SIRC

SEED INDUSTRY RESEARCH CENTRE

Annual report 2021-2022

SEED INDUSTRY RESEARCH CENTRE

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Predicting the time of flowering among perennial ryegrass genotypes

Project H16-16

Authors Richard Chynoweth (FAR)

Duration Years 1 to 5 of 5 (PhD study)

Location Lincoln, Canterbury

Funding FAR and SIRC

Acknowledgements Derrick Moot, Mariana Andreucci (Lincoln University) and Hamish Brown (Plant & Food Research)

Key points

- Perennial ryegrass can be vernalised at temperatures below approximately 12°C.
- Floral initiation is determined by a genotype-specific photoperiod during spring.
- Perennial ryegrass must have at least five leaves before it can begin reproductive initiation.

Background

Perennial ryegrass is the most widely sown pasture grass used in New Zealand. It thrives in irrigated or summer moist dairy pastures where it is popular as a long-term pasture species (Stewart et al. 2014). The supply of seed is the delivery mechanism for improved forage and endophyte genetics to pasture and amenity markets.

It is generally accepted that perennial ryegrass requires exposure to cool temperatures (primary induction (PI)) followed by long photoperiods (secondary induction (SI)) for flowering to occur (Heide 1994). Understanding when plants switch to reproductive development allows producers to match crop and cultivar performance with different climatic conditions. Additionally, the time of stem elongation coincides with important agronomic management timings for defoliation, nitrogen, fungicide and plant growth regulator applications used to reduce stem internode length to encourage seed growth (Chynoweth et al. 2010; Chynoweth & Moot 2017). In pastures, stem elongation and ear emergence results in loss of pasture quality and a subsequent reduction in animal performance (Chapman et al. 2014). Thus, determining when the switch from vegetative to reproductive development occurs is important in seed production and grazing/mechanical defoliation to retain pasture quality. The switch to reproductive development is visualised by a change from producing vegetative organs (leaves) to producing reproductive organs (spikelets and seed sites).

Traditionally, the time of flowering can be predicted empirically from metadata in an environment using the mean of historical observations. Alternatively, it can be predicted mechanistically as a function of temperature accumulation and its modification by photoperiod (Pp) and vernalisation requirements (Weir et al. 1984; Jamieson et al. 1998).

The aim of this project was to create a predictive model of the time to flowering for perennial ryegrass. To achieve this required the phenological development of perennial ryegrass to be quantified in relation to different temperatures and photoperiods.

The relationship was investigated through a series of controlled environment chamber and field experiments completed between 2016 and 2020. These had four objectives.

- To identify germplasm with a range of responses to vernalisation, photoperiod and temperature treatments.

- To quantify the vernalisation and thermal time requirements for the phenophases (growth stages) up to final leaf emergence of four representative perennial ryegrass genotypes grown under long and short photoperiods.
- To quantify the timing of phenophases from emergence to flowering of four perennial ryegrass genotypes grown under field conditions with natural changes in photoperiod.
- To use the data collected in the previous experiments to determine what, if any, changes were required to adapt existing phenological models for wheat (*Triticum aestivum* L.), for them to be able to predict perennial ryegrass phenophases.

Methods

Objective 1 was investigated through four experiments that screened germplasm from a wide geographic origin, ranging from Africa to Northern Europe. Lines with different induction mechanisms were selected from Objective 1 for use in later experiments to quantify vernalisation and photoperiod responses (Objectives 2 and 3). Objective 2 involved controlled environment chambers to quantify phenological development using both (i) accumulated temperature (thermal time) modified by vernalisation and photoperiod and (ii) changes in the final number of leaves after exposure to different vernalisation and photoperiod treatments. In Objectives 2 and 3 the key assessments are the final number of main stem leaves and the number of primordia on the stem apex. Vernalisation was quantified from eight chamber experiments which examined the influence of four temperatures on the rate of vernalisation under either short or long photoperiods. Analysis of the reduction in the number of main stem leaves and time of commitment to the final leaf allows calculation of cardinal temperatures (minimum, optimum and maximum), the duration required and the rate of vernalisation. These can then be used in the development of predictive equations. Counting of the number of primordia allows estimation of the inflection point in primordium production which is the time of floral initiation (FI). With the addition of the number of leaves and the rate of primordia production, data can be used to estimate the final number of leaves. Objective 3 involved four genotypes sown on five dates in the field to quantify the photoperiod response. In Objective 4, a framework was proposed to estimate final leaf emergence and flowering dates for perennial ryegrass. Thus, the resulting predictive model is the final step in achieving the aim.

Results and Discussion

In Objective 1, the influence of temperature and Pp on the development of perennial ryegrass was investigated using genotypes from different origins grown under controlled environment conditions. Initial screening showed many ecotypes that originate from ~33 to 46° latitude became reproductive in constant 18°C, 20 h Pp, while few flowered in constant 18°C, 14 h Pp. These results demonstrate that flowering occurred in response to a long Pp, without prior PI in some ecotypes.

Three flowering groups, assessed where 50% of plants in flower constitutes flowering, were identified using agglomerative clustering with binary data (a statistical grouping method) (Figure 1). Additional analysis using the percentage of plants flowering at the final assessment, separated group two based on a vernalisation response. The response types identified were (obligate = required, non obligate = not required));

- Group 1. Non obligate for vernalisation, obligate for medium Pp. Flowering in response to Pp only where Pp longer than 11 h induced FI, thus vernalisation was not required for flowering, e.g. 'Medea'.
- Group 2.
    - Non-obligate for vernalisation in long Pp, obligate for long Pp. Achieved flowering in response to 20 h Pp without vernalisation, thus vernalisation was not obligate, e.g. 'Grasslands Nui'.
    - b. Obligate for vernalisation satisfied under long Pp, obligate for long Pp, e.g. ecotypes originating from latitudes of ~45-60°N, e.g. ecotype 6.

- Group 3. Obligate for vernalisation. Ecotypes that did not flower in any experiments, thus demonstrating a strong requirement for short days, or extended duration of cold, e.g. 'Kleppe'.

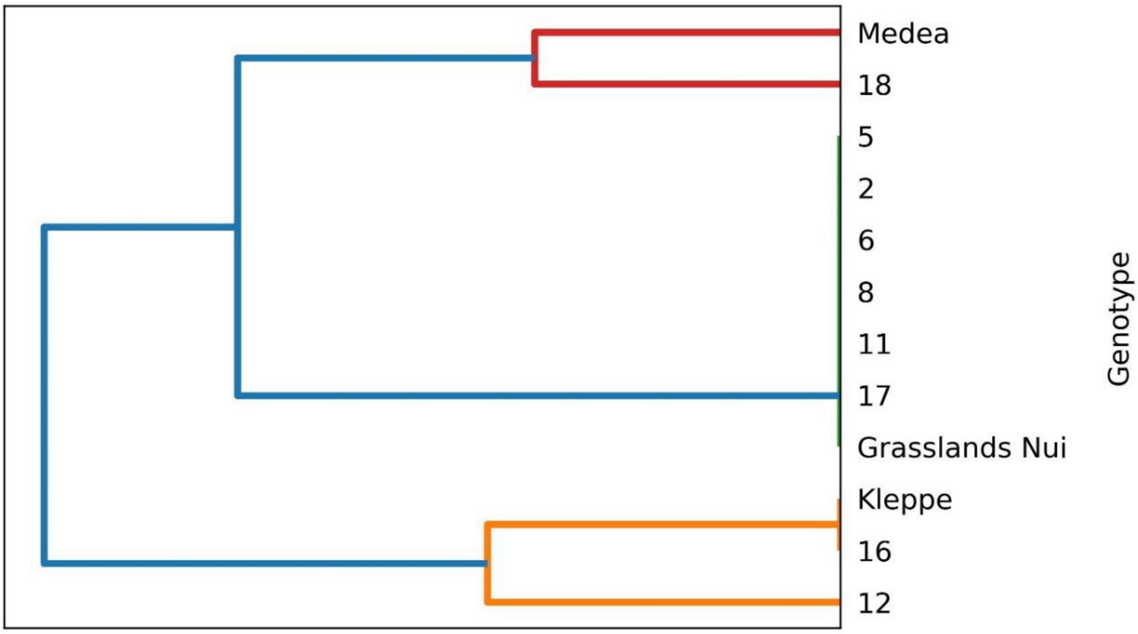

Figure 1. Dendrogram demonstrating clusters of ecotypes established using Agglomerative Clustering based on binary flowering responses when grown under four temperature and photoperiod combinations in controlled environment chambers at Lincoln University, New Zealand.

