mixed to provide the same active ingredients as Jaguar®. TropotoxTM Ultra was also shown to 'hold' thistle development for follow up applications (Vreugdenhil and Chynoweth 2019).

Methods

Trial 1

The trial was established in an irrigated paddock of first year white clover cultivar Merlin, near Barrhill, Mid Canterbury. Fifteen treatments were investigated over two application dates on 22 July and 10 September, 2019. The trial received standard farm management except for herbicide. On 24 October, 200 kg/ha of sulphate of ammonia was applied to treatments 9 and 15 (Table 1) in an attempt to promote growth from severe stunting following the application of 3 L/ha of Agritone® 750. The trial was a randomised complete block design with four replicates.

Visual assessments of clover damage, general weed cover, and thistle damage were carried out weekly from 29 July to 7 October, 2019. Scores were on a 0-10 scale, where 0 was not damaged and 10 was dead. Once a thistle was scored a '10' for three weeks consecutively, it was considered dead and no longer scored. Flower counts (0.08 m^2, two per plot) were carried out weekly from the beginning of flowering (19 November, 2019) until three weeks after peak flowering (14 January, 2020). Flowers were determined to be flowering when they had five florets present, and to be finished when one third of the flower was pollinated. A pre-harvest dry matter cut (0.25 m^2) from every plot was carried out on 10 February, 2020, to determine total flower number and biomass. The trial was desiccated on 13 February, 2020, with 3 L/ha Reglone® (a.i. 200 g/L diquat) + 25 mL per 100L Actiwett® (Linear alcohol ethoxylate 935 g/L) and harvested on 17 February, 2020, with a Wintersteiger plot combine harvester.

Trial 2

In the same paddock, the timing of late season Tropotox® Plus applications was investigated using two treatment timings with four replicates. Tropotox® Plus was applied at 4 L/ha on 4 November and 26 November 2019. The trial was harvested at the same time as the herbicide trial.

Results and Discussion

The spiny leaved sow thistle (*Sonchus asper*) was the predominate thistle present at the beginning of the trial.

All herbicide treatments reduced sow thistle numbers per plot compared with the untreated control on 4 January 2020 (<0.001) (Table 1). The treatment in which 3 L/ha Agritone® was applied July had more sow thistles present than many other treatments. In both Agritone® treatments (Treatments 8 and 9), many of the sow thistles present on 4 January germinated and established in the spring as a result of decreased clover growth. This was the second consecutive season where such germination occurred, whereas the crop treated with Relay® Super S achieved row closure prior to the spring sow thistle germination (in approximately early November, 2019). For all other treatments, thistles recorded were those that re-grew following herbicide treatment. All diflufenican and bromoxynil mixtures were similar in weed control and seed yield (Table 1).

Machine dressed seed yield was influenced by herbicide treatment, but many treatments were not different from the untreated control (Table 1). No differences were present in total flower numbers pre-harvest (data not shown), but there were differences in dry matter production, especially where 3 L/ha of Agritone® was applied in July reducing dry matter mass by 40% from the untreated control (6,300 kg DM/ha) (data not shown). However, the differences in dry matter production between treatments did not correlate to differences in seed yield (R^2 =0.05).

There were substantial differences in the MoC for sow thistle herbicide programmes relative to the control because of the relatively high seed yield from control plots, but most were considered statistically non-significant. Treatment 3 (July application of Quantum® + Bromotril® + Relay® Super) had the highest MoC of $670. Agritone® was very detrimental to seed yield, reducing the seed yield compared with the untreated control by 22%, especially in Treatment 9 (3 L Agritone®, July application). This resulted in a loss of $940 when considering costs of application and resulting seed yield (Table 1).

The ability for late weed control in white clover seed crops using Tropotox® Plus up to late November was investigated. Tropotox® Plus when applied at 4 L/ha at early November (>20 flowers/m^2) gave a 13% reduction in seed yield. When applied 3 weeks later (approximately 100 flowers/m^2 a further 19% reduction was recorded, resulting in an overall loss of 32% from the untreated control (Table 2). Further research is needed to understand when the latest application of herbicide can be applied without affecting the seed yield of the white clover. In the previous year's trial, all treatments of TropotoxTM Ultra on 23 August reduced seed yield compared to the best performing sow thistle programmes (Vreugdenhil and Chynoweth 2019).

Summary
In 2018-19, alternatives herbicides to Jaguar® demonstrated good sow thistle control, including paraquat (Gramoxone® 250) or diflufenican (Quantum®) and bromoxynil (Bromotril®), mixed to provide the same active ingredients as Jaguar® (Vreugdenhil and Chynoweth 2019). In 2019-20, these herbicide treaments performed well, while the addition of 2,4-D ester (Relay® Super S) to diflufenican + bromoxynil combinationsalso provided effective sow thistle control and high seed yield when applied on 22 July or 10 September.

The introduction of a new diflufenican and bromoxynil formulation (Argosy®) to replace Jaguar® was shown to have a similar efficacy. In contrast, MCPA herbicide Agritone® reduced clover growth resulting in spring germination of sow thistle between drill rows. Tropotox® Plus, containing a mix of MCPA and MCPB, also reduced seed yield suggesting these may not be useful for sow thistle management.

Reference

Vreugdenhil, S, and Chynoweth, R (2019). Sow thistle control options in white clover. *FAR Research Results 2018/19*. Pp 108-110.

Table 1. Seed yield, thistle suppression and Margin over Cost for a first-year crop of white clover cultivar Merlin, grown near Barrhill, Mid Canterbury in the 2019-20 growing season using different herbicide treatments for sow thistle control.

Treatment Number	Herbicide treatment and timing		Sow thistles[1] (count/plot)	Seed yield (kg/ha)	MoC[2] ($/ha)
	22 July 2019	10 September 2019			
1	-	-	59	720	0
2	Jaguar® (1.5 L/ha) + Relay® (1.75 L/ha)	-	2.0	790	260
3	Quantum® (200 mL/ha) + Bromotril® (950 mL/ha + Relay® (1.75L/ha)	-	0.8	860	670
4	Argosy® (1.5 L/ha) + Relay® (1.75 L/ha)	-	0.3	830	470
5	-	Jaguar® (1.5 L/ha) + Relay® 1.75 L/ha)	1.0	800	310
6	-	Quantum® (200 mL/ha) + Bromotril® (950 mL/ha) + Relay® (1.75 L/ha)	2.3	800	330
7	-	Argosy® (1.5 L/ha) + Relay® (1.75 L/ha)	1.0	800	330
8	Agritone® 750 (2 L/ha)	-	11*	700	-190
9	Agritone® 750 (3 L/ha)	-	30*	560	-940
10	Tropotox® (4 L/ha)	Tropotox® (4 L/ha)	14	850	530
11	Tropotox® (4 L/ha) + Sharpen (5 g/ha)	Tropotox® (4 L/ha)	6.0	780	70
12	Gramoxone® 250 (2 L/ha)	Gramoxone® 250 (2 L/ha)	5.8	800	350
13	Gramoxone® 250 (2 L/ha)	Tropotox® 4 (L/ha) + Sharpen® (7.5 g/ha)	11	710	-170
14	Gramoxone® 250 (2 L/ha)	Sharpen® 25 (g/ha)	15	750	70
15	Gramoxone® 250 (2 L/ha)	Agritone® 750 (3L/ha) + Sharpen® (5 g/ha)	6.5	730	-80
		Mean	10.9	766	115
		P Value	<0.001	0.029	0.046
		15.34	146	15.34	867

Note: Yellow indicates the treatment was amongst the treatments showing the greatest seed yield ($p<0.05$), greatest number of thistles/plot or highest MoC. Chemical active ingredients (a.i.): Jaguar® (a.i. 25 g/L diflufenican and 250 g/L bromoxynil), Relay® = Relay® Super S (a.i. 680 g/L 2,4-D ester), Quantum® (a.i. 500 g/L diflufenican), Bromotril® (a.i. 400 g/L bromoxynil), Argosy® (a.i. 25 g/L diflufenican and 250 g/L bromoxynil), Agritone® 750n (a.i. 750 g/L MCPA), Tropotox® = Tropotox® Plus (a.i. MCPB 375 g/L and MCPA 25 g/L), Gramoxone® 250 (a.i. 250 g/L paraquat) and Sharpen® (a.i. 700 g/kg saflufenacil). [1] Thistles per plot were measured on 4 January 2020. [2] Margin over Cost (MoC): White Clover seed price + $5.50 kg and $20 per spray application. * includes spring germinating sow thistle due to reduced clover growth. NB. When comparing the MoC data for this trial with the FAR 2018/2019 Annual Report, the previous reports values are higher by $1328/ha per treatment, the value calculated as the return with nil herbicide.

Table 2. Seed yield of white clover cultivar Merlin, grown near Barrhill, Mid Canterbury in the 2019/20 growing season following treatment with Tropotox® Plus (a.i. MCPB 375 g/L and MCPA 25 g/L), applied at one of three timings.

Treatment number	Application timing	Seed yield (kg/ha)
1	Untreated	1080
2	4 November 2019	940
3	26 November 2019	760
	Mean	928
	P value	0.003
	$LSD_{0.05}$	113

Note: Yellow indicates the treatment with the greatest seed yield ($p<0.05$)

The effect of row spacing on seed yield of medium and large leaved white clover cultivars grown with and without irrigation

Project code H19-20

Authors Owen Gibson, Richard Chynoweth and Phil Rolston (FAR)

Duration Year 1 of 3

Location FAR Chertsey Arable Research Site, Mid Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator)

Key points

- White clover seed yield was greater when sown in 60 cm rows than 30 or 45 cm rows when irrigated.
- Under irrigation the seed yield of the larger leafed cv 'Legacy' was 64% higher in 60 cm rows compared with 30 cm wide rows.
- When grown under dryland conditions, there was no difference in seed yield when medium or large leaved cultivars were sown in 30, 45 or 60 cm row spacing.

Background

Shading of stolons can reduce light penetration to the leaf axis from where flowers are developed. Additionally, shading of flowers and their associated leaf can result in flower abortion and reduced seed yields. White clover seed crops are traditionally sown in 30 cm rows, where the stolons have the ability to run across open ground before they meet the neighbouring row. Altering the row spacing will change the distance the stolons can run before they meet the next row and become shaded. This may also influence leaf density and shading. Row spacings of 15, 30 and 45 cm were compared by Clifford (1987) who found 30 cm rows to be the most efficient at providing maximum space for floral expression and therefore maximum seed yield (for cultivars Huia (medium leaf) and Pitau (large leaf). He noted that these results may vary with development rate of individual cultivars and with soil fertility.

In general soils used to grow white clover for seed in Canterbury have a higher available phosphorus (Olsen P) and are more likely to be irrigated than when the 1987 study was reported by Clifford. The aim of this trial was to investigate if wider row spacing may be an advantage to growing modern, larger leaved white clover cultivars under irrigation.

Methods

The trial evaluated seed crops of white clover cultivars Quartz, of medium leaf size, and Legacy, a large-leaved white clover, at three row spacings (30, 45 and 60 cm) under both dryland and irrigated conditions. The trial was conducted in adjacent columns (one dryland and the other irrigated) at the FAR Chertsey Arable Research Site, Mid Canterbury. The soil type was a Chertsey shallow silt loam. The trial was drilled with a tractor mounted research plot drill; each row spacing was drilled as a separate pass through the trial on 21 March, 2019. There were 6 treatments (2 cultivars and 3 row spacings) for the dryland and irrigated blocks, with four replicates in a randomized block design with plots 10 m long and 1.5 m wide. The trial received standard management for both the dryland and irrigated trials, see Appendix 1 for details.

Establishment was slow for both dryland and irrigated columns, with slug damage and resultant frost heave of underdeveloped plants during winter resulting in low clover cover in some areas. Thus, herbicides were not applied until late winter. This contributed to weed pressure and resulted in hand-weeding of plots in spring as stolons began to run.

Irrigation decisions were based on weekly readings of neutron probes, and a total of 230 mm of water was applied in seven applications between 5 November, 2019, and 7 January, 2020.

A pre-harvest dry matter cut was taken from every plot to determine total flower number and biomass on 28 January, 2020, for dryland, and 13 February, 2020, for irrigated. The trial was harvested with a roto cut push mower and then transferred into a Wintersteiger plot combine for thrashing. The sample was cleaned to a First Generation Seed Certification Standard.

Results and discussion

Under dryland conditions, there was no seed yield response to row spacing and no difference between the two cultivars (Table 1). In contrast, under irrigation, seed yield was increased by row spacing (average of both cultivars) increasing from 450 to 620 kg/ha as row spacing increased from 30 to 60 cm (Table 2). There was a trend (p=0.065) for the response to be greater in the large-leaved cultivar Legacy, which had a 65% seed yield increase as row spacing increased, compared with a lower increase of 14% in the smaller leaved cultivar Quartz (Table 1 and Figure 1).

Table 1. White clover seed yields when sown at three row spacings and grown under dryland and irrigated conditions at Chertsey, Mid Canterbury in the 2019-20 growing season.

Treatment	Cultivar	Row spacing (cm)	Seed Yield (kg/ha)	
			Dryland	Irrigated
1	Quartz	30	370	480
2	Legacy	30	390	420
3	Quartz	45	360	450
4	Legacy	45	410	470
5	Quartz	60	370	550
6	Legacy	60	420	690
		Mean	390	510
		P value	NS	0.001

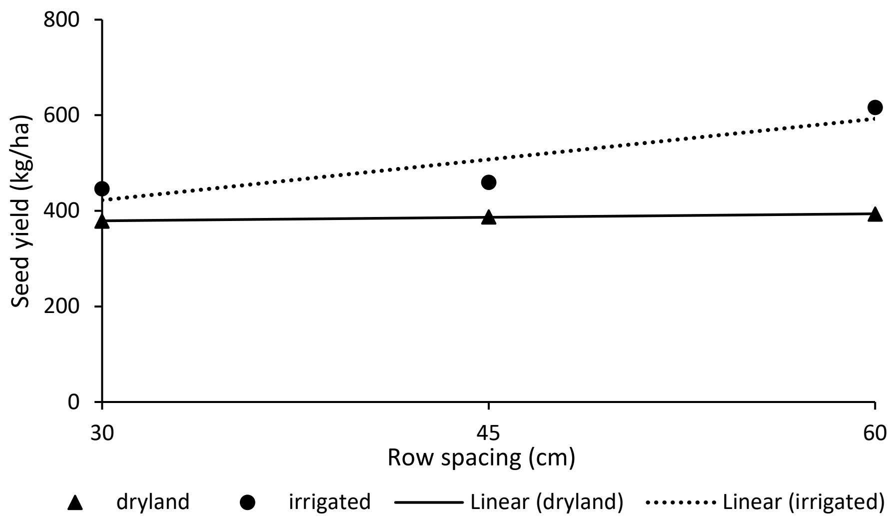


Figure 1. Seed yield of white clover, average of the cultivars Legacy and Quartz, when sown at three row spacings and grown under dryland and irrigated conditions at Chertsey, Mid Canterbury in the 2019-20 growing season.

There was a small, but significant thousand seed weight (TSW) increase with irrigation, 0.64 g versus 0.68 g ($LSD_{0.05}$= 0.02), but no difference in TSW between the two cultivars. The two wider row spacings had a small, but significantly higher TSW compared to 30 cm row spacings, 0.64 v 0.67 g (($LSD_{0.05}$= 0.02).

There was no significant difference in dry matter production in the dryland trial (data not presented), suggesting that water supply limited growth and development. Drought stress resulted in very uniform flower numbers between treatments in the dryland trial with no significant differences observed. The irrigated trial produced 60% greater dry matter in the 30 cm row spacing treatment compared with the 60 cm row spacing (p value = 0.001, data not presented) and was observed for both varieties.

This first year of data suggests that seed yields benefit from using wider rows than the current standard 30 cm for large-leaved cultivars when irrigation is available. This work requires further trials to determine the repeatability of the results.

Summary

The seed yield of a medium leaf size cultivar (cv. Quartz) and a large leaf size cultivar (cv. Legacy) were compared under dryland and irrigation with three row spacings, 30, 45 and 60 cm. Under dryland conditions there was no seed yield difference between cultivars and row spacing. Under irrigation, however, the seed yield response for the large leaf type was increased by increased row spacing from 420 kg/ha at 30 cm to 690 kg/ha at 60 cm wide row spacing.

Reference

Clifford, P.T.P. 1987. Producing high seed yields from high forage producing white clover cultivars. International Seed Conf. Tune, Denmark, June 1987.

Appendix 1

Management for both the dryland and irrigated trials

21 March 2019	Trial sown
21 August 2019	1.5L/ha Jaguar® (25 g/L diflufenican and 250 g/L bromoxynil)
10 September 2019	0.5L/ha Arrow® (360 g/L Clethodim) + 2L/ha Hasten® (704 g/L Ethyl and Methyl Esters)
27 September 2019	2L/ha Gramoxone® (250 g/L Paraquat)
25 October 2019	4L/ha Tropotox® (375g/L MCPB and 25g/L MCPA) + 7.5g/ha Sharpen® (700 g/kg saflufenacil)
1 November 2019	0.5L/ha Arrow® (360 g/L Clethodim) + 2L/ha Hasten® (704 g/L Ethyl and Methyl Esters)
29 January 2020	4L/ha Reglone® (200 g/L Diquat) + Contact™ Xcel (980g/L linear alcohol ethoxylate) (**Dryland**)
31 January 2020	Harvest (Dryland)
21 February 2020	5.0L/ha Buster® (200 g/L Glufosinate-ammonium) (**Irrigated**)
3 March 2020	3L/ha Reglone® (200 g/L Diquat) + Contact™ Xcel (980g/L linear alcohol ethoxylate) (**Irrigated**)
6 March 2020	Harvest (Irrigated)

Beneficial and pest invertebrates of red clover seed crops in Canterbury

Project code H19-21

Author Joel Faulkner (Lincoln University)

Duration Year 2 of 5

Location Methven, Mid Canterbury (GPS: 43° 34' 12.01" S; 171° 39' 40.20" E)

Funding Seed Industry Research Centre (SIRC), FAR

Acknowledgements Ian Marr and Hamish Marr (trial hosts), Scott Hardwick (AgResearch), NZ Arable (trial operator), FAR

Key points

- The main insect pests captured by suction sampling and sweep netting were aphids and mirids.
- Thrips were commonly found when seed heads were dissected, but were not detected as well by suction sampling and sweep netting. Red clover case bearer male moths were plentiful in number in a pheromone trap, but larvae were only infrequent in seed heads.
- Beneficial insects that predate on insect pests were plentiful, including lace wings, damsel bug, lady bird, hover fly and European harvestman.
- Spring topping reduced the abundance of predator species, at least in the short-term.
- A number of insecticide treatments resulted in a reduction in pest and predator numbers and an increase in seed yield.

Background

Red clover case bearer (*Coleophora deauratella*) was first reported in New Zealand in December 2016, although subsequent pheromone trapping in 2017-18 reported widespread distribution suggesting the pest had established some years prior to its discovery (Chynoweth et al. 2018). Red clover case bearer larvae eat developing seeds, and growers have reported severe seed yield losses when the pest is present.

In 2018-19, as a result of the discovery of red clover case bearer, we began to study strategies for management of this pest, testing insecticide programmes suitable for control and assessing their impact on beneficial insects in the crop (Rolston *et al*. 2019). However, little research has been conducted on the dynamics of pest and beneficial insects in red clover seed crops in New Zealand.

This study begins to explore invertebrate dynamics for red clover to understand options for Integrated Pest Management (IPM) (Barzman et al. 2015) of the crop, underpinning a future PhD on the topic. Over the summer of 2019-20, trials were undertaken in two red clover seed crops with the aim to: 1. investigate the dynamics of pest and beneficial invertebrate populations in red clover seed crops by thoroughly sampling insects during spring and summer; 2. provide a detailed explanation of the invertebrates present and their average abundance throughout the season, and 3. investigate how spring topping impacts pest and beneficial invertebrate populations.

Methods

Two red clover (cultivar Relish) paddocks on neighbouring farms in Methven, Mid Canterbury were set up with five large plot (300+ m long) treatments: (i) untreated control, (ii) 'short cut' (5-7cm) topped crop with IPM, (iii) 'short cut' topped crop with conventional insecticide programme, (iv) 'long cut' (7-9cm) topped crop with IPM, and (v) 'long cut' with conventional insecticide programme. Each trial had two replicates of each treatment.

Treatments were topped on 22 November. To compare an IPM programme to a conventional insecticide treatment, Group 28 insecticide Exirel® (100 g/L cyantraniliprole) (IPM) or Group 3 insecticide Mavrik®Aquaflo (240 g/L tau-fluvalinate) (conventional) were applied on 14 January 2020. Exirel® was selected as the IPM option because it is only active as a feeding blocker on invertebrates feeding directly on the sprayed plant, whereas Mavrik® was selected because it is a broad spectrum synthetic pyrethroid that kills on contact. In addition, a small plot trial with a wider range of insecticides was evaluated (trial design not presented).

For invertebrate sampling, both a suction sampler (inverted leaf blower) and sweep net were used to better capture the range of different invertebrates present in the crop. The sampling regime was; suction sampler, four by 5 second intervals of suctioning the crop spaced 10m apart. Sweep net, 10m. For each treatment in each rep, two sweep and two suction samples were taken. The samples collected where frozen, and identified. Invertebrates were sampled before and at weekly intervals after mechanical topping was completed.

The report describes preliminary data from the collection of invertebrates under these trial conditions and from treatment of the crop with different topping regimes and insecticide programmes. A full data set and further statistical analysis will be performed in future to confirm any relationships between topping or insecticide programmes on pest and beneficial invertebrate populations. The associated costs-over-margins will also be calculated.

Results and Discussion

The most common pests identified in the two red clover crops in Methven, Mid Canterbury were the lucerne aphid, potato mirid, Australian crop mirid (native), red clover thrip and the red clover casebearer moth (data not shown). Potato mirid nymphs occurred in high numbers (average of 5 per suction sample) around the paddock margin from late spring but begin spreading throughout the crop as they mature. Mirids prefer feeding on the developing flower heads of many crop species, so they can cause economic damage to seed crops if high populations occur. Thrips were obvious if flowers were picked and dissected while red clover casebearers were commonly found in the pheromone trap. The most common predators were the Tasmanian lace wing (native), Pacific damsel bug (native), eleven spotted lady bird, New Zealand hover fly (native) and European harvestman.

Significantly lower numbers of all invertebrate groups were present in topped plots compared with the untreated plots (data not shown). This decline was probably a result of the removal of available habitat in the crop, making it easier for birds to prey on invertebrates and an increase in exposure to weather. Some invertebrate groups recovered faster than others. For example, parasitic wasps reached higher densities than prior to topping only 11 days after topping, whereas lacewing populations did not recover until early January 2020 (a month later). The response of beneficial insect populations was probably dependent on the recovery of prey or host species populations, so the rapid increase of parasitic wasps could be explained by the immediate increase in aphids observed post-topping as the red clover plants produce fresh shoots (the preferred feeding site of many aphid species).

Insecticide treatments resulted in a reduction in pest and predator numbers. In the large plot trial, red clover that was treated with Mavrik®Aquaflo saw a greater decline of both pest and beneficial invertebrates when compared with the untreated control or Exirel® (data not shown). The seed yields in both crops were low (150 to 200 kg/ha) and there were no differences between insecticide treatments (data not shown).

As expected, seed yields were low in the small plot trials as well. Nevertheless, treatment with two insecticides, either Mavrik®Aquaflo or Movento® 100SC (150 g/L spirotetramat), doubled seed yield (Table 1). Movento® 100SC is a different insecticide group (Group 23) to the other insecticides used in this trial and is registered for use in potato and tomato for use against Tomato Potato Psyllid in New Zealand, not legume seed crops. In Australia, it is used in IPM programmes, especially for sucking insects and thrips. It is toxic to bees, so the timing of its application is critical to avoid bee deaths.

Table 1. Seed yield of red clover, cultivar 'Relish', grown near Methven, Mid Canterbury in the 2019-20 growing season following application of seven insecticide treatments.

Treatment	Insecticide[1]	Insecticide application rate	Seed yield (kg/ha)	
1	water	--	122	c
2	Lorsban® EC	500 mL/ha	147	c
3	Karate Zeon®	40 mL/ha	180	bc
4	Mavrik®Aquaflo	150 mL/ha + Actiwett 50mL/100L	236	ab
5	Exiril®	150 mL/ha + Actiwett 50mL/100L	157	c
6	Movento®	560 mL/ha	259	a
7	Spata™	150 g/ha + Actiwett 50mL/100L	181	bc
		LSD (p=0.05)	63	
		F.prob	0.003	

Note: Yellow indicates the treatment was amongst the treatments showing the greatest seed yields.
*Seed yield with the same alphabetical letter are not significantly different.
[1]Lorsban® EC (500 g/L chlorpyrifos); Karate Zeon® (250 g/L Lambda-cyhalothrin); Mavrik®Aquaflo (240 g/L tau-fluvalinate); Exiril® (100 g/L cyantraniliprole); Movento® (150 g/L spirotetramat); Spata™ (120 g/kg spinetoram).

Summary

This was of a preliminary study and highlighted many areas for future study, but most importantly it showed that showed that red clover seed production systems can already support a diverse community of invertebrates. High invertebrate biodiversity is very important as it indicates a potentially high level of biological control is already present in red clover crops that can be enhanced to help manage pests, such as the red clover case bearer. It also suggests that arable landscapes may be less damaging to wild species than some might suggest.

Invertebrates are resilient and all groups (predators, pests and parasitoids) recovered from both topping and insecticide spraying. Nevertheless, feeding blocker sprays such as Exiril® are a safer option for conserving in-field predator and parasite populations, than broad spectrum sprays like Mavrik®Aquaflo. Further investigation of Movento® is required to understand its potential role in integrated management of legume seed crops including its influence on beneficial predators.

More knowledge is also required on the economic thresholds for the major pests found in this study, such as the potato mirid or lucerne aphid, as these thresholds would allow decisions on insecticide applications or other management practices to be a more informed to maximise economic returns and ecological benefits.

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A comparison of seed production of annual ryegrass cultivars Gulf and Winterstar

Project code H19-22

Duration Year 1 of 1

Authors William Mitchell, Owen Gibson, Phil Rolston and Richard Chynoweth (FAR)

Location Kowhai Farm, Lincoln, Canterbury (GPS: 43°38’15.85”S; 172°28’16.64”E)

Acknowledgements NZ Arable (trial operator)

Key points

- Topping increased ryegrass seed yield by 90% across both cultivars and all plant growth regulator (PGR) treatments.
- PGRs increased seed yield by 31%.
- Annual ryegrass cultivar Winterstar yielded 15% higher than cv. Gulf.
- Topping in conjunction with 1.6 L/ha of Moddus® Evo increased seed yield by 177% to 2,879 kg/ha (average for both cultivars), increasing revenue from $3,700 to $6,980/hectare.

Background

New Zealand and Oregon (United States) are both large producers of ryegrass seed. The Canterbury region lies on the same parallel as Oregon in the opposite hemisphere. In Oregon, growers can achieve similar seed yields to New Zealand growers, but the use of plant growth regulators (PGRs), particularly trinexapac-ethyl, is not as common as in New Zealand (pers. com: NP Anderson, Oregon State University). The use of trinexapac-ethyl based PGRs (e.g. Moddus®) in New Zealand has increased seed yields of ryegrass seed crops by 50% since their introduction in 2000 (Chynoweth *et al*. 2010). The New Zealand standard management is to either graze or cut ryegrass for silage a number of times until mid/late October, and then allow the crop to grow for seed production. In contrast, the standard management in Oregon is to leave the ryegrass seed crop to grow untouched from planting to harvest. The aim of the current trial was to determine if the differences in PGR responses between regions is due to cultivar, environment, or management differences (perhaps reflecting the availability of animals).

Methods

This trial was set up with two standard annual ryegrass cultivars, Gulf (Oregon standard annual ryegrass) and Winterstar II (PGGWrightson). It was located near Lincoln, Canterbury. The soil type was a Wakanui silt loam. The field had been sown in a faba bean seed crop for the 2018/19 season.

The trial was established with a disc plot drill on 18 April, 2019, in 10 m x 3 m plots with 15 cm row spacings. The trial was a randomised block design with 12 treatments and four replicates (Table 1). SustaiN® was applied at 60 kg nitrogen (N)/ha on 23 September and 60 kg N/ha on 5 November. Three herbicide applications were applied to control broadleaf weeds: 1.5 L/ha of Pasture-Kleen™ Xtra (a.i. 680 g/L 2,4-D ester) was applied on 15 May, 4 L/ha of Nortron® (a.i 500 g/L ethofumesate) was applied 11 June, and 1.5 L/ha of Jaguar® (a.i 25 g/L diflufenican and 250 g/L bromoxynil) was applied on 21 August. Fungicide applications included 440 mL/ha of Folicur® (a.i. 430 g/L tebuconazole) at PGR application and 440 mL/ha of Folicur® plus 750 mL/ha Amistar® (a.i. 250 g/L azoxystrobin) at mid-flowering.

Two topping regimes were implemented, (i) ‘nil topping’, where the plots were left to grow from sowing, and (ii) ‘topped’, where the plots were mown with a rotary cut, ride-on lawnmower at a height of 70 mm, three times before the crop was closed for seed production. Treatments were topped on 3 September and 27 September, and the final topping (closing) on 21 October, 2019. Three rates of Moddus® EVO (active ingredient (a.i.) 250 g/L trinexapac-ethyl), 0 L/ha, 0.8 L/ha (200 g TE/ha) and 1.6 L/ha (400 g TE/ha), were applied at growth stage (GS) 32 (Zadoks et al. 1974). The trial was irrigated with a total of 85 mm in 4 passes. The nil topped treatments received one irrigation application of 23 mm before they were windrowed.

After each topping, 50 tillers were selected from the topped foliage for each cultivar to inspect whether any growing points had been removed. Visual lodging assessments were done weekly between 17 September and 20 December. Two drill rows by 50 cm were cut from each plot during flowering (21 November for nil topping and 9 December for topped treatments) to assess dry matter (kg DM/ha) production. A pre-harvest cut to assess harvest components (seed head densities, spikelets/head, florets/spikelet, floret site utilisation, and final DM yield) was conducted on 16 December for nil topping and 6 January, 2020, for topped treatments. At harvest a 1.8 m strip was windrowed from the middle of each plot using a modified John Deere plot windrower on 6 December for nil topped treatments and 7 January, 2020, for topped treatments. The trial was harvested using a Wintersteiger Elite Nursery master plot combine. The nil topped treatments were harvested on 24 December, 2019, and the topped treatments on 14 January, 2020. Post-harvest a three row by 50 cm area was vacuumed for seed loss analysis.