In Objective 2, progress through PI was assessed at 4, 8, 12 and 18°C, in 8 or 17 h Pp. Plants were exposed at two weekly intervals for up to 12 weeks and subsequently transferred to non-primary inducing conditions, 18°C, 17 h Pp which would fulfil the SI requirements. Flowering was defined as when 50% of plants produced seed heads following SI, thus, plants could be removed from growth chambers before flowering occurred. FI was determined by tracking accumulated organ number (primordia plus leaves) relative to leaf number which was quantified using Haun Stages (HS) (Haun 1973). The expected pattern was represented by three straight lines (Figure 2). The first period represents vegetative growth with a rate of ~2 primordium/HS. The second stage began at FI when the rate of primordia production increased. The final period was when primordium production ceased and terminal spikelet (TS) was observed, which was represented by no further increase in the number of primordium/HS. FI and TS were calculated as the inflection points for this relationship.

Maximum temperatures for completing PI in an 8 h Pp and 17 h Pp (respectively) were 18°C and 18°C for 'Medea', 12°C and 4°C for 'Kleppe', 12°C and 8°C for 'Grasslands Nui' and 12°C and 12°C for 'Grasslands Impact'. Thus, a function was required to reduce the upper limit of effective temperatures as Pp increased for some genotypes. No treatment achieved FI prior to exposure to long photoperiods. Thus, optimum temperatures for progression through PI were defined from treatments exposed to short days (8h). V_{sat} was defined as when the number of leaves produced post transfer reduced to 4HS from the shortest treatment duration. For 'Medea', this was 18°C and V_{sat} occurred after 28 days exposure, 'Grasslands Impact' required 56 days at 12°C, while 'Grasslands Nui' and 'Kleppe' required 70 days between 4 and 12°C.

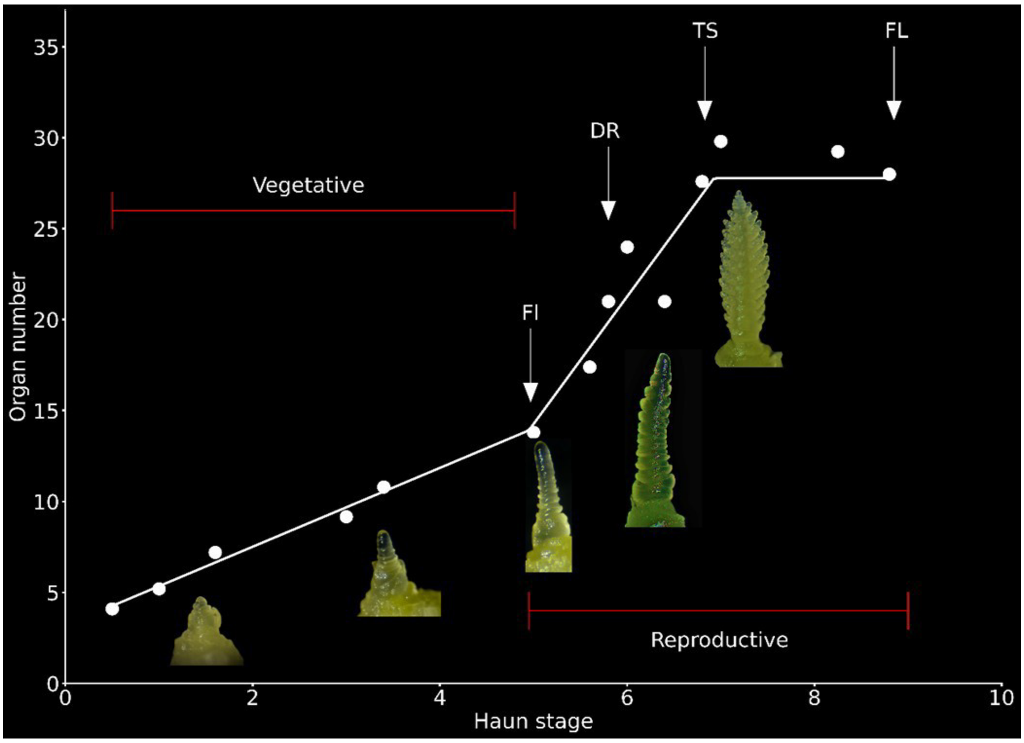

Figure 2. Example of the expected model from 'Medea', grown in 12°C, 8h Pp for 2 weeks followed by 18°C 17 h Pp to determine floral initiation (FI) and terminal spikelet (TS) relative to Haun Stage with examples of apical development. Double ridge (DR) and final leaf emergence (FL) plotted for reference.

V_{base}, defined as the minimum exposure required at the optimum temperature for 50% of plants to flower, was 0 days for Medea, 23 days for 'Grasslands Impact' and 46 days for 'Kleppe' and 'Grasslands Nui'. After V_{sat} plants continued to produce primordium at the vegetative rate until they were transferred to 17 h Pp, when FI occurred. This confirmed exposure to a long Pp was an obligate requirement for flowering in all genotypes. Additionally, no plant achieved FI prior to obtaining HS4-5, which sets a base HS for photoperiod perception while the minimum number of main stem leaves was nine.

In the field (Objective 3), primary induction was achieved by all genotypes from autumn and winter sowing dates prior to the shortest day. Subsequently FI was triggered by lengthening Pp at a genotype specific base Pp (Pp_{base}) of ~10.5 h for 'Medea', 'Grasslands Nui' and 'Grasslands Impact' and 12 h for 'Kleppe'. When FI occurred at Pp_{base}, 'Grasslands Nui', 'Grasslands Impact' and 'Kleppe', produced ~6.5 leaves compared with 'Medea' that produced 5.5 while all genotypes reduced towards four leaves when FI occurred at the saturating Pp (Pp_{sat}). Pp_{sat} were 14 h for 'Medea', 15.7 h for 'Kleppe', 15.6 h for 'Grasslands Nui' and 17 h for 'Grasslands Impact'. Therefore, combinations of the vernalisation response and the current HS allow the release of flowering following which the Pp_{base} and the slope of Pp response separated the genotypes and described the time from FI to final leaf emergence. Concurrently the relationship between the number of leaves to emerge post FI multiplied by the phyllochron (the leave appearance rate) determined the date of final leaf emergence. Since ~2HS remained to emerge at TS for all sowing dates, the mechanism reducing the duration from FI to final leaf emergence is a reduction in the HS duration from FI-TS as Pp increases.

During Objective 4, two modelling techniques were calibrated to incorporate vernalisation and Pp responses. These predicted competence to flower and final main stem leaf emergence to within 6 days for four genotypes sown on five dates between early autumn and late spring.

Summary

Following emergence, perennial ryegrass is a vegetative juvenile and goes through primary (PI) and secondary induction (SI) phases before becoming reproductive and exhibiting floral initiation (FI). Experimental evidence shows the duration of primary induction is influenced by temperature while photoperiod (Pp) may influence the duration of both primary and secondary induction. The range of flowering responses shown by perennial ryegrass genotypes may be characterized by genotype responses to Pp and temperature. The full PhD thesis can be accessed via the Lincoln University library.

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Stem rust in different ryegrass seed crop cultivars

Project code H19-03-02

Duration Year 4 of 4 (season 2021-22)

Authors Nicholas Davies (AgResearch) and Phil Rolston (FAR)

Location PGG Wrightson Seeds Kimihia Research Station, Lincoln.

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Sean Bennett (Lincoln University summer student), Richard Sim, Murray Kelly, Will Mitchell, Louise Carpenter (PGG Wrightson Seeds)

Key Points

- Differences in stem rust (caused by *Puccinia graminis*) tolerance are likely to be quantifiable among perennial ryegrass (*Lolium perenne* L.) cultivars.
- An exponential relationship between infected tillers and total pustules was confirmed for reproductive organs.
- A substantial proportion of tillers became infected before pustule counts increased, indicating that stem rust disease spreads rapidly between tillers as disease severity increases.
- Most New Zealand forage ryegrass cultivars show higher tolerance to stem rust than turf types and northern hemisphere cultivars.

Background

Stem rust, caused by the fungus *Puccinia graminis* subsp. *graminicola* (*P. graminis*), is a disease which infects perennial ryegrass (*Lolium perenne* L.). *Puccinia graminis* damages the stems and heads of ryegrass plants by cutting off the supply of nutrients to the seeds which can cause significant losses in the overall seed yield of a ryegrass crop. Yield losses depend on seasonal conditions, but previous FAR trials have shown yield reductions of 20-50+ % (some recent examples include Davies et al. (2020), Chynoweth et al. (2021)). New Zealand bred forage cultivars appear to be more tolerant to stem rust infection than cultivars bred overseas, and a multi-cultivar trial conducted in 2020-21 supported this finding.