Results and Discussion

The treatment that had the largest impact on seed yield of the ryegrass crop was topping (Figure 1; Table 1. P<0.001). Yield was increased by 98% and 82% for cultivars Gulf and Winterstar, respectively, when the crop was topped. On average topping increased seed yield from 1,350 kg/ha to 2,550 kg/ha. Topping significantly reduced harvest losses by 59% from 1,860 kg/ha to 760 kg/ha. The total seed produced pre-harvest was calculated by adding harvest losses to machine-dressed yields. Total yields were increased by topping (Table 1). The topping response was due to a number of factors including reduced lodging, higher plant densities, a reduction in the spread of flowering resulting in less seed shatter on early headsand better light interception during seed fill. Topping removes biomass which helps to delay lodging and increase yield (Figure 2). Topped treatments had an average 55% of the growing points removed at closing (data not shown). Despite this, topping had a higher seed head density of 1,810 heads/m^2 compared to the nil topping treatment of 1,260 heads/m^2 (data not shown). The topped treatment, however, was found to have smaller seed heads with fewer spikelets per seed head compared to the untopped treatments.

Table 1. Treatment list for annual ryegrass trial located near Lincoln, Canterbury in the 2019-20 growing season, including machine-dressed (MD) seed yields, seed loss and combined seed yield and harvest loss.

Treatment number	Cultivar	Closing date	PGR (L/ha)	MD yield (kg/ha)	Seed loss (kg/ha)	Total yield (kg/ha)
1	Winterstar	Nil	0	1250	1110	2360
2	Winterstar	Nil	0.8	1640	880	2520
3	Winterstar	Nil	1.6	1550	1480	3030
4	Winterstar	21-Oct (3x toppings)	0	2270	1040	3310
5	Winterstar	21-Oct (3x toppings)	0.8	2600	1420	4020
6	Winterstar	21-Oct (3x toppings)	1.6	3200	960	4160
7	Gulf	Nil	0	830	2560	3390
8	Gulf	Nil	0.8	1290	1710	3000
9	Gulf	Nil	1.6	1540	1960	3500
10	Gulf	21-Oct (3x toppings)	0	2390	1390	3780
11	Gulf	21-Oct (3x toppings)	0.8	2300	950	3250
12	Gulf	21-Oct (3x toppings)	1.6	2550	780	3330
			Mean	1950	1350	3300
			LSD (p=0.05)	451	1055	1189
			P value (0.05)	<.001	0.058	0.117

The average yield increased 16% from 1,690 kg/ha with no PGR to 1,960 kg/ha with 0.8 L/ha Moddus® EVO. A further yield increase to 2,212 kg/ha was achieved with the full rate (1.6 L/ha) of PGR making an overall increase of 31%. PGR increased the yield at a higher rate for cv. Winterstar.

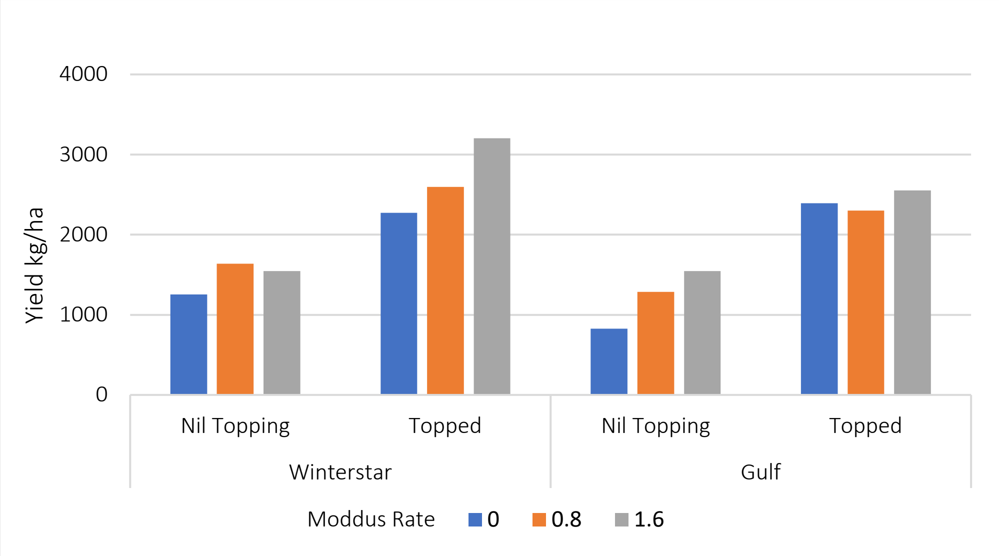

Figure 1. Effect of different rates of the plant growth promoter Moddus® Evo on machine-dressed yields of annual ryegrass cultivars Gulf and Winterstar.

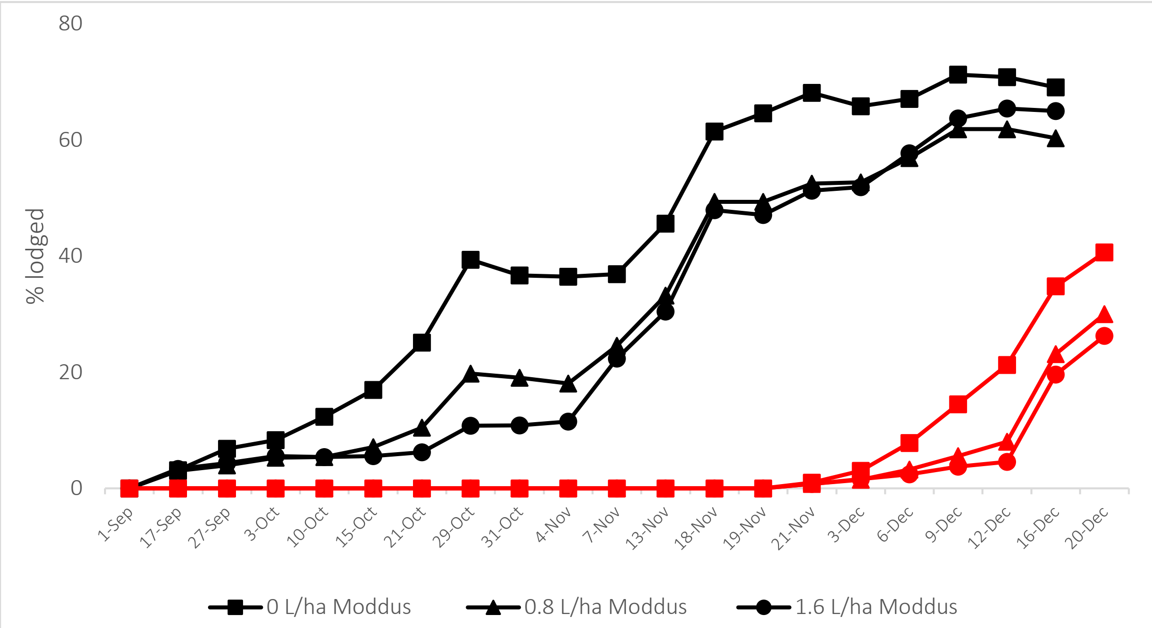

Figure 2. Average annual ryegrass lodging scores (%) for nil topping and topped treatments in response to different plant growth promoter rates of Moddus® Evo for a crop grown near Lincoln, Canterbury in the 2019-20 growing season.

Lodging of the ryegrass was affected by the two different topping treatments as seen on Figure 2. The nil topped treatment began lodging on 17 September whereas in the topped treatments lodging was delayed for over two months until 21 November. By the time the topped treatment started lodging the nil topping treatment was on average already 57% lodged.

Ryegrass cv. Winterstar yielded 15% more seed than Gulf (Table 1). These differences were only in harvested yields. Once harvest losses were included the two cultivars were within 140 kg/ha of each other (Table 1). Over the duration of the trial the topped plots had 59% less harvest losses than the nil topping treatment (Table 1). At the time of windrowing the seed heads in the nil topping plots were at various stages of maturity (some ripe, some shattered, and some immature) compared to the topped plots which were comparably more even.

Table 2. Revenue and Margin over Cost for different topping (nil topping & topped) treatments and plant growth promoter (PGR) rates for annual ryegrass cultivars Gulf and Winterstar combined.

	Nil topping			Topped		
PGR rate (L/ha)	0	0.8	1.6	0	0.8	1.6
Topping revenue ($/ha)				450	460	420
Seed revenue ($/ha)	1,870	2,630	2,780	4,200	4,410	5,180
Straw revenue ($/ha)	1,830	1,770	2,110	1,180	1,270	1,380
Total revenue ($/ha)	3700	4400	4890	5830	6140	6980
Margin over cost ($/ha)	**0**	**700**	**1190**	**2130**	**2440**	**3280**

Unit prices: Silage $0.20/kgDM, Seed $1.80/kg, Straw $0.8/kg, Moddus® Evo $90/L, Application $20/ha.

With no PGR, the topped treatment returned 58 % more revenue than the nil topping treatment (Table 2). At 1.6 L/ha of Moddus® Evo the topped treatment returned 42 % more than the no-topping treatment. The revenue from straw was 35 % lower for the topped treatment at 1.6 L/ha of PGR compared to the nil topping. However, the seed revenue was 86 % higher.

Strong financial gains can be achieved as a result of using the best treatments. Table 2 shows topping made the crop more financially viable as there was on average $440 extra income per hectare. Topping resulted in less harvest biomass which reduced the income from straw by 35% (with 1.6 L/ha of Moddus® Evo). However, the 90 % increase in seed yield from topping (Table 2) meant there was an extra $2,090/ha margin over cost (Table 2).

Seed yields of both New Zealand bred and US bred cultivar commonly used in Oregon were both responsive to topping and PGR. Differences in management approaches between New Zealand and Oregon reflect the historical integrated livestock and seed production systems developed in New Zealand. The combination of topping/grazing and PGR improve seed yield and margin over costs for both cultivars.

Summary
Annual ryegrass seed crop management in Oregon and NZ are very different, with NZ crops being grazed and treated with the stem shortening PGR trinexapac-ethyl. Management with plus/minus spring topping (simulated grazing) and PGR were compared with two cultivars Winterstar (New Zealand) and Gulf (Oregon). Topping increased seed yield of both cultivars by 90 % and PGR increased seed yield by 31 %.

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Red chard seed crop tolerance to herbicides used for mallow control

Project code B19-01

Duration Year 2 of 3

Authors Phil Rolston, Matilda Gunnarsson, Richard Chynoweth (FAR)

Location Irwell, Mid Canterbury (GPS: 43° 41’ 12.40” S; 172° 19’ 59.24” E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Glenn Smith (trial host), NZ Arable (trial operators), James Taylor (South Pacific Seeds NZ)

Key points

- The Group G herbicide carfentrazone (Hammer® Force) caused severe leaf burn on red chard when applied to the crop in mid-May 2019, but not when applied in June, July or August 2019.
- The crop treated in mid-May recovered, but the seed yield was 13% less than in the untreated control.
- Carfentrazone (Hammer® Force) was also mixed with other herbicides used in beets, including Goltix®, Stomp® Xtra and Norton®. These mixes had seed yields similar to Carfentrazone (Hammer® Force) alone.

Background

A number of weed species (mallows, cleavers and field pansy) are hard to control in vegetable beet seed production. Two common mallow species occur in arable crops: large-flowered mallow (*Malva sylvestris*) with purple flowers, and small-flowered mallow (*Malva parviflora*) with smaller whitish flowers.

The Group G herbicide Hammer® Force (active ingredient (a.i.) carfentrazone-ethyl) has been used to control velvet leaf (*Abutilon theophrastia*). Like mallow, velvet leaf is in the Malvaceae family. In New Zealand, Hammer® Force is registered as an additive for herbicides used in grass seed crops, wheat and barley and as a desiccant in potato at harvest. A preliminary trial in 2018 identified that the herbicide carfentrazone-ethyl has potential for management of mallow in beets, with up to 83% control. Consistent with product guidelines, the trial also showed that it can be mixed with other herbicides including Goltix®, Nortron® and Stomp® in beets to extend the weed spectrum, speed up knockdown, and improve control of some hard to kill weeds such as mallows (Chynoweth and Rolston 2019).

Under warm moist conditions, herbicide symptoms may be accelerated when using Hammer® Force, while under very dry and cold conditions, the expression of herbicidal symptoms is slower. The initial trial and observations in some grower paddocks confirmed that the timing of Hammer® Force application may be important, and that applications made in autumn are susceptible to leaf burn. This trial was set up with a range of treatment dates to determine crop tolerance to this herbicide in relation to time of application, and in a mixture with other herbicides commonly used in chards and beets.

Methods

The trial was established in a commercial hybrid red chard seed field at Irwell, sown on 4 March 2019, with beds of 16 female rows (Red Chard 10319) followed by a bed of six male rows (Red Chard 10320), all at 50 cm row spacings with a 1 m gap between beds. The soil type was a Mayfield f-1 silt loam.

Experimental plots were 3.2 m wide and 12 m long and included one bed of female rows (8 m) and one bed of male rows (3 m), with 4 replicates in a randomized block design. There were 11 experimental treatments with a focus on the herbicide Hammer® Force (a.i. 240 g/litre carfentrazone-ethyl) applied at five timings from mid-May to late October, 2019 (Table 1). Other herbicides evaluated as potential mixing partners were Goltix® (a.i. 700 g/kg metamitron), Nortron® (a.i. 500 g/L ethofumesate) and Stomp® Xtra (a.i. 455 g/L pendimethalin). Sharpen® (a.i. 700 g/kg saflufenacil), a Group E herbicide, was used as a standalone treatment. Sharpen®, is a broadleaf herbicide that is commonly used as an additive to other herbicides to improve efficacy. All other crop inputs, including pre-trial weed control, disease control, fertilisers and irrigation were managed by the grower.

Crop damage was assessed separately for male and female rows by visual scores (0=nil; 10=dead) on five occasions from the 14 June to 17 September, 2019. A mean crop damage score was determined for male and female rows. Plant height and lower leaf disease damage (0=nil; 10=severe) were assessed on the 1 November, 2019. Weather data from the nearest NIWA Station (Broadfields) was summarised for seven days before and after each application date. The crop was desiccated with diquat (2 L/ha with uptake oil at 1 L/ha) 10 days before harvest. The plots were direct combined on 26 February, 2020 using vertical cutting knives to separate plants. The seed was cleaned to give machine dressed yield that was calculated to include the area in the male rows.

Results and Discussion

The mallow population was sparse and not evenly distributed in the 2019-20 trial and no data on mallow control was collected. However, the previous year's trial had shown effective control of mallow using Hammer® Force.

Hammer® Force and Sharpen® applied in mid-May resulted in severe crop damage (leaf burn) when compared with June, July, August or early October herbicide applications (Table 1, Figure 1). Leaf burn was especially pronounced in female rows, whilst male rows were damaged slightly less severely (Table 1). Adding other herbicides commonly used in chard did not cause leaf burning when applied in June or July.

At early bolting there was little difference in crop height between treatments, with males and female plants averaging 48 and 32 cm on 1 November, respectively (Table 1). There were differences in lower leaf disease ratings (Table 1), with herbicide-damaged treatments having less disease, associated with leaf loss from the herbicide treatment and new emerging leaves expressing less disease.

The trial seed yields were high, with an average yield of 3,560 kg/ha (Table 1). A yield depression of between 11 and 13% was observed where Hammer® Force or Sharpen® were applied in mid-May and in Treatment 11, that also had a split application of Hammer® Force (July and early October) when compared to the untreated control.

The greater crop damage associated with application of herbicide in May is believed to be a result of temperatures experienced around herbicide application, although observations where Hammer® Force was applied in farmer paddocks suggests that frost post application was a factor in some instances (*personal communication* James Taylor, SPS NZ). Immediately before application, maximum daily temperatures were 4 to 5 °C warmer for the 17 May treatments than prior to the later herbicide applications, and 2 to 4 °C warmer after application (Table 2). Minimum temperatures were also 1.4 to 1.6 °C higher for the 17 May application when compared with those at the time of the 5 June applications, which caused minimum damage (Table 2).