There are a number of effective fungicide options for managing stem rust, however, they need to be applied prior to initial infection. This presents two challenges; 1. how to identify and treat cultivars depending on their genetic tolerance, and 2. how to optimise fungicide inputs for a given crop. Understanding how stem rust infections progress in different cultivars is important to improve understanding of how to optimize fungicide application programs. The objective of this study was to understand and quantify differences in cultivar susceptibility.

Methods

The trial was conducted at Kimihia Research Station (PGG Wrightson Seeds) located near Lincoln, North Canterbury. Nine perennial ryegrass cultivars were selected to track crop development and disease susceptibility. The cultivars (Table 1) were selected based on the results the FAR trial conducted during the 2020-21 growing season (Davies et al. 2021) to best represent the genetics of turf and forage-type ryegrasses developed in New Zealand, North America, and Europe with a range of heading dates from 0 (Nui) to +35 days. Asa result of commercial sensitivities, all cultivar names except Nui have been redacted.

Cultivars were replicated twice with each cultivar represented by two isolated rows approximately 2 m long and one plant wide. The rows of selected cultivars were monitored for stem rust with the weekly sampling of cultivars commencing once pustules characteristic of stem rust were observed.

For each cultivar, stem rust sampling consisted of 25 tillers per row (50 tillers per cultivar) being randomly selected and cut at ground level at three random positions within each plot and then combined together. For each tiller, the number of pustules were recorded on the stem, head, and leaves. If the infection rate was 1 tiller in 100, a 50-tiller sample (25 from each of the two replicates) gives a 40 % probability of finding an infected tiller in any given sampling. An infection rate of 6 infected tillers in 100 gives 95% probability of finding at least one infected tiller within the collection of 50 tillers.

The final sampling occurred on 5 January 2022, when the trial area was topped.

Table 1. Perennial ryegrass (*Lolium perenne*) cultivars used in the trials at Lincoln from 2020-2022, organised based on their growth type (F = forage, T = turf) and origin.

Cultivar	Heading Date (Nui = 0)	Type	Origin
F1 (Nui)	0	Forage	New Zealand
F2	+20	Forage	New Zealand
F3	+8	Forage	European
T1	+11	Turf	New Zealand
T2	+12	Turf	New Zealand
T3	+18	Turf	New Zealand
T4	+11	Turf	European
T5	+20	Turf	North America
T6	+35	Turf	European

The total number of pustules and percent infected tillers were analysed using a Bayesian model implemented in python using the pyMC library. The Bayesian model was used to fit logistic curves using the following equation:

$$Infection = \frac{c}{1 + e^{\left(\frac{b-t}{a}\right)}}$$

Where: *a*, *b* and *c* are cultivar specific parameters and *t* is time.

The logistic curves were parameterised using start date, the rate of increase, the end date, and the ultimate end height. The rate of increase in pustules was used as a measure of tolerance to stem rust. Start date was the date at which the disease reached a level of infection which could be detected. The end date and height were the date at which the maximum infection level was reached for the season. These parameters allowed for a comparison of cultivar features such as heading date, type and origin with stem rust tolerance and infection onset.

A single analysis incorporating both years of the trial was also conducted to enable partial separation of the trial/year effects from the cultivars. Because individual cultivar names are commercially sensitive, and because of the level of work involved in assessing a single cultivar, this analysis is presented with cultivars grouped by breeding provenance and type. Note that only one Northern hemisphere forage is present in the dataset. Specific details about how this was conducted are available on request but are out of the scope for this publication.

Results and Discussion

Both the percentage of infected tillers and the total number of pustules per 100 stems followed a logistic curve (Figure 1 and Figure 2). Throughout the infection cycle the number of pustules increased in an exponential timeframe, meaning the number of pustules doubled over a set timeframe (e.g. pustule numbers doubled at approx. 10-day intervals) (Figure 1). Cultivars showed differences in the rate of infection increase, as well as the ultimate number of pustules present at the season end. All cultivars reached near 100 % of tillers infected (Figure 2), however, the difference in the final number of pustules between F2 (a NZ forage with 5628 pustules per 100 stems) and some of the turf ryegrasses (T5, 14534 pustules per 100 tillers) was over double (Figure 1). This was very similar to the previous trial where Nui had about half the total number of pustules seen in some of the northern hemisphere turfs (Davies et al. 2021). Because the plots were not harvested, the differences in seed yield between cultivars could not be determined in this trial. Note that there was only one northern hemisphere forage in the dataset (F3) and consequently it was a variable. Therefore, it was difficult to extrapolate any further differences between New Zealand and foreign forages.

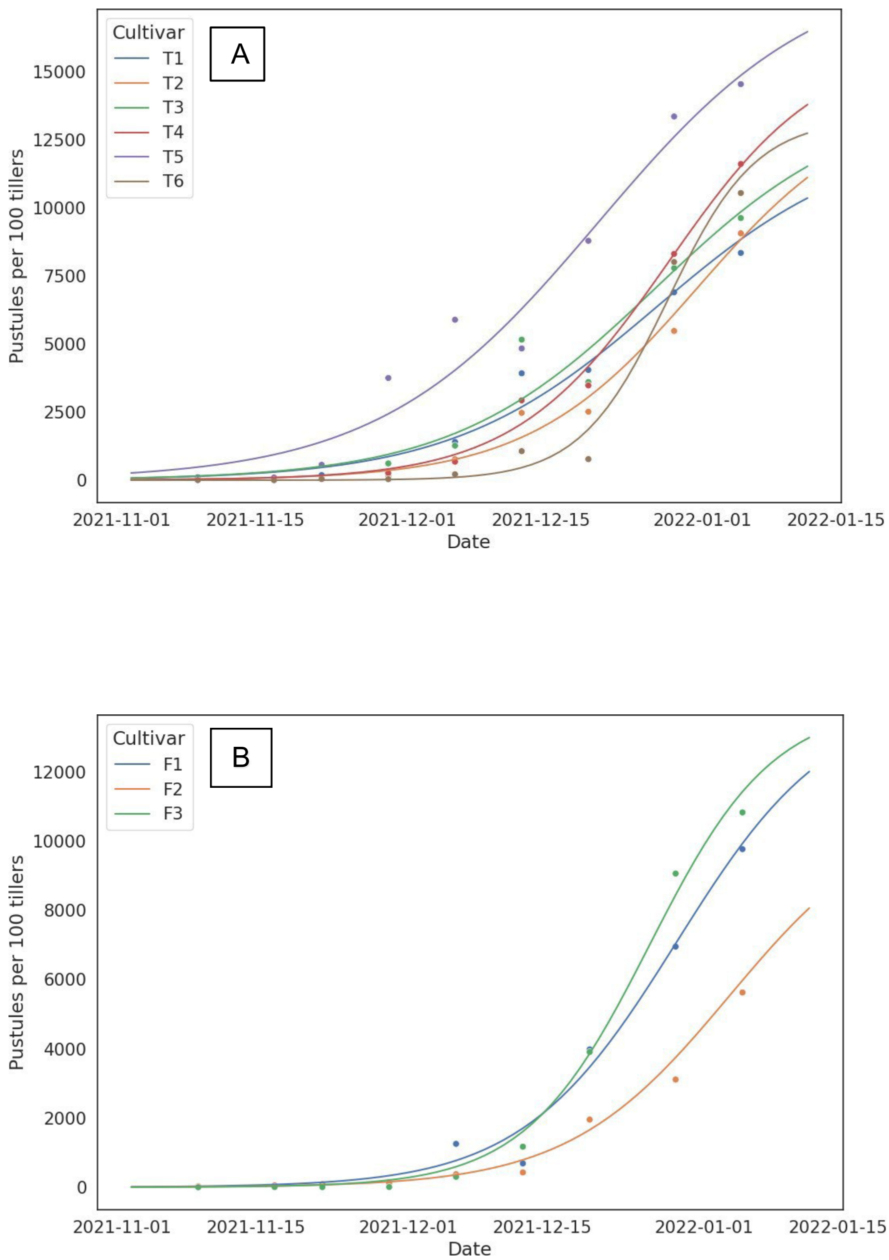

Figure 1. Number of stem rust pustules per 100 tillers on six turf cultivars (A) and three forage cultivars (B) of perennial ryegrass grown near Lincoln in the 2021-22 growing season. Note, F indicates a forage cultivar, T indicates a Turf-type cultivar.