Table 1. Average crop damage scores, foliar disease scores, crop height and machine dressed seed yields# for red chard crops grown using one of 11 herbicide treatments and rates per ha, at Irwell in the 2019-20 growing season. Herbicide treatments consisted of different herbicides and dates of application.

Treatment number	Herbicide rate (per hectare)	Time of application	Damage score*1		Disease Score[2]	Height (cm)[3]		Seed yield# (kg/ha)	
			Male	Female		Male	Female		
1	Nil		0	0.3	4	55	30	3540	ab
2	Hammer® Force (150 mL)	17 May	4.0	6.6	1	43	35	3080	b
3	Sharpen® (25g)	17 May	4.0	6.5	1	52	30	3160	b
4	Hammer® Force (150 mL) + Stomp® Xtra (2.5 L)	5 Jun	1.8	2.0	2	52	35	3860	a
5	Hammer® Force (150 mL)	25 Jul	1.2	0.3	4	44	32	3740	a
6	Hammer® Force (150 mL) + Goltix® (6.0 L) + Nortron® (1.5 L)	25 Jul	1.1	0.4	3	49	32	3460	ab
7	Hammer® Force (150 mL) + Stomp® Xtra (2.5 L)	25 Jul	1.0	0.5	3	50	32	4030	a
8	Hammer® Force (150 mL)	19 Aug	0.2	0.2	4	44	35	3770	a
9	Hammer® Force (150 mL)	8 Oct	0.0	0.3	5	50	29	3500	ab
10	Hammer® Force (150 mL)	5 Jun fb 25 Jul	2.4	1.7	3	44	39	3870	a
11	Hammer® Force (150 mL)	25 Jul fb 30 Oct	0	0.2	5	51	30	3120	b
		LSD (p=0.05)	0.5	0.5	1	9	7	590	
		F. prob.	<0.001	<0.001	<0.001	0.13	0.17	0.02	

Note: Yellow indicates the treatment was amongst the treatments showing the greatest herbicide damage or the greatest yielding group of treatments (p<0.001). Seed yields with the same letter beside them are not significantly different. * Average crop damage scores were derived from five assessments between 14 June and 17 September, 2019. #Machine dressed seed yields included an area occupied by male rows. [1]Crop damage scores: 0 = nil; 10 = dead; [2] Foliar disease score at 1 November where 0 = nil; 10 = severe; [3] assessed on 1 November 2019.

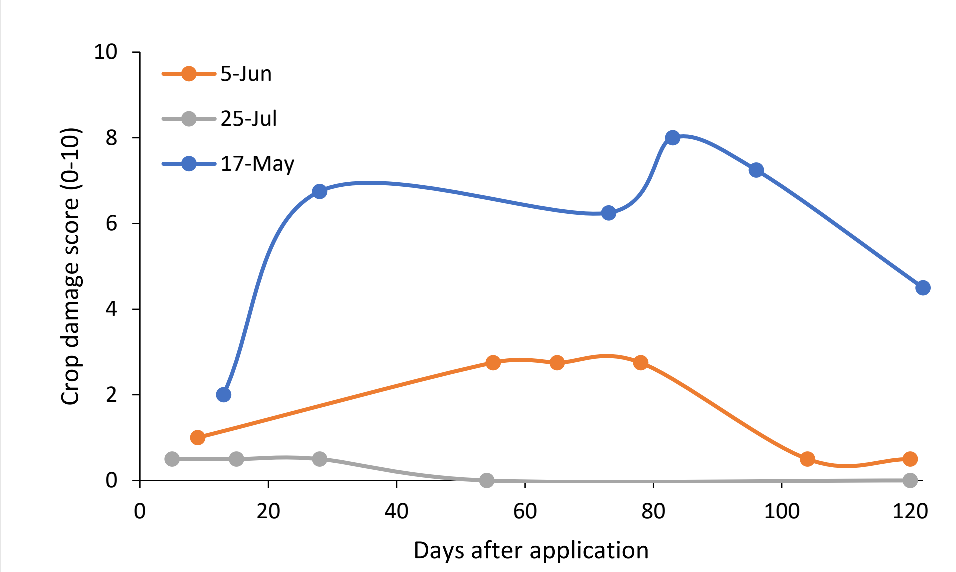

Figure 1. Crop damage scores for female rows in a red chard crop grown near Irwell, Canterbury in the 2019-20 growing season following the application of the herbicide carfentrazone-ethyl (Hammer® Force at 150 g/ha) at two timings (17 May or 25 July) or Hammer® Force mixed with pendimethalin (Stomp® Xtra) applied on 5 June.

Table 2. Herbicide application date and average crop damage score 28 days after treatment (DAT) with Hammer® Force and weather summary for the three days before (a) and after treatment (b), recorded from the NIWA 'Broadfields' weather station (Lincoln) in 2019.

a)

Herbicide application date	Average damage score (28 DAT)	Maximum Temp (°C)	Minimum Temp (°C)	Mean[b] Temp (°C)	10 cm Soil Temp[1] (°C)	Sunshine (hours)
17 May	6.8[a]	16.3	0.8	8.6	4.9	3.5
5 Jun	2.8	9.6	-0.6	4.5	8.5	1.3
25 Jul	0.5	11.1	6.0	8.6	5.6	3.2
19 Aug	0	11.1	6.0	8.6	5.6	3.2

b)

Herbicide application date	Average damage score (28 DAT)	Maximum Temp (°C)	Minimum Temp (°C)	Mean Temp (°C)	10 cm Soil Temp (°C)	Sunshine (hours)
17 May	6.8	14.5	-1.4	8.0	5.6	5.8
5 Jun	2.8	10.1	-3.0	6.5	3.2	4.4
25 Jul	0.5	12.1	4.1	4.0	7.6	6.4
19 Aug	0	11.7	1.4	5.2	5.3	6.1

[a]Herbicide damage score: 0= nil; 10 = dead, [1]recorded at 9 am; [b] Mean temperature calculated from the maximum and minimum temperatures.

Summary
Crop tolerance to the herbicide carfentarzone (Hammer® Force), which has shown promise in a previous trial for the control of mallow in red chard, was investigated to establish the effect of time of application. Severe leaf burn was observed after an early (mid-May) application of this product but there was limited, or no burn, from applications of Hammer® Force when applied alone or in mixes with Goltix® + Nortron® or Stomp® Xtra later in winter. Sharpen®, a broadleaf herbicide commonly used as an additive to improve efficacy, produced similar leaf burn to that of Hammer® Force. The red chard recovered in the spring from herbicide applications in May, producing a lower reduction in seed yield (between 11 and 13%) than expected from initial crop damage scores. A repeat application of Hammer® Force in July and again in early October also reduced seed yield by a similar amount.

Further trial work is being undertaken in 2020 to understand herbicide crop damage in beet crops and the influence of temperature interactions as well as to confirm weed control efficacy.

Reference
Chynoweth, R and Rolston, P. (2019). Can mallow be controlled in beet seed crops? *FAR Research Results Report 2018-19*. Pp. 126-127.

A review of bacterial blight in vegetable seed crops

Project code B19-02

Duration Year 1 of 1

Authors Mark Braithwaite (Plant Diagnostics Ltd), John Hampton & Ali Kakhki (Lincoln University)

Funding Seed Industry Research Centre (SIRC)

Key points

- Bacterial blight caused by *Pseudomonas syringae* is primarily spread by water. Managing irrigation to reduce long periods of leaf wetness is a management strategy worthy of research.
- Bacterial disease control currently relies on copper-based bactericides and antibiotics. Resistance to copper has been reported in *P. syringae* internationally and the use of antibiotics is unsustainable.
- Bio-pesticides are a future option for *P. syringae* control, but currently there are few available.

Background

The detection of bacterial pathogens on exported seed has recently resulted in the rejection of consignments by overseas clients. Bacterial pathogens of brassicas and beets, particularly those belonging to the *P. syringae* species complex, appear to be of greatest concern to the high-end micro-green market, as plants infected with these pathogens develop black spotting prior to harvest while infected seeds appear to have a shortened shelf life. Bacterial infections have also been reported to cause issues during seed production in both radish and beet.

An understanding of the biology, life cycle and infection process used by these pathogens, in particular the *P. syringae* species complex, would assist in implementing better disease management strategies during the growing season to minimize or eliminate them from exported seed. Here, summary information from a recent review of the literature is presented.

Review

Bacterial blight caused by* Pseudomonas syringae*: A review of biology and infection in relation to seed production

The importance of the water cycle to infection

The lifecycle of the *P. syringae* species complex is closely associated with the water cycle and water plays a critical role in the spread and development of diseases caused by members of this complex. Transmission of *P. syringae* from seeds to young seedlings occurs when the bacterium grows on the surface of the growing seedling and then infects the plant if humidity is high. Water on the surface of plant leaves is essential for infection, with the bacterium using this moisture to invade natural openings in the plant such as stomata and hydathodes and to move up the plant and into the seed heads. Secondary spread of *P. syringae* occurs within a crop when bacteria from initial infections are spread in wind-blown rain. Cool to moderate temperatures and wet conditions favour secondary spread of *P. syringae*. For example, disease caused by *P. syringae* on coriander is more severe in crops following rain or overhead irrigation.

Other possible modes of transmission

Plant to plant contact can result in the spread of bacterial pathogens such as those in the *P. syringae* species complex as can machinery and staff working in the crop. Such activities not only enable secondary spread, but can also exacerbate disease by causing wounds that act as additional points of entry into the plant.

Insects have been shown to transmit bacterial pathogens including *Pseudomonas* species. For example, pea aphids can vector *P. syringae* pv. *syringae* under experimental conditions while feeding on plants as they acquire the bacteria, the bacteria passes through the digestive tract, multiply, and are excreted in the aphid honeydew, resulting in inoculation of the plant surface. Nevertheless, spread of *P. syringae* by aphids may not be epidemiologically important as aphids can succumb to bacterial sepsis. Pollinators (honey bees (*Apis mellifera*) and bumblebees (*Bombus terrestris*)) studied in natural conditions, can also be contaminated with *P. syringae*, but they are unlikely to be epidemiologically important as the pathogen's transmission via pollinators is contrasted by its short survival in the hive.

Antibiotics and copper-based bactericides as potential control options for bacterial diseases

Control of bacterial diseases has historically relied on antibiotics and copper-based bactericides. However, the use of antibiotics is not deemed sustainable because of the development of resistance and the possibility of transfer of this resistance to human pathogens of medical importance. For this reason, antibiotic use in some countries has been banned.

Resistance to copper has also been reported and resistant strains in other *Pseudomonas* species have emerged. In addition to resistance, some bacteria can produce biofilms which provide protection against copper. For the above reasons, international research has investigated the use of integrated or alternative solutions, including biological control options. Copper can still be a very useful control measure, but it must not be the focus for control.

Copper has shown increased effectiveness against some bacterial pathogens when combined with other products. The combination of copper hydroxide and ethylene bis dithiocarbamate (EBDC, maneb) reduced disease severity of *P. syringae* in watermelon field trials. Maneb is no longer available but mancozeb, a fungicide from the same chemical group could be tested for efficacy. In the same field trials Actigard (which activates systemic acquired resistance), applied as either a foliar spray or drip, also reduced disease severity in the field. In coriander, a combination of copper and Actigard reduced disease levels of *P. syringae* by 77%. Copper hydroxide plus Actigard also reduced of *P.s.*pv. *tomato*. Other alternative chemical treatments used for control of *P. syringae* have included extracts from the plant *Reynoutria sachalinensis*, humic acid, silica-based products and phosetyl-aluminium (Alliette®). Silica applied to tomato was shown to reduce disease severity of *P. s.* pv. *tomato* through direct effect on the bacterium rather than boosting the plants defence system. Silicon products are available in New Zealand and would be worth assessing against bacterial diseases of beet and radish.

Research has also investigated the use of biocontrol agents for control of *P. syringae*. A 92% reduction in leaf tip necrosis of beet caused by *P. s.* pv. *aptata* was reported for a lipopeptide extract from *Bacillus amyloliquefaciens*. The strategy of biological control is to suppress pathogenic bacteria or induce systemic acquired resistance. There is considerable scope to explore biological control of bacterial pathogens of beet and radish either with available products or bioprospecting for new products. Such approaches could also include plant-growth-promoting rhizobacteria which have shown some promise. A number of products available in New Zealand based on *Bacillus* species, some with *Pseudomonas syringae* as a target, could be investigated in an integrated control program. Bacteriophages have also been investigated with some success and may be worth further investigation.

Potential control strategies for radish

- Water plays a critical role in the spread and development of *P. syringae*-related disease, hence practices to reduce leaf wetness such as reducing overhead irrigation and growing in areas less prone to rain, help reduce disease severity.
- Irrigation sources should be from deep wells to avoid possible introduction of strains from environmental sources.

- Any overhead irrigation should be minimized as this could be a cause of epidemics. If used, overhead irrigation should be applied early in the day to allow the crops to dry out quickly.
- Under-canopy watering systems do not wet the foliage and are less likely to cause disease spread.
- Paddocks must be kept free of all weeds, alternate hosts (e.g. Shepherds purse) and volunteer plants
- Crops must be regularly monitored from an early development stage and any plant showing disease symptoms removed from the crop and destroyed.
- Treatments to minimize or control infection should be commenced early to prevent disease establishment and the development of an epidemic.
- A control programme needs to be developed based on combinations of chemicals and including an integrated biocontrol strategy.
- Any machinery or people should only be in the crop when it is dry, and any machinery should not be moved between crops without being cleaned.
- Seeds should be harvested under dry conditions using cleaned equipment and care should be taken to not spread the disease among different seed lots by the harvesting equipment.
- Clean fields should be harvested before infected fields.
- Harvested seed should be tested for the presence of bacterial infection after harvest. A suitable seed treatment may need to be developed to remove bacteria from seed.

Summary
Seed-borne infection with a pathogen belonging to the *P. syringae* complex can occur from plants that have not exhibited any disease symptoms, as bacteria can survive epi(endo)phytically on or within plants without causing disease. This means a proactive management strategy is imperative. As the pathogen can live on a multitude of plant hosts and the water cycle is critical to the spread of disease, such a management strategy should investigate the options for weed suppression in the paddock and rationalising irrigation within the crop to reduce extended periods of moisture. On-farm biosecurity measures will also reduce the transmission of the pathogen within and between paddocks.

For a full copy of the review of bacterial blight in vegetable seed crops, please contact Phil Rolston (phil.rolston@far.org.nz) or Richard Chynoweth (richard.chynoweth@far.org.nz).

A review of white blister in vegetable seed crops

Project code B19-04

Duration Year 1 of 1

Authors Mark Braithwaite (Plant Diagnostics Ltd), John Hampton & Ali Kakhki (Lincoln University)

Funding Seed Industry Research Centre (SIRC)

Key points

- Systemic transmission has often been reported as important in spread of *A. candida*, but white blister (caused by this pathogen) was not controlled using seed treatments including two fungicides, hot water and *Trichoderma atroviride.*
- A review of field trials evaluating fungicides for white blister control suggests that the greatest seed yield response has come from fungicide treatments which include azoxystrobin (Group 11 Fungicide).

Background

This review provides background information on white blister disease in radish (*Raphanus sativus* L.) caused by the oomycete plant pathogen *Albugo candida*. It covers key information and recent findings about the pathogen including its biology, life cycle and epidemiology as well as chemical and non-chemical control methods. Included in the review are findings from a Seed Industry Research Centre (SIRC)-funded trial that was used by MSc student Huong Pham (Pham 2019) and FAR-funded trials (Braithwaite et al. 2018). Finally, the review identifies foci for future research.

Review

White blister of radish caused by* Albugo candida*: A review of the pathogen and its control in relation to radish seed production in New Zealand.

- *A. candida* contaminates seed when oospores adhere to the radish seed coat. *A. candida* is not transmitted internally in seed.
- *A. candida* was not detected inside seeds or inside radish plant tissues when assessed using PCR, but was readily detected on radish plant tissues, from roots, stems, leaves, seed heads and seeds.
- Seed treatments including two fungicides, hot water and *Trichoderma atroviride* did not prevent disease transmission to the resultant plants. These results challenge the literature which often refers to systemic transmission of *A. candida.*
- Bleaching seeds for five minutes followed by washing seeds in sterilised distilled water killed oospores on the seed; this method has potential for consideration as an industry standard for seed treatment?
- Applying the first fungicide eight weeks after sowing might be too late to supress disease spread; monitor the crop and spray immediately when the first symptoms are observed.
- From different field trials, the greatest response (seed yield) has come from fungicide treatments that include azoxystrobin (Table 1).
- Race 1 of *A. candida,* the race identified in the USA on radish, is reported to have developed resistance to metalaxyl-M.
- Overhead irrigation encourages spread of the disease within the crop; ground surface watering should be considered.
- Efficacy testing to determine an effective IPM programme (fungicides/biocontrol options) will be required.
- The full review includes suggestions for potential control strategies, with a focus on the use of clean seed and early intervention to reduce/prevent the spread of the pathogen through the crop.

Table 1. Summary of three fungicide trials in radish seed crops, Canterbury between the 2015-16 and 2018-19 seasons.

	Season	2015-16[1]	2016-17[1]	2018-19[2]
Fungicide application	Weeks after sowing	8	8	8
	Number of applications	4	6	5
	Time between applications (weeks)	4	2	2-3
Seed yield (kg/ha)	Negative control	588	933	1227
	Highest yielding fungicide treatment	728[3]	1558[4]	1453[5]
	Increase in highest yielding fungicide treatment compared to control (%)	24%	66%	18%
	Statistical significance ($P<0.05$)	**	***	NS
Incidence of infection (%)	Negative control	71	58	34
	Highest yielding fungicide treatment	26[3]	38[4]	21[5]
	Metaloxyl-M + mancozeb treatment	53	48	24

[1]Braithwaite et al. (2018); [2]Pham (2019); [3]azoxystrobin; [4]isopyrazam plus azoxystrobin; [5]combinations of metalaxyl-M + mancozeb, azoxystrobin, isopyrazam, boscalid + pyraclostrobin.

Recommendations for possible research

- Identify the races of *A. candida* occurring on different hosts in New Zealand, and particularly whether the race infecting radish (Race 1) also infects weed hosts and other brassica crops.
- Investigate whether races of *A. candida* in New Zealand are resistant to fungicide.
- Determine the role of inoculum surviving on buried host tissue as an inoculum source for new crops (i.e. how many years will oospores survive in the soil under New Zealand conditions).
- Develop a seed treatment method that kills all oospores adhering to the seed coat; this will remove the major inoculum source.
- Repeat the PCR testing of radish tissue with and without visible symptoms to confirm that *A. candida* is not transmitted systemically.

For a full copy of the review of white blister in vegetable seed crops, please contact Phil Rolston (phil.rolston@far.org.nz) or Richard Chynoweth (richard.chynoweth@far.org.nz).

References

Braithwaite, M, Chynoweth, R, Gunnarsson, M, Braithwaite, L, Harvey, I and Rolston, P (2018). White blister disease control in radish seed crops. *New Zealand Plant Protection*, 71, 325-331. DOI: 10.30843/nzpp.2018.71.172.

Pham, H T T. (2019). Strategies for control of white blister disease in radish *(Raphanus sativus L.)* seed crops. Unpublished MSc thesis, Lincoln University, Canterbury.

Alternative pollinators for seed crops – drone fly mass rearing

Project code B19-07

Authors Brad Howlett and Sam Read (Plant & Food Research), Phil Rolston (FAR)

Duration Year 2 of 3

Location Mid Canterbury sites including Lincoln and West Melton

Funding MPI SFF and Seed Industry Research Centre (SIRC)

Acknowledgements Troy Barrell and Andrea Reid (trial hosts, West Melton carrot field site), Bond Earth Works, New Zealand Institute for Plant & Food Research, Richard van Garderen (South Pacific Seeds)

Key points

- Drone flies can be raised off-site and transferred to seed fields, where individuals can remain within fields providing pollination services for several days.
- Drone flies raised in-field in plastic lined ditches with grass clippings or old baleage produced many thousands of drone flies.
- Significant potential exists to boost drone fly numbers further within target fields using a combination of flexible rearing options that allow movement of large numbers within and between fields.

Background

Growers of vegetable seed crops in New Zealand rely almost entirely on the managed honey bee, *Apis mellifera*, to provide pollination services despite the provision of additional pollinators improving yields for most crops. Dependence on a single managed pollinator also leaves growers vulnerable to a loss of pollination services should honey bee supply be disrupted. Yet, growers currently have few options to employ additional managed pollinators in a cost-effective manner.

The drone fly is a non-bee pollinator that is showing significant promise as a managed insect. It is an effective pollinator of a range of crops, including vegetable seed crops, and has a simple lifecycle, making it easy to rear on a range of readily available substrates. It also appears to complement honey bee pollination by being more active under cooler temperatures.

To develop drone flies as an easy to manage crop pollinator, a number of key questions still need to be addressed: Can we mass rear large numbers and provide the flexibility to supply them effectively within targeted fields? Do the reared flies actually move into target fields and stay there or do they move into the surrounding habitat? For non-bee pollinators such as drone flies, these questions are particularly important to understand because, unlike bees, adults are not dependent on nest or colony sites which act to anchor their movements to a central known location.

Here, we report on the potential to mass rear drone flies under open-site (farm and peri-urban) conditions for the transport of populations to field sites (Trial 1) and on-farm rearing and pollination activity (Trial 2).

Methods

Trial 1. Twenty-four drone fly rearing containers were each set up at two dairy farms. At the Lincoln farm, all containers were filled with dairy effluent collected from the farm. At the Bankside farm, 12 containers were filled with dairy effluent (from the farm) and 12 with ryegrass-clover baleage. The containers were designed to be capable of supporting the development of the drone fly larval and pupal stages. To do this, an inner plastic 31-L container (24 cm height x 33.5 cm width and 39 cm length) was used to hold the substrate. The baleage substrate replicates were submerged in water that was filled to 10 cm of the inner container rim; the effluent replicates were also filled to the same level. Each container was then placed into a larger 54-L container (25 cm height x 37 cm width x 60 cm length) and the gap between the containers filled with non-treated pine wood shavings. To keep the wood shavings dry, a corflute lid was cut to cover the container leaving the substrate exposed at the centre. Containers were regularly monitored and water was added if the upper surface of the substrates showed signs of desiccation. All containers were established at the two dairy farms on 19 November 2019.

Over 1000 raised flies were marked with a white honey bee queen marking pen (uni POSCA) on the top of their thorax (Figure 1) before being released in a carrot field to monitor dispersal. Monitoring occurred at set points at four times a day from 10.00 to 16.00 h on each survey day (2, 8 and 13 days) after release. In addition, flies were released in the field from two containers with custom built fluorescent powder marking devices. These were designed to deposit moderate amounts of powder on both the dorsal and sternal aspects of the flies. After dark, with UV lights the position of marked carrot umbels were recorded.

Figure 1. Drone flies with marked backs.

Trial 2. Four ditches were prepared on the western side of a 4.7 ha hybrid carrot field, all being approximately 5 m from the crop edge and 2 m from a conifer hedgerow and approximately 150 m from a hybrid radish field. Each ditch was spaced 8 to 10 m apart. The dimensions of each ditch were 6 m length, 0.5 m width and 0.4 m depth. Heavy duty polythene (200 microns thick) was used to line the ditches with two overlapping layers of the liner, which were pegged in place, prior to the placement of the substrate and water. To prevent the drone fly larvae from escaping the ditches into the surrounding vegetation, a PVC panel barrier was constructed surrounding the perimeter of each ditch (Figure 2). Mesh bird netting was used to cover each ditch. Two different substrates, (i) baleage and (ii) grass clippings, were used to attract gravid drone flies to oviposit and then support the development of larvae. The baleage consisted predominantly of ryegrass with clover (slightly rotting) while grass clippings had been cut approximately 4 weeks prior to placement in ditches. Each substrate was replicated twice by placing each in two ditches, submerged in water to a depth of 30 cm, on 13 November 2019. Ditches were then monitored weekly and water added if there were signs of desiccation on the surface of each ditch.

At the ends of each ditch, lidded black plastic boxes were installed, covering the width of the ditch. An opening was cut into the base of each box and the plastic liner fed inside to help funnel crawling drone fly larvae into each box. Non-treated wood chips were placed inside each box as the medium to support pupation.

Ditches were surveyed for larvae and pupal development on six occasions between 27 November 2019 and 20 January 2020. Larval counts were conducted from within each ditch. Prior to sampling, substrates were stirred to increase the evenness of their distribution within each ditch. Counts were conducted by collecting samples using five 0.25 L cups. Pupae were sampled over three periods from 18 December 2019 to 20 January 2020. Within field abundance and distribution of drone flies were evaluated on seven occasions within the carrot field and five occasions within the radish field to assess drone fly and honey bee activity throughout the flowering period. There were 32 honey bee hives in and around the crop and an additional 36 hives within 300 metres of the carrot pollinating the neighbouring radish and Chinese cabbage crops.

Pollination deficit in the carrot field was assessed by comparing hand cross-pollination at three points along a diagonal transect across the field with similar neighbour inflorescences that were insect pollinated.

Figure 2. A ditch with a PVC panel to stop drone flies escaping and a rearing box at each end. Image is prior to placement of bird netting**.**

Results and Discussion

Trial 1. Drone flies were successfully reared within the containers; fresh dairy effluent, baleage or grass clippings often producing between 200 and 400 drone fly pupae. Numbers produced per container showed wide variation, reflecting a number of issues such as evapotranspiration and indicating that the system may require closer monitoring or further refinement to provide consistent production of pupae.

A release of 7175 drone flies, (of which 1175 were marked), into a target hybrid vegetable carrot seed field did not result in a greatly increased number of surveyed drone flies. However, the presence of marked flies two weeks following release highlighted that at least some flies remained in the crop.

A further release of flies marked with fluorescent powder near to a hybrid vegetable carrot field led to a transfer of the powder onto umbels of carrots in both the male and female rows up to 30 m from the release point. This demonstrated that many flies moved directly into the field, visiting both fertile and sterile umbels. Window traps placed outside of target fields did not detect large numbers of drone flies moving into the surrounding landscape.

Trial 2*.* Drone fly larvae numbers peaked at over 6,000/ditch between the 18 December and 3 January (5-7 weeks after ditches were filled with substrate and water). There were more drone fly larvae on the grass clippings substrate than the baleage. Both drone flies and honey bees visited the male and female sterile inflorescences in the carrot and radish fields. However, in the carrot field, honey bees were more frequently found on male umbels than on female umbels whereas drone flies were more evenly distributed between umbel type. For radish, counts of both insects were evenly spread across male fertile and sterile inflorescences. Adult drone flies were more commonly observed at cooler temperatures (<20°C), complementing honey bee activity.

The yield of seed on hand-pollinated carrot umbels was double that of insect pollinated umbels, suggesting a significant pollination deficit still existed in this paddock. The yield was 830 kg/ha (60% above target). The observed ratio of honey bee to drone flies on carrot umbels was 4.3:1. The theoretical ratio based on 10,000 worker bees/hive and 6.9 hives/ha and the number of drone fly pupae counted was 19:1, suggesting fewer honey bees were present in the crop than the hive number should supply. Using more ditches than the 1 ditch/1.1 ha used in the trial would show whether there is an opportunity to reduce hive density.

Summary

The trials demonstrated that off-site raising of drone flies was possible and that they could be successfully transported and released into a vegetable seed crop**.** This raises the opportunity for contractors of pollination services to supply drone flies to fields, rather than growers raising their own on site.

Raising drone flies on-site proved a relatively simple and cheap option for growers. In this field experiment, where a seed yield greater than that expected commercially was achieved, hand pollinated umbels produced double the seed yield of the honey bee-drone fly pollinated umbels suggesting an ongoing pollination deficit. A greater density of pollinators could further increase seed yields and be supplied if more ditches than the 1 per 1.4 ha evaluated in this trial were established.

The third and final year the project will evaluate larger, 1000 L portable multiplication tanks for rearing drone flies.

Bee Minus to Bee Plus and Beyond

Project code G13-04

Authors David Pattemore, Brad Howlett and Flore Mas (Plant & Food Research)

Duration Year 5 of 5

Location National

Funding MBIE with co-funding from Zespri Group Ltd, NZ Avocados, Summerfruit NZ and FAR. KiwiNet

Acknowledgements The many dozens of arable farmers and kiwifruit, avocado and summerfruit growers who hosted trials

Key points

- Increasing wild bumble bee numbers on farm/orchard using various artificial nest designs was not consistent enough to recommend as a strategy.
- An off-site system to cost-effectively rear short tongue bumble bee colonies for crop pollination in open orchards and farms was developed that is being has been trialled by bee keepers.
- Floral odours released by clovers and other crops that attract honey bees were identified and characterised.
- The importance of alternative pollinator species was quantified, including native bees and flies, and key pollinator species of value to arable crops were identified.
- Methods to increase populations of some key alternative pollinators in arable fields were developed and trialled, and this work is now continuing in new projects.
- On-farm landscape features (e.g. exotic hedgerows, native plantings, ponds) support different pollinating species that contribute to on-farm pollinator diversity and pollination.
- This knowledge can help guide farmers in decisions on managing landscape features and crop placement.

Background

Pollination in New Zealand is largely reliant on honey bees. As a result, pollination is vulnerable to any disruption by diseases or other factors that may negatively impact on honey bees. The project was developed to identify ways to make pollination less vulnerable to disruption, and to deliver a range of new tools for pollination for growers to use.

This report provides a summary of the results from this project.

Results and Discussion

The BumbleBox™

The project evaluated a number of tunnel and nest systems to improve a short tongue bumble bee (*Bombus terrestris*) density in fields, but these were inconsistent at improving bumble bee density. As a result, the project changed its focus from field-based systems to developing an artificial lab-based rearing system, which has been successful.

The outcome of developing an artificial lab-based rearing system was BumbleBox™, a bumble bee rearing system designed to be operated by beekeepers as part of the pollination services to growers. BumbleBox™ was run as an internal-spinoff, and an international patent for the system was registered. Further development of the system was undertaken by running commercial rearing and pollination trials with seven beekeeping operations in 2019, funded by KiwiNet. In a controlled trial in a single 2.5 ha entirely-netted kiwifruit orchard, the team demonstrated that bumble bees reared in the BumbleBox™ system were sufficient on their own to achieve full pollination of the crop, at an equivalent efficacy to wet pollen sprayed directly onto individual flowers. This paved the way for growers not only to supplement honey bees with bumble bees, but to replace them entirely if required.

Alternative pollinators
Research on non-bee pollinators included studies on native bee species and on various fly species. Key knowledge generated through the programme led to the commencement of Sustainable Farming Fund project 405657 focusing on managing non-bee pollinators. The project successfully mass reared the drone fly (*Eristalis tenax*) in hybrid vegetable seed fields using freely-available on farm substrates. The results demonstrated the significant promise this species has as a managed pollinator. For more information on this project, see Rolston and Howlett (2019) and the FAR research results report on alternative pollinators for seed crops – drone fly mass rearing, in this FAR Research Results publication.