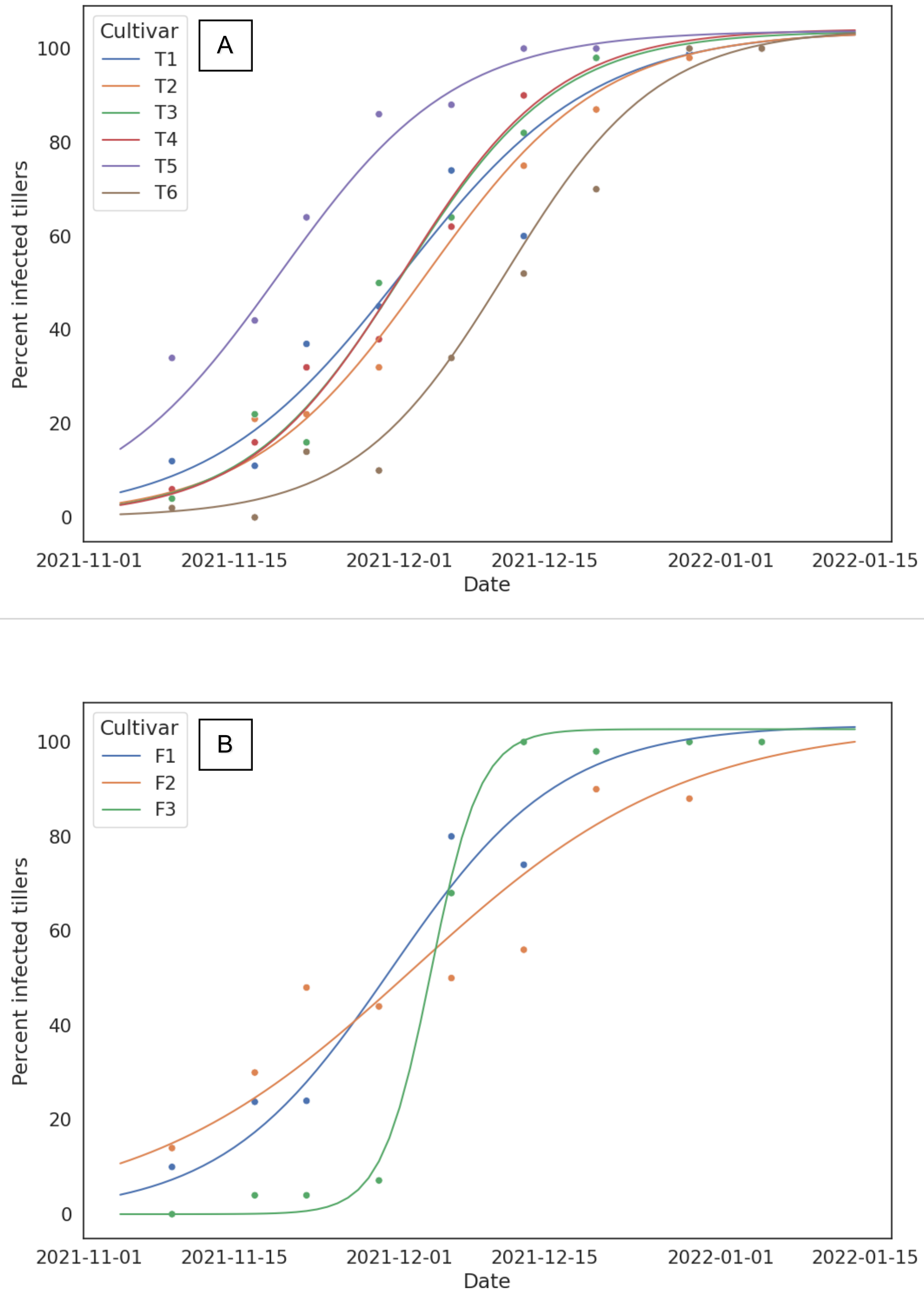

Figure 2. Percent of tillers infected with stem rust during the 2021-22 season for six turf cultivars (A) and three forage cultivars (B) of perennial ryegrass when grown near Lincoln. F = Forage, T = Turf.

The differences in disease progression among cultivars allowed cultivars to be placed into risk categories where those with rapid disease progression require more conservative fungicide strategies. For the turf types, the New Zealand germplasm generally showed slower disease progression when evaluated by the number of pustules present compared with northern hemisphere germplasm. However, all cultivars were similar when the percentage of tillers infected were compared.

At the end of the 2021 season, many cultivars reached 100% of tillers with pustules. However, the cultivar Nui and the other New Zealand forage (heading date of Nui +20) contained approximately half the pustules of the of the worst affected turf types, which aligns with previous year's results (Davies et al. 2021). The slow spread of disease within these cultivars suggest they possess an additional degree of tolerance. F3 is the single Northern hemisphere forage. The particularly steep build up in infected tillers is likely due to sampling variation and model fitting. F3 did not perform in this way in the 2020/21 trial.

It appears a substantial proportion of tillers became infected prior to the first pustule assessments, as indicated by the rapid increase in pustule number, even though pustules were not visible. This indicates that stem rust spreads between tillers and then within tillers over time. The strong relationship between the log of the number of pustules and the percent of infected tillers observed in the current study align with results from previous seasons (Davies *et al.* 2021).

Summary

There are differences in stem rust infection rates between cultivars, which can be linked to both breeding type (turf or forage) and origin (NZ or Northern hemisphere). Further work is required to validate the quantitative nature of these relationships. Furthermore, it may be possible to quantify stem rust resistance of cultivars by using the parameters of the logistic curves fitted to observed data. The development of a method for fitting observed data by cultivar is another step toward the development of a predictive model for stem rust infection to increase the efficiency of fungicide programmes.

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Pre-harvest strategies to improve the yield and quality of annual ryegrass seed crops, especially under wet season conditions.

Project code	H19-06-01
Duration	Year 2 of 3
Authors	Owen Gibson, Richard Chynoweth, Phil Rolston (FAR)
Location	Yaldhurst, Canterbury (GPS 43°30'34.7"S 172°31'44.6"E)
Funding	Seed Industry Research Centre (SIRC)
Acknowledgements	NZ Arable (trial contractors), NZ Seedlab (germination testing) and Mark Reed (trial host)

Key points

- Highest seed yield (2040 kg/ha) of annual ryegrass was achieved by cutting at 42 % seed moisture content.
- As seed dried at 2% a day from 42 % moisture content, yield reduced by 185 kg/ha each day that windrowing was delayed.
- The application of either diquat or glyphosate did not influence seed yield when applied to annual ryegrass windrowed two days after application.
- Dampening the crop with 3mm water had no impact on yield.
- Seed germination 6 months post-harvest was significantly lower as a result of greater proportion of abnormal seedlings following the application of some pre-windrowing treatments.

Background

Widespread practice in New Zealand is to cut Italian and annual ryegrass seed crops at approximately 42-45 % seed moisture content (SMC) at night or early morning when humidity is high to reduce seed loss due to shattering. Ryegrass seed is considered to have reached physiological maturity at approximately 37 % SMC, but is not safe to store until it reaches 12 % moisture content. Often threshing occurs prior to seed drying to 12 % SMC because of unfavourable weather conditions. Applying a desiccant prior to harvest can reduce the time from cutting to threshing, while also reducing the amount of re-growth through the row before harvest and/or lowering the SMC at harvest.

At physiological maturity, developing seeds stop accumulating assimilate via translocation, reducing the risk of transferring agrichemicals into the seed. However, the seed is still vulnerable to direct chemical uptake while it remains green. Previous work in the United Kingdom has shown that the application of a desiccant prior to harvest results in a high level of abnormal seed and low germination rates (Roberts and Griffiths 1973). During particularly wet seasons like that in 2021-2022, the application of a desiccant could potentially increase the rate of ryegrass desiccation and reduce the interval between cutting (windrowing or mowing) and harvest. However, potential contamination of seeds treated with the chemicals used for desiccation has raised human-health concerns overseas, and alternative methods for safely producing ryegrass seed are required

The aim of this study was to assess:

- if annual ryegrass can be cut at lower SMC than the standard 42-45% without reducing machine-dressed seed yield due to seed shatter.
- if cutting in early morning in the dew increases seed yield compared to cutting at mid-day.
- the impact of applying 3 mm irrigation prior to cutting on machine-dressed seed yield.

- if the application of diquat (Reglone®) or glyphosate reduces seed quality when applied at or above 40 % SMC.

Methods
A trial was established on 5 January 2022 in a paddock of annual ryegrass located at Yaldhurst, Christchurch. The trial had a randomised complete block design with 15 treatments and four replicates. Plots were 2 m wide and 10 m long. The soil type was a Waimakariri moderately deep silt (Waim_2a.1). Paddock details are presented in Appendix 1.

SMC was monitored from trial commencement until harvest according to ISTA regulations. When SMC reached 45 % on 10 January 2022, the treatments were initiated as per Table 1.