The function of on-farm landscape features in delivery of pollination services
On-farm landscape features (ponds, conifer hedgerows, native plants, exotic farm gardens, bare fencelines were found to be associated with different unmanaged bee and non-bee pollinating species. Together, these features contribute to on-farm pollinator diversity. The diversity of pollinators associated with these landscape features were found to provide pollination services to plots of *Brassica*. Diverse, on farm landscape features therefore support the delivery of pollination services above the intended purpose of the landscape feature (e.g. shelter, irrigation, enjoyment). Decisions by growers to add or remove on-farm landscape features can therefore have unintended consequences on crop pollination services.

Using crop odours to attract honey bee pollinators
The project enhanced our knowledge on the complex interactions between the crop and honey bee pollinators. Honey bees have a wide range of odours that they perceive. This allows them to exploit the novel floral resources that are present at different times throughout the year. For resource-poor crops that are flowering at the same time as resource-rich crops, this means that they can lose out on honey bee pollination services. Through our collaboration with world leaders in the area of honey bee management, we have harnessed the conditional-response behaviour of honey bees to improve attraction of bees to odours, such as those produced by carrot flowers, post training with the feeder. This technology can be used in the future to retain honey bees that have been placed in the crop for pollination services in the target crop, rather than losing them to resource-rich neighbouring crops. Knowing which floral odours are attractive to honey bees provides opportunities to understand the plant genetics of floral odours and for crop breeders to be able to increase floral odours to improve floral attractiveness.

Global grower knowledge and perceptions of non-bee pollinators
We led an international Super B (http://superb-project.eu/) workshop at Reading UK bringing together scientists from the UK, Germany, Poland, Spain, Israel, South Africa, Guatemala, Slovenia and Belgium to evaluate global grower knowledge and perceptions of non-bee pollinators. A publication is currently in preparation highlighting the link between scientific and grower knowledge between crop growers from around the world. This is the first study of its kind and will provide unique underpinning information for guiding future applied research.

Summary
This project provided new knowledge, tools and technologies to improve pollinator services in a number of crops in New Zealand. global grower knowledge and perceptions of non-bee pollinators was also evaluated to assist in the adoption of these new tools and technologies.

Reference
Rolston, P, and Howlett, B (2019). Alternative pollinators for seed crops – drone fly mass rearing. *FAR Research Results 2018/19.* Pp 131-133.

A review of integrated weed management in arable crop systems

Project code H19-05 and X18-35

Duration Year 1 of 3

Authors Charles Merfield (BHU Future Farming Centre), Matilda Gunnarsson and Phil Rolston (FAR)

Funding Seed Industry Research Centre (SIRC), FAR

Key points

- A 100-page review was produced that synthesises the global information on developing integrated weed management (IWM) programmes for arable crops.
- With herbicide resistance becoming an increasing problem, the review identifies non-chemical interventions that can be integrated into on-farm weed management.
- Some techniques involving remote sensing and steerage guidance systems are already well developed for row crops and are being developed for broad acre use.
- The review will form the basis of grower user extension material and inform local research to support continued adoption of an integrated weed management approach.

Background

At the time of writing, the number of positively identified herbicide resistant (HR) species had reached 19 in New Zealand. The first instance of herbicide resistance was identified in 1979 and there has been a linear increase over the last four decades. While the number of HR plant species continues to increase, the same is not true of new herbicide chemistry. The last novel mode-of-action (MoA) was the acetolactate synthase (ALS) inhibiting herbicides introduced in the 1980s. No new herbicide MoA has been introduced since.

The key purpose of this work was to review integrated weed management (IWM) strategies that could be used by arable growers in New Zealand to minimise the evolution of new HR plants. IWM can reduce the agrichemical footprint of a crop, maintain efficacy of available herbicides by minimising the evolution of new HR weed species, and provide alternative strategies for weed management should chemistries become unavailable or redundant. Grower user extension material would then be produced to support use of this weed management approach.

This report provides an insight into the review of integrated weed management for arable crops. To request more information or a copy of the review, please contact Phil Rolston (phil.rolston@far.org.nz) or Richard Chynoweth (richard.chynoweth@far.org.nz).

Review

How does herbicide resistance emerge on-farm?

Evolved resistance is most commonly associated with agrichemicals such as herbicides. However, evolution can evolve 'resistance' to any 'static' control measure (i.e. a control measure that is not evolving or changing itself). For example, harvest weed seed control systems, where weed seeds harvested along with cereal grain by headers/combine harvesters are destroyed (e.g. Harrington Seed Destructor), rather than being returned to the soil, have resulted in weeds where the seed heads shatter more easily so seeds are released when cut by the sickle bar, falling on the soil rather than entering the header/combine. Furthermore, herbicides do not cause plants to develop HR (i.e., create genetic mutations). Rather, in any population of plants there already exist individuals with random genetic variation that makes them resistant. Indeed, plants had resistance genes in them well before the first herbicide was invented. For example, a herbarium specimen of black grass (*Alopecurus myosuroides*) collected in 1888, was found to have ACCase resistant genes, 90 years before ACCase-inhibiting herbicides were first used.

There are two means by which HR genes move among paddocks and among farms: as seeds and pollen. Farm machinery is a key means of weed seed movement, including tractors and cultivators where the seed is in soil attached to the machines, and especially in harvest equipment, transport trucks and bailers. Planting seed is also another source, with the recent velvetleaf introduction via fodder beet seeds an example of this route. Brought in feed is an important route, especially hay and straw, but also grains. HR gene movement via seeds can therefore be both over short (e.g. within and between paddocks) and long distance, between farms, regions and countries. Movement by pollen is much more restricted.

The highest risk factor for selecting HR plants is repeatedly using the same Mode of Action (MoA) in a herbicide programme, or worse, exactly the same herbicide product.

Managing HR using an integrated weed management approach

The use of diverse MoAs in a herbicide programme is an immediate solution to reduce the likelihood of HR on a farm (i.e. avoid repeatedly applying the same herbicide to the same paddock/area of land). Ideally, a MoA should only be used on the same paddock/land once a year, and where more than one weed spray is required, then, a different MoA should be used (i.e. have a sequence of different MoAs). If genetically similar crops are being grown in rotation (e.g. the cereals, wheat, barley, oats, etc.), it is much harder to diversify and rotate MoAs. Therefore, having as diversified rotation as possible is a key means of having a diversified MoA sequence.

IWM implies all possible weed management tools are used in a purposefully combined/integrated system to achieve excellent weed management. It is divided up into four main approaches: (i) physical, (ii) chemical, (iii) biological and (iv) ecological that can be considered the four toolboxes of IWM. Physical tools are mostly mechanical approaches, such as interrow hoes and cultivation. Chemical tools are principally herbicides. Biological and ecological tools overlap, and are also called cultural tools. They are based on biological and ecological interactions among the living things in a paddock; for example biocontrol agents, competition between the crop and weeds, and rotations.

The foundations of integrated weed management include understanding of weed seed banks and seed dispersal. The weed seedbank is managed though prevention and depletion. The old farming adage 'One year’s seeding: seven years weeding' speaks to the fact that it is easier to control weeds by preventing weed seeds entering the seedbank (weed seed rain) than it is to control the subsequent weed plants that emerge from the seedbank. The primary reason the weed seedbank persists is because of dormancy.

Integrated weed management systems rely on rotations, varying between spring and autumn sown crops and avoiding having sequences of crops that are taxonomically similar (e.g. different cereals). Include in the rotation crops where mechanical weeding is highly effective (e.g. potatoes, interrow hoed cereals), so that some herbicides can be swapped for steel. A pasture phase also assists. To avoid grass weed build up in minimum tillage systems, rotational ploughing (e.g. once every 5+ years, resets the system, as the half-life of buried grass seeds is generally less than five years. Therefore, there are few viable seeds brought back up next time the plough is used.

Cultivation and pre-establishment management. Cultivation/tillage can have a significant impact on weed management as it allows direct manipulation of the weed seedbank. Very shallow cultivation immediately after harvest can stimulate weed seed germination, especially barren brome (*Bromus sterilis*), volunteer cereals and oil seed rape. For best effect, soil must be moist. However, cultivation prevents birds eating weed seeds, and also kills seed-feeding invertebrates such as ground beetles. False and stale seedbeds are two highly effective ways to reduce in-crop weeds at establishment. The terms false and stale are often used interchangeably, but they are used here to describe different but related techniques. False and stale seedbeds are based on three properties of seedbanks: (i) Most seeds in the seedbank are dormant; (ii) Cultivation/tillage is highly effective at causing non-dormant seeds to germinate; (iii) Most arable crop weeds can emerge only from the top five centimetres of soil, mostly half that. Both techniques start with the establishment of the seedbed ready for planting, except that planting is then delayed to allow the weed seeds to germinate. Although planting is delayed, it is essential that the seedbed is of the highest quality (i.e.

good tilth and moisture), to encourage the largest possible weed flush. In the false seedbed technique, sufficient time is allowed to elapse after seedbed preparation so that non-dormant weed seeds can germinate and emerge. Depending on the time of year/soil temperature and weed species this is typically between one and three weeks. Then, the emerged weeds are killed by very shallow re-cultivation/re-tillage, which also makes a new seedbed. False seedbeds therefore get their name because the first seedbed that was created is destroyed by the re-cultivation to kill the weed seedlings, and therefore is not the 'true' seedbed into which the crop is planted. Stale seedbeds differ from false seedbeds in that the weeds are not killed by cultivation, but, either broad-spectrum herbicides (both contact and systemic) or thermal weeders. They are called 'stale' because the seeds are planted into the original seedbed (unlike false seedbeds) but the seedbed has become old or 'stale' at planting time.

Crop establishment is a critical time for IWM in arable crops due to many crops being able to strongly compete with weeds. The foundation for this is good crop emergence, so, all the usual requirements for good emergence need to be correct. There are also a range of other establishment practices, that can provide significant levels of non-chemical weed management, including using higher sowing rates, banded fertiliser placement below the crop seeds to preferentially feed the crop and not the weeds. Row spacings and arrangements can have a major impact on crop yield and weed management, but, with the dominance of herbicide-based weed management, there has been limited focus on row spacings for weed management. However, row spacings and arrangements have a critical role to play in IWM - both for physical and biological/ecological control approaches. Before the advent of computer guided hoes, the minimum practical row spacing for weeding was typically 30 cm, but with computer guidance, row spacings of 15 cm can be weeded.

Mechanical weeders come in two broad categories: (i) Contiguous weeders that weed the whole paddock surface (aka 'broad-acre'); (ii) Incontiguous weeders, that weed in-between crop rows (e.g. interrow hoes). There are four main contiguous weeders, suitable for arable crops: spring tine weeders, Einbock Aerostar-Rotation, spoon weeders and Combcut®. Remote sensing and steerage guidance systems are already well developed for inter-row weeding in row crops.

Roguing (hand-weeding) is widely used in seed crops to control off types for certification, and, also noxious weeds in any crop (e.g. wild oat in grass seed or cereals). Roguing will also have an increasing place in HR weed management as part of monitoring for HR weeds in paddocks and taking action, for example, the removal of weeds that have survived spraying - regardless if it was poor application or suspected HR weeds.

Summary
This report summarises some of the information gathered as part of a review of IWM internationally and its use for herbicide resistance management in arable crops. Future work will begin to deliver grower user extension material and produce local research data to support continued adoption of this weed management approach to arable cropping in New Zealand.

2019-20 Herbicide Resistance Survey

Project code X18-35

Duration Year 2 of 5

Authors Matilda Gunnarsson (FAR), Chris Buddenhagen (AgResearch), Phil Rolston (FAR)

Location South Canterbury

Funding MBIE programme supported by FAR and Seed Industry Research Centre (SIRC)

Acknowledgements Zachary Ngow (AgResearch), Harry Washington and summer students (FAR)

Key points

- A survey of two field from each of 37 randomly selected growers in the South Canterbury area, representing 23% of arable growers in the district, was undertaken pre-harvest in the 2019/20 season.
- The fields selected were mostly crops of either wheat or barley. The weed species collected were perennial and annual ryegrass, wild oats, *Vulpia* hairgrass and bromes.
- Preliminary data for the screening of ryegrass on 17 of the 26 farms with ryegrass identified herbicide resistance to several commonly used Group A and B herbicides.
- Of those tested, 59% of farms have Group A herbicide resistance (mostly to haloxyfop-P and pinoxaden) and 53% of farms had Group B resistance (iodosulfuron or pyroxsulam)

Background

Herbicide resistance is increasingly being verified in crops throughout New Zealand. To date, 17 weed species have been identified as having resistant populations. AgResearch is leading an MBIE-funded Herbicide Resistance programme with FAR as a major industry partner/co-funder. As part of this project, FAR is conducting a series of annual surveys in various arable-growing regions to identify resistance issues by collecting surviving weeds from paddocks at the end of a growing cycle. In 2018-19, a survey was undertaken in the Selwyn District, Canterbury, which identified suspected resistance in ryegrass and wild oats to several commonly used herbicides (Gunnarsson *et al*. 2019). In 2019-2020, a second survey was conducted in South Canterbury.

Methods

Using the FAR database of 160 arable growers in South Canterbury (covering the area between the Rangitata and Waitaki rivers including the Farlie Basin (approximately 50 km x 100 km in size), growers were placed in random order. The first 40 growers on the random list (representing 25% of the list) were contacted and asked if they wished to participate in the survey. For a two-week period in January, 37 farms (23% of the arable growers in South Canterbury) were visited by three people who collected mature seeds from up to ten plants from the target species. Each species was collected and put in a paper bag, with individual plants kept separate. Samples were collected from one or two fields per farm, each identified by GPS coordinates. Later, the seeds were rubbed out by hand, sieved and blown to give a clean seed sample. The ryegrass was provisionally separated into perennial (*Lolium perenne*), annual/Italian ryegrass (*L. multiflorum*) and hybrids based on the presence of awns at time of collection.

Seed was planted into seed trays (6 rows, 10-25) seeds per row (a median of 13 plants germinated per row). Four rows were from individual plants collected during the field survey. The other two rows, experimental controls, were known susceptible and resistant seed from previous experiments. After sowing, the trays were moistened and left in a refrigerated room at 7°C for 72 hours in an attempt to break dormancy. Planted trays were sprayed with three Group A herbicides: Sequence™ (active ingredient (a.i.) 240 g/L clethodim), Ignite® (a.i. 100 g/L haloxyfop) and Twinax® (a.i. 100 g/L pinoxaden), and two Group B herbicides: Hussar® (a.i. 50 g/L iodosulfuron-methyl) and Simplicity™ (a.i. 30 g/L pyroxsulam) at label rate on 25 May 2020 when ryegrass had 2-4 leaves. Mortality was assessed on 8-9 June, 2020 for Group A herbicides and for Group B herbicides on 15 June. Group G (glyphosate 510 g/L) was tested on ryegrass samples from 29 fields, and samples from four fields with suspected partial resistance were re-tested.

This report provides data for ryegrass (perennial, Italian and hybrid) samples planted between 4 and 8 May 2020, but the ryegrass species data have been combined until genetic tests confirm the *Lolium* species. Testing of the remaining farms and samples of bromes and wild oats has started, but is not reported here.

Results and Discussion

Ryegrass seed was collected on 26 (70%) of the 37 farms. Herbicide resistance was detected in half the fields tested. This is a higher percentage than seen in Selwyn District during sampling in 2018-19 and might reflect the reduced crop rotation options in South Canterbury. The presence of herbicide resistance by herbicide is presented in Table 1.

Table 1. Number of paddocks from which ryegrass with herbicide resistance (HR), partial resistance (1-20% of plants survived) or no resistance was collected in South Canterbury in January, 2020.

Herbicide Group	Herbicide	Number of fields tested	Fields with HR	Partial HR	No HR
A	Clethodim	14	2	1	11
A	Haloxyfop	29	12	3	14
A	Pinoxaden	28	14	3	11
B	Iodosulfuron	28	12	5	11
B	Pyroxsulam	11	9	2	0
G	Glyphosate	29	0	0	29

The screening of ryegrass confirmed that herbicide resistance in this weed is widespread in South Canterbury. Many growers in the survey previously suspected they had resistance to the Group A herbicides haloxyfop and pinoxaden, but resistance to Group B herbicides occurred at a level similar to the Group A herbicides too (Table 1). There was no resistance to glyphosate detected and the few plants that survived from four fields all died when they were re-tested.

Use patterns of herbicides where weeds are developing resistance will need to be examined by growers and advisors. The use of herbicides in other groups, rotating crops to allow a wider range of herbicide groups to be used, and including non-chemical control options are important components of a robust herbicide resistance management strategy.

Summary

Volunteer grasses were collected pre-harvest on 37 farms in South Canterbury, representing 23% of farms in the region. Seventy percent of farms had ryegrass present in cereals pre-harvest and suspected herbicide resistance was identified in this ryegrass on 36% of farms. Of the farms that had ryegrass in cereals at harvest, 59% were herbicide resistant. Weed management strategies to avoid herbicide resistance need to be implemented by arable growers and other sectors that place a heavy reliance on herbicides for vegetation and weed management.

In the summer of 2020-21, surveys will be undertaken in cereal crops throughout Southland and in maize crops throughout the Waikato-Bay of Plenty districts.

References

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The potential of biologicals AGR96X and AGR626 to protect grain yield of wheat from grass grub larval feeding

Project code X19-01

Duration Year 1 of 3

Authors Mark Hurst, Sarah Mansfield, Maureen O'Callaghan, *et al*. (AgResearch), Richard Chynoweth and Lauren McCormick (FAR)

Location Southbridge, Canterbury (GPS 43°48'34.43"S; 172°15'54.07"E)

Funding MPI SFF, FAR and Seed Industry Research Centre (SIRC)

Acknowledgements Matt McEvedy (trial host), NZ Arable (trial operators)

Key points

- All treatments increased the mortality and disease levels of grass grub larvae above the untreated control.
- All treatments had similar plant populations at the end of winter, irrespective of how they controlled grass grub larval feeding.
- SuSCon® Green and Poncho® increased grain yield above the untreated control, however these were similar to many of the other treatments including the biological treatment combination of AGR96X and AGR626.

Background

The New Zealand grass grub (*Costelytra giveni*) is one of New Zealand's major pasture pests and frequently causes damage to pasture and crop plants by feeding on their roots. Devastating outbreaks frequently occur during the plant establishment phase.

New Zealand's use of organophosphate insecticides was reviewed by the Environmental Protection Authority (NZ EPA 2013), leading to the removal of the active ingredient (a.i.) phorate from the New Zealand market in 2016, with terbufos removal in 2023-24 and diazinon scheduled for de-registration in 2028. Chlorpyrifos, the active ingredient in SuSCon® Green (a.i. 100 g/kg chlorpyrifos) is also scheduled for review (NZ EPA 2019) and has recently been removed from use in the European Union with a zero-residue policy adopted for food crops (European Union 2020). Neonicotinoid insecticides are commonly used alongside organophosphate insecticides to provide seedling protection against grass grub in some arable crops, but neonicotinoids are also under scrutiny and banned in some countries (European Food Safety Authority 2015). It is therefore important to find non-chemical alternatives for grass grub control (Mansfield *et al*. 2017).

Recently, a bacterium active against both grass grub and manuka beetle has been identified. *Serratia proteamaculans* (AGR96X) was isolated from diseased *C. giveni* larvae. In laboratory bioassays AGR96X killed 90-100% of *C. giveni* larvae within 5-12 days of ingestion. The rapid kill of *C. giveni* larvae post-ingestion of AGR96X is more similar in speed to an insecticide (Hurst *et al*. 2018). Through the course of AGR96X infection of *C. giveni* larvae, AGR96X rapidly multiplies to degrade the larvae, from where it is likely that the bacteria can recycle to re-infect other healthy larvae (Hurst *et al*. 2018). The objective of this study was to determine field efficacy of AGR96X and *Serratia entomophila* (AGR626), for control of grass grub in an autumn sown wheat crop, compared with an organophosphate insecticide SuSCon® Green, a neonicotinoid insecticide, Poncho® (a.i. 600 g/L clothianidin) and a commercial biological product GrubZero.

Methods

To determine background disease levels in the grass grub population, larvae were collected from a trial site on 19 and 21 March, 2019, placed in individual cells in ice cube trays and provided a small piece of fresh carrot (approximately 3 mm cube). After 12 days, the grubs were assessed visually for disease symptoms. Fifty-nine grass grub were healthy with no disease symptoms and 3 had died from handling injuries. Thus, the site had no detectable background disease and was suitable for the intended field trial. On 21 March, ten spade squares along 2 transects were dug in the target paddock to determine background larvae populations. On average, there were >6 grubs/spade square, indicating the field site had >180 grubs/m^2. This far exceeded the minimum threshold of 90 grubs/m^2.

AGR96X was applied via an inert organic granule drilled with the seed containing 3.98x10^8 cells/g at an application rate of 30 kg/ha independently and in combination (15 kg of each) with AGR626 (1.81x10^9 cells/g). Poncho® was applied at 60 mL/100 kg seed and SuSCon Green® was drilled with the seed at 15 kg/ha. Wheat cultivar 'Griffin', pre-treated with the fungicide Raxil® (a.i. 25 g/L tebuconazole, applied at 1.0 L/t seed), was direct drilled at a target plant population of 150 plants/m^2 using a custom built, double disc, cone seeder in 12 x 3.5 m plots with six replicates per treatment on 13 May. GrubZero was applied according to product instructions at 10 L/ha by spray application on 11 June when surviving plants had 2 fully expanded leaves. The trial area was irrigated, the previous crop was white clover and all inputs, except for insecticide application, were managed by the host farmer.

On 24 June, 2019, three spade squares were dug in each plot to count the number of larvae present and then to assess the level of mortality/disease for each treatment. Mortality/disease was assessed using the same protocol as the pre-trial setup, with larvae assessed for latent signs of disease 10 days after collection. For statistical analysis, plant numbers were assessed on August 27, 2019 after plant decline had stabilized. This was the final date when plant numbers could be accurately assessed before tillering made it impossible to distinguish between individual plants. Plots were harvested on 24 February with a Sampo plot combine with yield data adjusted to 14.5% grain moisture content.

Results and Discussion

All treatments increased the mortality and disease levels of grass grub larvae above the untreated control, with the highest mortality/disease in the three bacterial treatments (58-60%) and the Poncho® (clothianidin) treatment (48%) (Figure 1). Mortality/disease was intermediate in the SuSCon Green® and GrubZero treatments (41-42%) (Figure 1). The untreated control had the lowest level of grass grub mortality/disease at 19% (Figure 1).

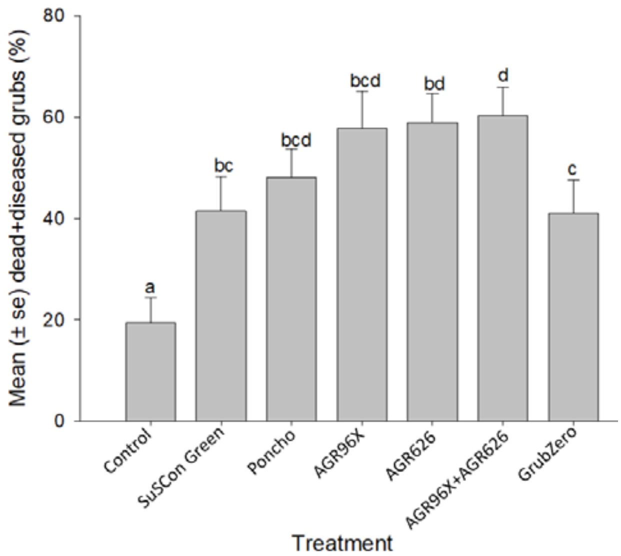

Figure 1. Mortality and disease observed in grass grub larvae collected from a crop of wheat, cultivar Griffin, grown near Southbridge in the 2019/20 growing season following treatment with different insecticides, prototype biopesticides containing *Serratia* spp. (AGR96X, AGR626), or GrubZero. Treatments that share a common letter do not differ at the 5% significance level.

Plant numbers averaged 78 plants/m^2 (± 6) across all treatments, ranging from 70 plants/m^2 in the AGR96X treatment to 93 plants/m^2 in the Poncho® treatment (Table 1). There was no treatment effect on final plant numbers. Wheat heads were counted in February and were similar across treatments with a mean of 655 heads/m^2 (± 35). Grain yield was high due to favourable environmental conditions during grain filling. Yield was, however, increased by SuSCon® Green and Poncho® above the untreated control. The biological treatment combination of AGR96X and AGR626 had similar grain yield to the SuSCon® Green and Poncho® insecticide treatments.

Table 1. Grain yield of wheat, cultivar Griffin, planted at a target plant population of 150 plants/m^2 following treatment with seven products in the presence of ~180 grass grub larvae/m^2, grown near Southbridge in the 2019-20 growing season.

Treatment	Plants/m^2	Heads/m^2	Grain yield (t/ha)	
Untreated	75[1]	630	10.98	abc*
SuSCon® Green	75	670	12.11	e
Poncho®	93	660	11.95	de
AGR96X	70	700	11.11	abcd
AGR626	79	630	10.92	abc
AGR96X + AGR626	81	680	11.65	bcde
GrubZero	71	620	10.72	a
P value	0.147	0.646	0.01	
LSD (p=0.05)	NS	NS	0.87	

Note: Yellow indicates the grass grub treatments that produced the greatest grain yields.
*Treatments that share a common letter do not differ at the 5% significance level.
[1]Plant population was measured on 27 August 2019.

Summary
All treatments had similar plant populations at the end of winter irrespective of how they controlled grass grub larval feeding. The biological treatment combination of AGR96X and AGR626 had similar grain yield to the SuSCon® Green and Poncho® insecticide treatments.

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Harvesting oilseed rape: pusher versus desiccation

Project code B19-05

Duration Year 3 of 4

Authors Jen McCulloch, Phil Rolston, Sonja Vreugdenhil (FAR) and Keith Gundry (PureOil NZ)

Location South Canterbury

Funding FAR

Acknowledgements Ashley Biggs (Fairlie), Hayden Porter (St Andrews) and Richard Peckitt (Pleasant Point) (Canterbury trial hosts), NZ Arable (trial operators)

Key points

- Pushing oil seed rape (OSR) is an alternative pre-harvest method to desiccating standing crops, in order to protect the crop from wind events causing shattering;
- In three trials over three years there were no wind events;
- OSR yields were similar to desiccation in one trial, but pushing too early reduced seed yields by 6 to 19% when pushing was 6 to 13 days before desiccation.

Background

Oil seed rape (OSR) is prone to seed loss from high wind events at harvest. Pushers have been used frequently in Canada to reduce seed losses from pod shattering. Pushers mechanically lodge the crop to reduce the potential impact of climate on pod shattering. Desiccation and direct harvesting the crop is a common approach used by growers in New Zealand. The trials reported here, assessed OSR yields from pushing versus desiccation.

Methods

Trial 1. The trial was undertaken at Fairlie, South Canterbury in 2017, in a commercial paddock of OSR (cultivar MDS16, a high oleic oil variety). Flowering finished on 4 November. There were two treatments with different dates of pushing (7 December and 11 December), which were compared with a desiccation treatment (2.5 L/ha Glyphosate 510 applied 20 December 2017). Plots were 410 m long and 9 m wide. The crop was harvested by the grower on 3 January 2018 and the yield was determined using a weigh wagon. There were no major wind events during the late seed filling pre-harvest period.

Trial 2. The trial was undertaken at St Andrews, South Canterbury in 2018-19, in a commercial paddock of oilseed rape (cv. MDS16). There were two dates of pushing compared with a desiccated (2.5 L/ha Glyphosate 510) section left standing which is common practise in some areas. The two pusher dates were 10 days apart (19 (T1) and 29 (T2) December 2018), while the desiccation was carried out on 30 December 2018. Each plot was two harvester widths (9 m each) by either 222 m or 164 m in length. Treatments were replicated two times. The trial was combine harvested by the grower. The OSR seed moisture contents (SMC) were 45% at T1 pushing, 39.5% at T2 pushing and 34% at desiccation. In all treatments, the loss of seed moisture was similar, with a final seed moisture at combine harvest of 5.8%. For more details on the trial refer to Vreugdenhil *et al*. 2019.

Trial 3. The trial was undertaken at Pleasant Point, South Canterbury, in a commercial paddock of oilseed rape (cv. MDS16) in 2019-20. There were two dates of pushing, 21 and 28 December 2019, and the control treatment was desiccated with glyphosate (3 L/ha Weedmaster 470 with 150 mL LI1000 surfactant) on 3 January 2020. There were two blocks for each treatment. The crop was combine harvested on the 21 January with plots 196 m long and two separate combine runs giving two yield assessments within each block. The treatment means are presented as the means of four harvest runs and the yields were adjusted to 8% moisture content. There were no major wind events during the late seed filling pre-harvest period.

Results and Discussion

In all three trials, there were no high wind events to cause severe seed shattering loss. In two trials, pushing 9 and 13 days (Trial 1) or 6 to 13 days (Trial 3) before desiccation (Tables 1 and 3) reduced yield by between 6 and 19% compared to desiccation. In Trial 2, pushing up to 11 days before desiccation did not reduce yield compared with the standard practice of desiccation (Table 2). The experience of farmers using the pusher is that plots pushed later, ripened faster and were easier to harvest. The next stage of this work is to compare pushing dates that are at, or after, desiccation timings. An observation by growers who are pushing OSR, is that they saw less bird feeding in pushed crops compared to desiccated standing crops.

Table 1. Mean seed yield of OSR following pushing at one of two dates or desiccation at Fairlie, South Canterbury, 2017-18.

Treatment and date	Weeks post flowering	Mean yield (t/ha)*
Pushed 7 December	4.5	3.88
Pushed 11 December	5.0	4.35 ± 0.07
Desiccation 20 December	6.0	4.79

*Mean yield of OSR (±Standard error of mean)

Table 2. Mean seed yield of OSR following pushing at one of two dates or desiccation at St Andrews, South Canterbury, 2018-19 (Vreugdenhil *et al*. 2019).

Treatment	Mean yield (t/ha)
Pushed 19 December	4.80
Pushed 29 December	4.90
Desiccated 30 December	4.80
Mean	4.83
LSD (p=0.05)	0.26

Table 3. Mean seed yield of OSR following pushing at one of two dates or desiccation at Pleasant Point, South Canterbury, 2019-20.

Treatment	Mean Yield (t/ha)	SEM*
Pushed 21 December	4.36	± 0.08
Pushed 28 December	4.22	± 0.22
Desiccated 3 January	4.75	± 0.25

*Mean yield of OSR (±Standard error of mean)

Summary

OSR and other brassica seed crops are susceptible to seed shattering in high wind events. Pushing OSR instead of desiccation is a pre-harvest option to reduce shaking and seed shatter. In three years of trials, there were no wind events at the trial sites. In two out of three trials pushing early, 6 to 13 days before desiccation time, reduced OSR yield by 6-9% (3 out of 4 pushing events) and 19% in one push. Growers using the pusher have observed that later pushed OSR crops ripen faster and are easier to harvest compared to early pushed plots. Growers also comment that they see less bird damage in pushed, compared to desiccated areas. Pushing is a non-chemical option for spreading harvest risk.