Early morning cutting treatments, hereafter referred to as “Dew”, were windrowed at 7 am while the corresponding nil irrigation and irrigated treatments were cut at mid-day. Chemical treatments were applied, either Reglone® at 3 L/ha, (MOA group 22, a.i. diquat) 200 g ai/L) + Contact® Xcel (a.i. Linear alcohol ethoxylate 980 g/L) or glyphosate at 2.1 L/ha as Deal 510RF (MOA group 9). Chemical treatments were applied via a backpack sprayer with an electric pressure pump suppling a two-metre spray boom fitted with six 110 015xr tee jet nozzles delivering 250 L/water per hectare at 210 kpa pressure, thus creating a very fine spray droplet. Application was the same day as the corresponding cutting treatments, and windrowing was two days later (Table 1). Irrigation treatments were applied at 8 am each morning with a 1.8 m handheld boom with six 8002 teejet® nozzles delivering 60 L water per plot (3 mm), applied prior to windrowing.

A modified John Deere windrower, cutting a 1.8 m swath, was used at the prescribed time of windrowing according to the treatment list (Table 1). Knife sections were under serrated and sharpened at the start of the trial. All plots were harvested on 22 January 2022 with a Sampo® plot combine. A 500 g field-dressed sub-sample was collected on the day of harvest and subsequently machine-dressed to a First-generation Seed Certification standard. Seed germination tests were completed by NZ SeedLab on the Dew, diquat (Reglone®) and glyphosate treatments on 7 July using a 6-day pre-germination chilling (at 5°C) and a 10-day final count. Thousand seed weight (TSW) was measured by counting 200 machine-dressed seeds and data converted to TSW in grams.

The SMC used for analysis was calculated from the linear regression equation resulting from SMC fitted against date (Figure 1), indicating SMC decreased at 2 % per day.

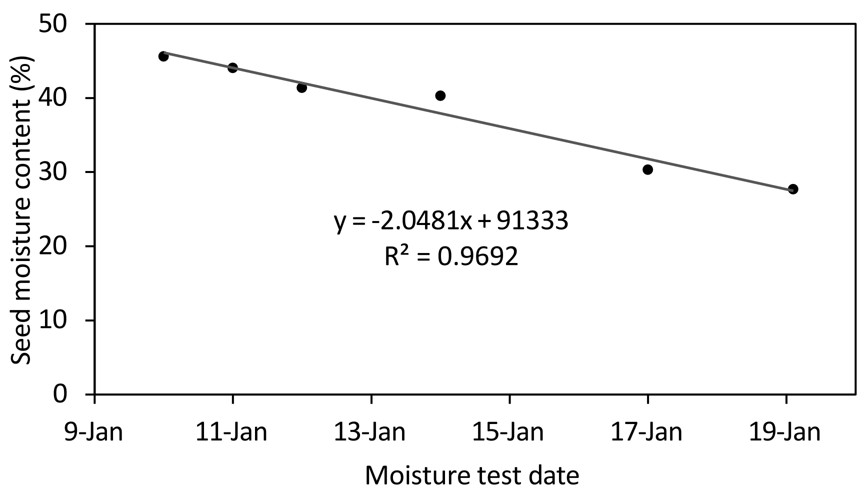

Figure 1. Seed moisture content (%) of annual ryegrass ‘Winterstar’ as measured over a ten-day period when grown near Yaldhurst, Christchurch in the 2021-22 growing season.

Seed yield was analysed via a two-way ANOVA comparing SMC (43,39 and 33%) and Dew, Nil and irrigation treatments. The chemical treatments were analysed separately via two-way ANOVA comparing SMC (39, 33 and 29%) and Reglone® and glyphosate treatments due to differences in SMC at windrowing. All data were combined and subjected to linear regression based on SMC at cutting. Data analysis was completed using Genstat®19 (VSN 2019) and the ‘scipy’ (Pauli Virtanen 2020) and ‘statsmodels’ (Seabold & Perktold 2010) package in the ‘python’ framework. The trial had standard management until time-of-cutting (Appendix 1).

Table 1. Pre-harvest treatments for an annual ryegrass ‘Winterstar’ see crop grown at Yaldhurst, Christchurch in the 2021-22 season.

Treatment No.	Windrow Date	Spray/Irrigation Date	SMC (%) at application/cutting	DessicationT reatment	Time of application
1	12.1.22	-	43%	Dew	7 am
2	12.1.22	-	43%	nil	12 pm
3	12.1.22	12.1.22	43%	Irrigation	12 pm
4	14.1.22	12.1.22	43/39%	Glyphosate	12 pm
5	14.1.22	12.1.22	43/39%	Reglone®	12 pm
6	14.1.22	-	39%	Dew	7 am
7	14.1.22	-	39%	nil	12 pm
8	14.1.22	14.1.22	39%	Irrigation	12 pm
9	17.1.22	14.1.22	39/33%	Glyphosate	12 pm
10	17.1.22	14.1.22	39/33%	Reglone®	12 pm
11	17.1.22	-	33%	Dew	7 am
12	17.1.22	-	33%	nil	12 pm
13	17.1.22	17.1.22	33%	Irrigation	12 pm
14	19.1.22	17.1.22	33/29%	Glyphosate	12 pm
15	19.1.22	17.1.22	33/29%	Reglone®	12 pm

Results and discussion

There was no interaction between time-of-cutting (SMC) and pre-windrowing treatment (p value =0.253) for any treatment combination. Windrowing at 43 % SMC maximised seed yield at 2040 kg/ha; this was significantly higher than windrowing at either 39 % (1460 kg/ha) or 33 % SMC (970 kg/ha) (Table 2). There was no difference between windrowing at 8 am or mid-day, and applying 3 mm irrigation at 8 am did not increase seed yield compared with treatments cut at 12 pm.
As a result of limitations in the equipment, only 3 mm of water was applied to the trial. This may not have been enough to adequately wet the seed heads to reduce seed shatter.

Table 2. Machine-dressed seed yield of annual ryegrass cv. Winterstar when grown at Yaldhurst, Christchurch, in the 2021-22 growing season, and windrowed at three seed moisture contents (SMC) with three daily treatments.

Windrow Timing	Machine-dressed yield (kg/ha) for seed cut at different seed moisture contents			SMC mean
	43% SMC (12/1/2022)	39% SMC (14/1/2022)	33% SMC (17/1/2022)	
Dew (7 am)	2040	1640	960	1550
Nil (12 pm)	2010	1280	1030	1440
Irrigation (12 pm)	2060	1450	930	1480
SMC Mean	2040 a	1460 b	970 c	
[1]P value SMC	<0.001			
$LSD_{0.05}$ SMC	165.9			

Note: Yellow indicates the treatments that were amongst those that produced the highest yield. [1]Time of cutting x treatment interaction P value = 0.253, P value timing =0.406

The application of either diquat (Reglone®) or glyphosate did not influence seed yield when applied to annual ryegrass windrowed two days after application (Table 3). Seed yield decreased by 52 % between early windrowed treatments at a rate of 185 kg/ha for each day that windrowing was delayed (Figure 2). Seed shattering between windrowing dates was observed to be the primary driver for seed losses as windrowing was delayed.

Table 3. Machine-dressed seed yield of annual ryegrass cv. Winterstar when grown at Yaldhurst, Christchurch, in the 2021-22 growing season, and windrowed at three seed moisture contents (SMC) and using two chemical pre-harvest treatments.

Windrow Timing	Machine-dressed yield (kg/ha) for seed cut at different seed moisture contents			SMC mean
	39% SMC (14/1/2022)	33% SMC (17/1/2022)	29% SMC (19/1/2022)	
Reglone®[1] (12 pm)	1930	1130	840	**1360**
Glyphosate[1] (12 pm)	1790	990	810	**1200**
SMC Mean	1858	1060	826	
[2]P value SMC	**<0.001**			
$LSD_{0.05}$ SMC	**132.1**			

Note: Yellow indicates the treatments that were amongst those that produced the highest yield.
[1] Reglone® and Glyphosate (Deal 510RF) windrowed two days after Dew, Nil and Irrigation treatments.
[2]Time-of-cutting x treatment interaction P value = 0.626, P value treatment =0.057.

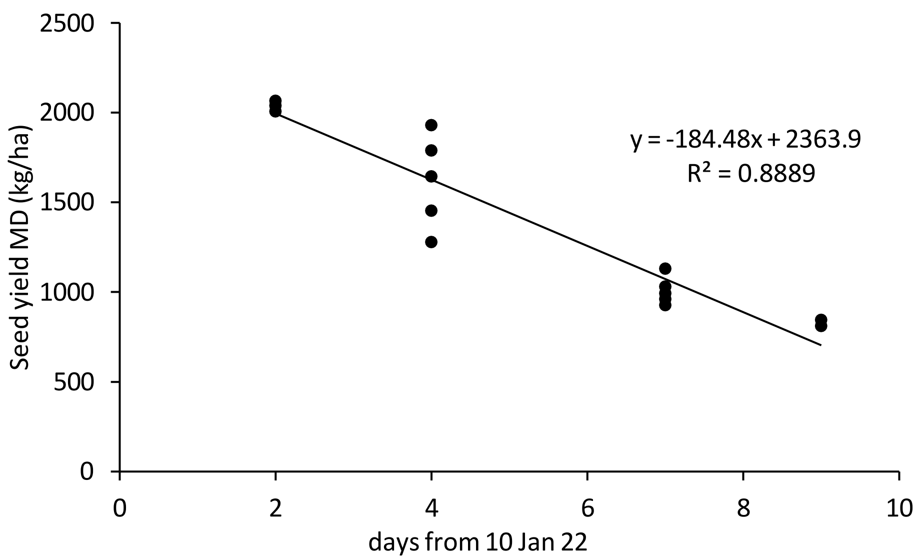

Figure 2. Machine-dressed seed yield of annual ryegrass, cv. Winterstar, following windrowing at four timings from 10 January 2022 in a time-of-windrowing trial at Yaldhurst, Canterbury in the 2021-22 growing season.

Germination results were consistent for the dew treatment (cut at 7 am) in all SMC cuttings: normal seedlings averaged 94 % (±0.6) and abnormal seedlings 1.5 % (±0.34) (Figure 3A, B, Appendix 2). There was an interaction between SMC and chemical application for both normal and abnormal seedlings but no difference in the number of dead seeds. The application of Reglone® or glyphosate prior to cutting resulted in an increased number of abnormal seeds, but there was no effect when glyphosate was applied at 30% SMC (Figure 3A, B, Appendix 2). Reglone® and glyphosate reduced the number of normal seeds compared with the dew treatment, but there was no significant difference between desiccant treatments (Table 4).

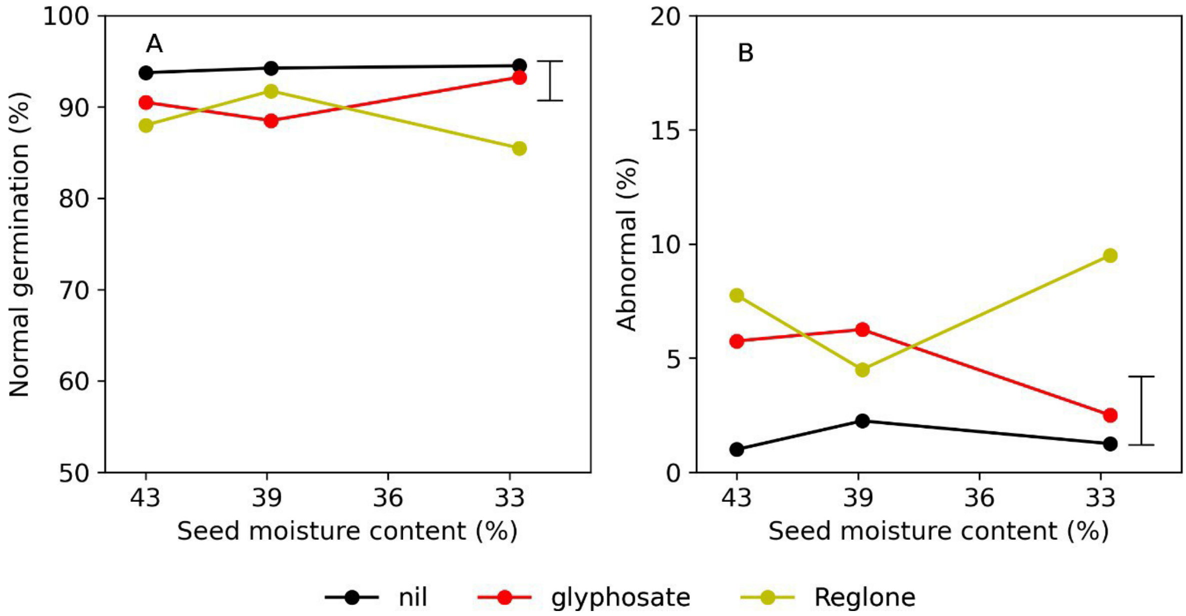

Figure 3. Percentage normal (A) and abnormal (B) seedlings from germination tests six months after harvest for annual ryegrass, cultivar Winterstar, when treated with three chemical treatments applied at three seed moisture content (SMC) percentages, grown at Yaldhurst, Canterbury 2021-22 growing season. Bar = LSD for the SMC by product interaction.

Summary

Annual ryegrass was used in this trial which traditionally has a greater amount of seed shatter as SMC reduces. SMC at time of windrowing was the largest factor in relation to seed yield loss in this trial. The application of 3 mm irrigation or cutting early morning had no effect on seed yield at the three different windrow timings. There was inconclusive evidence for desiccants reducing germination at six months post-harvest, however this could increase with prolonged storage. Further research is required to test the influence on germination from the application of desiccants prior to windrowing.

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Virtanen, P, Gommers, R, Oliphant, T E, Haberland, M, Reddy, T, Cournapeau, D, Burovski, E, Peterson, P, Weckesser, W, Bright, J, van der Walt, S J, Brett, M, Wilson, J, Millman, K J, Mayorov, N, Nelson, A R J, Jones, E, Kern, R, Larson, E, Carey, C J, Polat, I, Yu Feng, Moore, E W, VanderPlas, J, Laxalde, D, Perktold, J, Cimrman,R, Henriksen, I, Quintero, E A, Harris, C R, Archibald, A M, Ribeiro, A H, Pedregosa, F, van Mulbregt, P, and SciPy 1.0 Contributors (2020). SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python. *Nature Methods 17*: 261-272.

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Appendix 1.

Trial details

Sown:	31 March 2021
Paddock Closed:	20 October 2021
Fertiliser:	20 October 2021. 75 kg N as urea at closing.
	20 November 2021. 75 kg N as urea.
PGR:	10 November - 1.3 L Moddus® Evo (250 g/L Trinexapac-ethyl)
Fungicide:	10 November – 0.6 L Proline® (250 g/litre Prothioconazole – MOA 3)

Appendix 2.

Seed germination results

Seed germination results six months after harvest for percentage normal, abnormal and dead seed for annual ryegrass, cultivar Winterstar, when treated with three chemical treatments applied at three seed moisture content (SMC) percentages, grown at Yaldhurst, Canterbury 2021-22 growing season.

Treatment	SMC (%)	Water treatment	% Normal	% Abnormal	% Dead
1	42	Dew	94	1.0	5.3
4	42	Glyphosate	91	5.8	3.8
5	42	Reglone®	88	7.8	4.3
6	40	Dew	94	2.3	3.0
9	40	Glyphosate	89	6.3	5.0
10	40	Reglone®	92	4.5	3.8
11	30	Dew	95	1.3	4.3
14	30	Glyphosate	93	2.5	4.3
15	30	Reglone®	86	9.5	5.0
		Mean	**91**	**5**	**4**
		LSD (p=0.05%)	**4.3**	**3.0**	**3.9**
		[1]P value - interaction	**0.002**	**<.001**	**0.959**

The effect of windrowing and pre-harvest desiccants on annual ryegrass

Project code H19-06-01

Duration Year 2 of 3 (season 2021-22)

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

Location Yaldhurst, Canterbury – GPS 43°30'34.7"S 172°31'44.6"E

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial contractors), NZ Seedlab (germination testing) and Mark Reed (trial host).

Key points

- Highest seed yield (2040 kg/ha) of annual ryegrass was achieved by cutting at 42 % seed moisture content, the highest moisture content assessed.
- As seed dried at 2 % a day from 42 % moisture content, yield reduced by 185 kg/ha each day that windrowing was delayed.
- Germination percentage at 6 months after harvest was significantly lowered through the production of abnormal seedlings following the application of some pre-windrowing treatments.

Background

It is general practice to cut Italian and annual ryegrass seed crops at approximately 42-45 % seed moisture content (SMC) at night or early morning when humidity is high to reduce seed loss due to shattering. Ryegrass seed is considered to have reached physiological maturity (PM) at approximately 37 % SMC but is not safe to store until it reaches 12 % moisture content. Often threshing occurs prior to seed drying to 12 % SMC due to unfavourable weather patterns. Applying a desiccant prior to harvest can reduce the time from cutting to threshing, reduce the amount of regrowth through the row before harvest and/or result in lower SMC at harvest. However, concerns have been raised overseas about germination percentages following the application of desiccants to perennial ryegrass seed crops (Roberts & Griffiths 1973).