Reference

Vreugdenhil, S, McCulloch, J, and Rolston, P (2019). Timing for pushing oilseed rape to maximise seed yield. *FAR Research Results 2018/19*. Pp 147-148.

Spring nitrogen and sulphur rates and application timings on oilseed rape

Project code B19-06

Duration Year 1 of 3

Authors Phil Rolston, Sonja Vreugdenhil, Jen McCulloch, Richard Chynoweth (FAR)

Location Greendale, Mid Canterbury (GPS: 43°35’ 43.07” S; 172°07’ 17.47” E)

Funding FAR

Acknowledgements Earl Worsfold (trial host), NZ Arable (trial operators), Keith Gundry (PureOil NZ)

Key points

- To produce an oil seed rape (OSR) crop of 5 t/ha plus, a total spring nitrogen (N) (applied + soil mineral N 0-60 cm)/ ha) requirement was estimated at 126 kg/ha.
- A small, but economic response to 50 kg sulphur (S)/ha applied as ammonium sulphate (soil SO_4-S = 8 mg/kg and foliar S = 0.52%) was observed in the OSR crop.
- Oil content declined from 46.4% with no applied N to 40.5% with 224 kg N/ha.

Background

For OSR (*Brassica napus L*), the New Zealand recommendation for nitrogen (N) is to apply 200 - 300 kg N/ha split between green bud (GB) (100 - 150 kg N/ha at growth stage (GS) 51) and yellow bud (YB) (100 - 150 kg N/ha at GS59) (FAR 2011). The optimum applied N range was derived from trials with seed yields of 4 - 5 t/ha (three years of trials 2008 - 2010). However, in these trials, rates lower than 200 kg N/ha were not tested. Sulphur (S) is also thought to be important for OSR, but rates and interaction with N are unknown in New Zealand. This trial sought to build on a 2018-19 N rate and timing trial at Hook, South Canterbury, in which the total N (applied + soil mineral N 0-60 cm) for optimum yield was achieved using 174 kg N/ha, and to test if the Nitrogen Nutrition Index (NNI), which is used to guide N decision making in some crops, could predict N requirements as NNI. The NNI is based on the dilution curve of increasing biomass against declining foliar N%. When the NNI is below the critical N (usually 1.0), the crop will respond to additional N.

The 2018-19 trial confirmed that there was no difference in response between N applied at green bud or at yellow bud, or split between them, but splitting the N application is considered desirable to minimize N leaching losses from rain events.

Methods

The response of OSR to N and S was evaluated in a commercial dryland OSR (cultivar MDS 16) crop near Greendale, Central Canterbury, which was sown 25 March 2019 at 3 kg/ha (ex. barley crop). The crop was planted with 24 kg N/ha as Cropzeal 16N and all inputs except subsequent N applications were managed by the grower.

The soil (0-60 cm) had 26 kg mineral N on 20 August 2019. The soil pH was 6.2, Olsen P = 8, potassium = 5 MAF units and SO_4-S = 8 mg/kg. S was applied as ammonium sulphate (20% N and 23% S) and the balance of the N was applied as SustaiN® (46% N). Nitrogen was applied as a 50:50 split between green bud (3 September) and yellow bud (23 September). Plots were 3.3 m wide and 10 m long, with 13 treatments (Table 1) and four replicates in a randomized block design. Treatment 13 rate was based on a Nitrogen Nutrient Index (NNI) calculated from foliar N and biomass on 13 September. Six treatments shared an additional half width plot for destructive harvesting.

Plant heights were measured at four timings; 2 September, 23 September, 14 October and 11 December. Eight plants that were beside each other in a plot were collected on 11 December and plant biomass, stem diameter, number of branches with pods, pod number per plant and stem:pod dry matter ratio were determined. Plant density was determined after harvest by counting stem bases in a 1 m^2 quadrat. The crop was desiccated on the 20 December and direct harvested with a plot combine utilising vertical cutting knifes on 6 January 2020. Seed yields were adjusted to 9% seed moisture.

Foliar S% was tested on four nil S plots, on three dates covering early stem elongation to flowering (5 September, 30 September and 5 November). Above ground N and S% in stems+leaves, pods and seeds were assessed on samples collected on 11 December. Statistical analysis was completed using Genstat 19 while the N response utilised a piecewise regression fitted from SciPy (Pauli Virtanen 2020). The oil content of samples from all treatments was assessed by PureOil using near infrared (NIR) spectroscopy.

Table 1. Dates and quantities of sulphur (S) and nitrogen (N) applied to an oilseed rape (cultivar MDS 16) crop grown near Greendale, Central Canterbury in the 2019-20 season as well as the total N (applied N and soil mineral (min) N 0-60 cm) available to the crop based on soil testing and fertiliser application.

Trt	Nutrient application amount and timing				Total N (kg/ha)	
	N/S application 1		N application 2	N application 3		
	22.8.19 N (kg/ha)	22.8.19 S (kg/ha)	3.9.19 N (kg/ha)	23.9.19 N (kg/ha)	Total applied N	Total N (Applied+Min)
1	0	0	0	0	0	26
2	0	0	12	12	24	50
3	43	0	15.5	15.5	74	100
4	43	0	40.5	40.5	124	150
5	43	0	65.5	65.5	174	200
6	43	0	90.5	90.5	224	250
7	43	25	15.5	15.5	74	100
8	43	25	40.5	40.5	124	150
9	43	25	65.5	65.5	174	200
10	43	50	15.5	15.5	74	100
11	43	50	40.5	40.5	124	150
12	43	50	65.5	65.5	174	200
13	0	0	78	0	78	104

Results and Discussion

Seed yield: Seed yield was increased by 203 kg/ha (P=0.005) for OSR grown using 50 kg/ha of applied S compared with 0 and 25 kg S/ha which were similar (Table 2). There was no N x S interaction. N significantly increased seed yield from 4.34 to an average of 5.01 t/ha for all N treatments (range 4.72 to 5.19 t/ha; $LSD_{0.05}$ = 0.116). A split regression analysis predicted a breakpoint in yield at 126 kg total N/ha (R^2= 80.6) (Figure 1). This was less than the previous year's trial that predicted 174 kg total N/ha for maximum yield. Increasing N rates decreased oil content linearly from 46.4 to 40.5% oil as the total N rate was increased from 26 to 250 kg N/ha (Figure 2). If oil content exceeds 44% a price bonus is added, while below 40% oil a discount in price occurs.

The soil test sulphate sulphur was measured at SO_4 S = 8 mg/kg and corresponded to a spring foliar test average of 0.52% which is regarded as not deficient and above the foliar concentration of 0.4% deemed to be responsive in OSR trials in the United Kingdom (Withers et al. 1996).

Data from the two-year trial suggests that OSR seed yields of > 4 T/ha can be grown with rates of total N (applied + soil mineral N) that are between 126 and 174 kg N/ha and that rates of 200 kg N/ha and higher do not increase yield. Further work will be needed to define optimum N and S requirements at multiple locations throughout the OSR growing region.

Table 2. Seed yield (t/ha) for an oilseed rape (cultivar MDS 16) crop grown near Greendale, Central Canterbury in the 2019-20 season using three rates of applied sulphur (S) and three rates of total nitrogen (N) (applied+mineral N).

Total N (kg/ha)	**Applied S (kg/ha)**			**Average Yield (t/ha)**
	0	**25**	**50**	
100	4.72	4.92	4.99	4.88
150	4.96	4.99	5.19	5.04
200	5.00	5.00	5.11	5.04
Average Yield (t/ha)	4.89	4.97	5.10	
LSD (p=0.05)		0.11		
F.prob		0.005		

Note: Yellow indicates the treatment was amongst the treatments showing the highest yield.

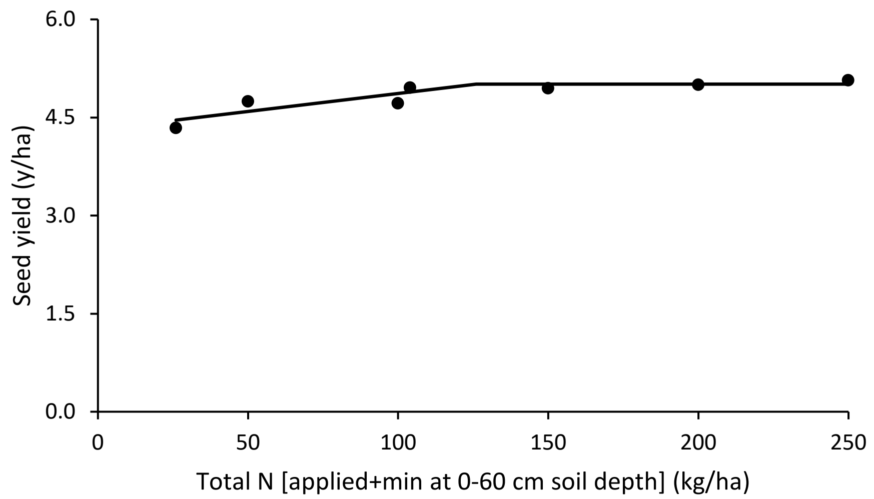

Figure 1. Seed yield of an oilseed rape (cultivar MDS 16) crop when grown near Greendale, Canterbury in the 2019-20 season following the application of seven nitrogen (N) rates.

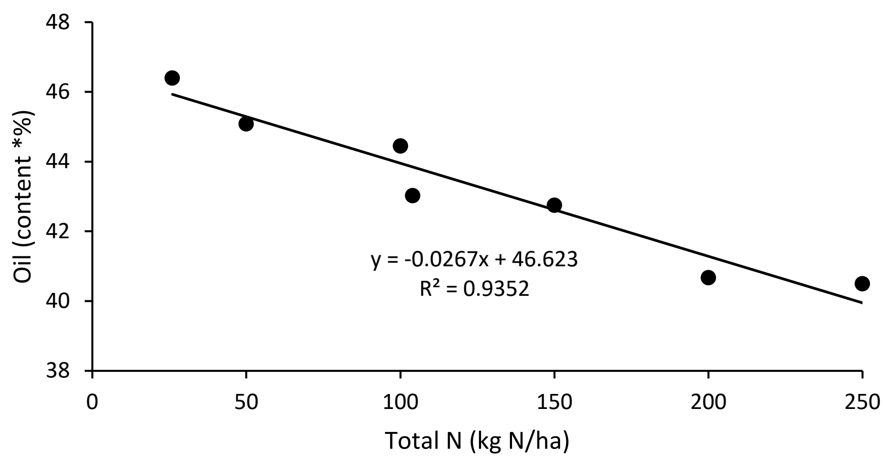

Figure 2. Effect of total nitrogen (N) (mineral N 0-60 cm and applied N) on the oil content of an oil seed rape crop grown near Greendale, Central Canterbury in the 2019-20 season.

Margin over cost (MoC): Although the yield responses are small, there was a significant MoC for the use of 50 kg S/ha of $145/ha compared with 0 or 25 kg S/ha. The MoC for N was highest ($230/ha) for the lowest applied N rate treatment (24 kg N/ha) and was positive for N rates up to 124 kg N applied/ha.

Summary

Measuring soil mineral N at the end of winter is important for planning spring N inputs. A target of between 126 and 174 kg total N/ha should be used for rational N application decisions. This trial series will continue in 1920/21.

References

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Can glyphosate activity on ryegrass be enhanced with additives?

Project code X19-03

Duration Year 1 of 2

Authors Matilda Gunnarsson, Phil Rolston (FAR)

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Key points

- None of the additives (fulvic acid, citric acid, fish fertiliser or ammonium sulphate) increased glyphosate efficacy.
- Glyphosate applied at recommended label rate (1470 g ai/ha) was more effective than lower rates for controlling ryegrass.
- Reduced rates of glyphosate (735 and 980 g ai/ha) were less effective in controlling ryegrass.

Background

Glyphosate is a valuable tool for vegetation management in direct drill and reduced tillage of arable crops. However, public concern about the potential negative impacts of glyphosate on the environment and human health is increasing, and several countries have restricted or banned its use. Alongside this, there is growing evidence of weed species developing glyphosate resistance. Maintaining both glyphosate efficacy, and the social license to use it, relies on appropriate and responsible use.

Environmental, water quality and biological factors can impact on the performance of glyphosate. A number of products are also used as additives to improve glyphosate efficacy, to provide alternatives to chemical additives or to provide environmental benefits. For example, some growers claim fulvic acid allows them to reduce glyphosate rates while others claim to use it to mop up residual glyphosate. Ammonium sulphate and fish-oil products are also used as additives by some growers. The modes of action of these additives are unknown, although some claims to lowering pH with citric acid have been made.

Methods

A trial was established in a perennial ryegrass field that was sown in April, 2018. The plots were 10 m long and 1.5 m wide designed as a randomised complete block design with three replicates. The trial was sprayed on 12 November, 2019, with a water rate of 165 L/ha when ryegrass plants were approximately 10-15 cm tall, air temperature 19°C and relative humidity was 49 %. The experiment had 18 treatments, including three different glyphosate rates (735, 980 and 1470 g glyphosate/ha using Lion® 490 DST (a.i. 490 g glyphosate/L as the potassium and ammonium salts)), and three rates (50, 100 and 150 g/ha) of a commercial fulvic acid product, as well as a single rate of ammonium sulphate (2 kg/100 L water with 1470 g rate of glyphosate), citric acid and fish fertiliser. Water pH was measured before and after glyphosate was added. Citric acid was added until the solution reached a pH of 4.5. Pulse®Penetrant (a.i. 800 g/L organosilicone) was added at the recommended rate of 100 mL/ha. Fish fertiliser (Bio Marinus™Hydrolysed Fish Fertiliser) was added at a rate of 4.4 L/ha.

Plots were visually evaluated; the first score was undertaken seven days after treatment (DAT) and the last one was done 65 DAT on brownout and re-growth (0-100). A tiller count was done 71 DAT by cutting three rows by 50 cm quadrat (0.25 m^2) and counting the number of green ryegrass tillers.

Results and Discussion

The addition of glyphosate to water lowered the water pH from 6.8 to 4.8.

This trial showed no benefit of using any additive with glyphosate, whether at label rate, or at either of the reduced rates. For example, glyphosate used alone, at half label rate (735 g ai/ha), reduced the relative average number of tillers to 100, significantly fewer than any treatments where fulvic acid was added (248 – 316 tillers) (Table 1). With fulvic acid, the nil treatment had fewer re-growth tillers than any of the fulvic treatments (Table 1).

The ammonium sulphate treatment did not improve glyphosate efficacy (data not shown).

Table 1. Relative average ryegrass green tiller count 71 days after treatment with different glyphosate formulations at the FAR Chertsey Arable Research Site, Mid Canterbury in 2019-20.

Glyphosate rate (g ai/ha)	**Fulvic rate (g/ha)**				
	0	**50**	**100**	**150**	**Average**
735	100	316	296	248	241
980	44	184	79	225	133
1470	16	44	57	21	35
Average	54	181	143	164	
	Glyphosate rate			Fulvic acid rate	
	LSD (p=0.05)	P value		LSD (p=0.05)	P value
	52	<0.001		59	<0.001

Summary

The key learning from the 2019-20 trial was that glyphosate rate is the most important factor in determining the level of ryegrass control. A glyphosate application of 1470 g/ai provided better control than any other treatment, whether or not any additive was included.

Fulvic acid at any rate decreased the efficacy of glyphosate.

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