At PM, developing seeds stop accumulating assimilate via translocation, thus reducing the risk of transferring agri-chemicals into the seed. However, the seed is still vulnerable to direct chemical uptake while it remains green. Previous work in the United Kingdom has shown that the application of a desiccant prior to harvest resulted in a high level of abnormal seed and low germination rates (Roberts and Griffiths 1973). During particularly wet seasons like that of 2021-2022, the application of a desiccant could potentially increase ryegrass desiccation and reduce the interval between cutting (windrowing or mowing) and combine harvest.

The aim of this study was to assess:

- if annual ryegrass can be cut at SMC lower than 42 % without reducing machine dressed seed yield due to seed shatter,
- if cutting in early morning in the dew increases seed yield,
- the impact of using irrigation to dampen seed heads prior to cutting on machine dressed seed yield,
- whether the application of Reglone® or glyphosate reduces seed quality when applied prior to cutting.

Methods

The trial was setup in a paddock of annual ryegrass located at Yaldhurst, Christchurch, on 5 January 2022 as a randomised complete block design with 15 treatments and 4 replicates. Plot size was 2 m wide and 10 m long. The soil type was a Waimakariri moderately deep silt (Waim_2a.1). Paddock details are presented in Appendix 1.

SMC was monitored according to ISTA regulations from trial commencement until harvest. When SMC reached 45 % on 10 January 2022, the treatments were initiated as per Table 1.

Early morning cutting treatments, hereafter referred to as "Dew", were windrowed at 7 am while the corresponding nil irrigation and irrigated treatments were cut at midday.

Chemical treatments were applied, either Reglone® at 3 L/ha, (MOA Group 22, a.i. diquat) 200 g ai/L) + Contact® Xcel (a.i. Linear alcohol ethoxylate 980 g/L) or 2.1 L glyphosate as Deal 510RF (MOA Group 9). Chemical treatments were applied via a backpack sprayer with an electric pressure pump suppling a two-metre spray boom fitted with six 110 015xr tee jet nozzles delivering 250 L/water per hectare at 210 kpa pressure, thus creating a very fine spray droplet. Application was the same day as their corresponding time of cutting treatments and windrowing was two days later (Table 1).

Irrigation treatments to dampen seed heads were applied at 8 am each morning with a 1.8 m handheld boom with six 8002 teejet® nozzles delivering 60 L water per plot (3 mm) applied prior to windrowing.

A modified John Deere windrower, cutting a 1.8 m swath, was used at the prescribed time of windrowing according to the treatment list (Table 1). Knife sections were under serrated and sharpened at the start of the trial. All plots were harvested on 22 January 2022 with a Sampo® plot combine. A 500 g field dressed sub sample was collected on the day of harvest and subsequently machine dressed to a First-Generation Seed Certification standard. Seed germination tests were completed by NZ SeedLab on the Dew, Reglone® and glyphosate treatments on 7 July using a 6-day pre-germination chilling (at 5°C) and a 10-day final count. Thousand seed weight (TSW) was measured by counting 200 machine dressed seeds and converted to TSW in grams.

The SMC used for analysis was calculated from the linear regression equation resulting from SMC fitted against date (Figure 1), indicating SMC decreased at 2 % per day.

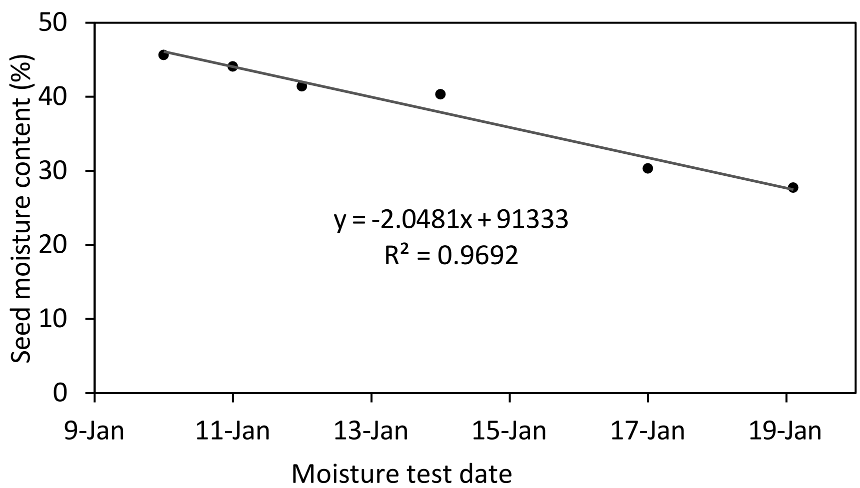

Figure 1. Seed moisture content (%) of annual ryegrass 'Winterstar' as measured over a ten-day period when grown near Yaldhurst, Christchurch in the 2021-22 growing season.

Seed yield was analysed via a two-way ANOVA comparing SMC (43,39 and 33 %) and Dew, Nil and irrigation treatments. The treatments of chemical treatments were analysed separately via two-way ANOVA comparing SMC (39, 33 and 29 %) and Reglone® and glyphosate treatments due to differences in SMC at windrowing. All data were combined and subjected to linear regression based on SMC at cutting. Data analysis was completed using Genstat®19 (VSN 2019) and the 'scipy' (Pauli Virtanen 2020) and 'statsmodels' (Seabold & Perktold 2010) package in the 'python' framework. The trial had standard management until time of cutting.

Table 1. Treatment and application details for annual ryegrass time-of-cutting trial at Yaldhurst, Christchurch in the 2021-22 season.

Treatment No.	Windrow Date	Spray/Irrigation Date	SMC (%) at application/cutting	Treatment	Time
1	12.1.22	-	43 %	Dew	7 am
2	12.1.22	-	43 %	nil	12 pm
3	12.1.22	12.1.22	43 %	Irrigation[1]	12 pm
4	14.1.22	12.1.22	43/39 %	Glyphosate	12 pm
5	14.1.22	12.1.22	43/39 %	Reglone®	12 pm
6	14.1.22	-	39 %	Dew	7 am
7	14.1.22	-	39 %	nil	12 pm
8	14.1.22	14.1.22	39 %	Irrigation	12 pm
9	17.1.22	14.1.22	39/33 %	Glyphosate	12 pm
10	17.1.22	14.1.22	39/33 %	Reglone®	12 pm
11	17.1.22	-	33 %	Dew	7 am
12	17.1.22	-	33 %	nil	12 pm
13	17.1.22	17.1.22	33 %	Irrigation	12 pm
14	19.1.22	17.1.22	33/29 %	Glyphosate	12 pm
15	19.1.22	17.1.22	33/29 %	Reglone®	12 pm

1. Irrigation applied at 8 am on the morning of cutting at 3 mm with the aim of dampening the seed head.

Results and discussion

There was no interaction between time of cutting (SMC) and pre-windrowing treatment (p value =0.253) for any treatment combination. Windrowing at 43 % SMC maximised seed yield at 2040 kg/ha, this was significantly higher than windrowing at either 39 % (1460 kg/ha) or 33 % SMC (970 kg/ha) (Table 2). There was no difference between windrowing at 8 am or midday and applying irrigation at 8am did not increase in seed yield compared with the treatments cut at 12pm. Due to limitations of equipment only 3 mm of irrigation was applied. It is likely that this dried prior to windowing and that the seed head was then too dry to reduce seed shatter.

Table 2. Machine dressed seed yield of annual ryegrass cv. Winterstar when windrowed at three seed moisture contents (SMC) with three daily treatments when grown at Yaldhurst, Christchurch, in the 2021-22 growing season.

Windrow Timing	Machine dressed yield kg/ha			Mean
	43 % SMC (12/1/2022)	**39 % SMC (14/1/2022)**	**33 % SMC (17/1/2022)**	
Dew (7 am)	2040	1640	960	1550
Nil (12 pm)	2010	1280	1030	1440
Irrigation (12 pm)	2060	1450	930	1480
SMC Mean	2040 a	1460 b	970 c	
[1]P value SMC	**<0.001**			
LSD (p=0.05) SMC	**165.9**			

[1]Time of cutting x trt interaction P value = 0.253, P value timing =0.406.

The application of either Reglone® or glyphosate did not influence seed yield when applied to annual ryegrass windrowed two days after application (Table 3). Seed yield decreased by 52 % between early windrowed treatments at a rate of 185 kg/ha for each day that windrowing was delayed (Figure 2). Seed shattering between windrowing dates was observed to be the primary driver for seed losses as windrowing was delayed.

Table 3. Machine dressed seed yield of annual ryegrass cv. Winterstar when windrowed at three seed moisture contents (SMC) with two desiccation treatments when grown at Yaldhurst, Christchurch, in the 2021-22 growing season.

Windrow Timing	Machine dressed yield kg/ha			Mean
	39 % SMC (14/1/2022)	33 % SMC (17/1/2022)	29 % SMC (19/1/2022)	
Reglone®[1] (12 pm)	1930	1130	840	1360
Glyphosate[1] (12 pm)	1790	990	810	1200
SMC Mean	1858	1060	826	
[2]P value -SMC	**<0.001**			
$LSD_{0.05}$ -SMC	**132.1**			

[1]Reglone® and Glyphosate (Deal 510RF) windrowed two days after Dew, Nil and Irrigation treatments.
[2]Time of cutting x treatment interaction P value = 0.626, P value treatment =0.057.

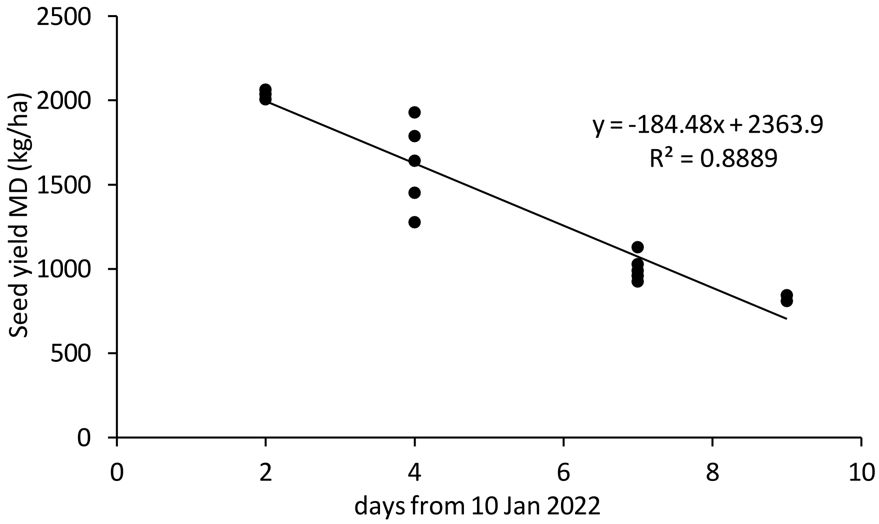

Figure 2. Machine dressed seed yield of annual ryegrass, cv Winterstar, following windrowing at four timings from 10 January 2022 in in time of windrowing trial at Yaldhurst, Canterbury in the 2021-22 growing season.

Germination results were consistent for the dew treatment (cut at 7 am) in all SMC cutting: normal seedlings averaged 94% (±0.6) and abnormal seedling 1.5% (±0.34) (Appendix 2). There was an interaction between SMC and chemical application for both normal and abnormal seedlings but no difference in the number of dead seeds. The application of Reglone® or glyphosate prior to cutting resulted in an increased number of abnormal seeds, but no consistent trend was observed (Appendix 2). Reglone® and glyphosate reduced the number of normal seeds compared with the dew treatment, but there was no significant difference between desiccant treatments (Appendix 2).

Summary

Annual ryegrass was used in this trial which traditionally has a greater amount of seed shatter as SMC reduces. SMC at time of windrowing was the largest factor in relation to seed yield loss in this trial. The application of irrigation or cutting early morning had no effect on seed yield at the three different windrow timings. There is potential for reduced seed germination when desiccants. There was inconclusive evidence for desiccants reducing germination at six months post-harvest, however this could increase with prolonged storage.

References

Virtanen, P, Gommers, R, Oliphant, T E, Haberland, M, Reddy, T, Cournapeau, D, Burovski, E, Peterson, P, Weckesser, W, Bright, J, van der Walt, S J, Brett, M, Wilson, J, Millman, K J, Mayorov, N, Nelson, A R J, Jones, E, Kern, R, Larson, E, Carey, C J, Polat, I, Yu Feng, Moore, E W, VanderPlas, J, Laxalde, D, Perktold, J, Cimrman,R, Henriksen, I, Quintero, E A, Harris, C R, Archibald, A M, Ribeiro, A H, Pedregosa, F, van Mulbregt, P, and SciPy 1.0 Contributors (2020). SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python. *Nature Methods 17*: 261-272.

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VSN (2019). *Genstat for Windows 19th Edition. VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk*.

Appendix 1.
Trial details

Sown:	31 March 2021
Paddock Closed:	20 October 2021
Fertiliser:	20 October 2021 - 75 kg N as urea at closing
	20 November 2021 – 75 kg N as urea
PGR:	10 November - 1.3 L Moddus® Evo (250 g/L Trinexapac-ethyl)
Fungicide:	10 November – 0.6 L Proline® (250 g/litre Prothioconazole – MOA 3)

Appendix 2.
Seed germination results six months after harvest for percentage normal, abnormal and dead seed for annual ryegrass, cultivar Winterstar, when treated with three chemical treatments applied at three seed moisture content (SMC) percentages, grown at Yaldhurst, Canterbury 2021-22 growing season.

Treatment No.	SMC (%)	Water treatment	% Normal	% Abnormal	% Dead
1	42	Dew	94	1.0	5.3
4	42	Glyphosate	91	5.8	3.8
5	42	Reglone®	88	7.8	4.3
6	40	Dew	94	2.3	3.0
9	40	Glyphosate	89	6.3	5.0
10	40	Reglone®	92	4.5	3.8
11	30	Dew	95	1.3	4.3
14	30	Glyphosate	93	2.5	4.3
15	30	Reglone®	86	9.5	5.0
		Mean	**91**	**5**	**4**
		LSD (p=0.05%)	**4.3**	**3.0**	**3.9**
		[1]P value - interaction	**0.002**	**<.001**	**0.959**

Optimum nitrogen application rates in ryegrass seed production and the use of the Potentially Mineralisable N test

Project code H19-15-01

Duration Year 2 of 2 (season 2021-22)

Authors Owen Gibson, Dirk Wallace and Richard Chynoweth (FAR)

Location Chertsey, Mid Canterbury (-43.791634, 171.961130)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (Trial operators)

Key points

- 170 kg/hectare (ha) total nitrogen (N) (soil + applied N) resulted in the highest yielding ryegrass seed treatments when applied as a three-way split in late August, early October and early November.
- The application of 40 kg/ha N in late August reduced the total N application rate by 40 kg/ha but maintained seed yields.

Background

Improvements in fertiliser management are critical to the economic and environmental sustainability of New Zealand's agricultural production systems. Effectively forecasting fertiliser nitrogen (N) requires the ability to predict the supply of plant-available N from soil and the demand for that N during crop growth. Accuracy in predicting the supply of N from mineralisation is one of the greatest limitations to: 1) forecasting the amount and timing of N fertiliser to meet, but not exceed, crop demand and 2) minimising the risk that excess N may be lost from arable and vegetable production systems via nitrate leaching and/or gaseous emissions.

This study evaluated whether soil test data (mineral N and potentially mineralisable N (PMN)) can be used to improve N fertiliser forecasting to maintain ryegrass seed yield while reducing applied fertiliser N. The FAR guideline for spring applied N is 172 kg N/ha minus soil mineral N in the 0-30 cm layer. The main N applications are split between closing (date of last defoliation, early stem extension, GS 30-31), and roughly five weeks later, i.e. plant growth regulator timing to flag leaf emergence (GS 32-GS39). Grass growth is very responsive to N; excessive, or poor timing of N will cause excessive vegetative bulk, increased disease susceptibility, lodging, light interception and ultimately reduced seed yield. The anaerobically mineralisable N (AMN) test has not been found to be reliable in predicting N availability in ryegrass seed crops, with research by FAR from 2003 to 2013 concluding the test was inadequate to predict N reproducibly. The modern, rapid PMN test using the hot water extractable organic N (HWEON) test has been calibrated with aerobic soil mineralisation and can be used to estimate how much N could potentially be mineralised from the soil under average climatic conditions for a region (Beare 2022).

This study evaluated if the industry standard N rate of 172 kg/N (applied + soil mineral N) remains the appropriate quantity of N required to attain the greatest yield and margin-over-N cost (MONC) in a seed crop of perennial ryegrass cv. Nui. In addition, the effectiveness of application of early N (in August, prior to closing) was evaluated.

Methods

Two trials were conducted at the FAR Research site in Chertsey, mid Canterbury (-43.791634, 171.961130). Each trial consisted of 11 N input treatments replicated four times under dryland or irrigated management, with an additional no N control treatment used as destructive harvest treatment.

A first-year cv. Nui perennial ryegrass seed crop was sown 8 April in the 2021-22 growing season in a Templeton silt loam. Soil was sampled on August 3. Initial soil mineral N results were low at 18 kg

N/ha (0-30 cm) and predicted in-field N mineralisation from October to December was 75 kg/N/ha (dryland) and 85 kg/N/ha (irrigated) (Table 1).

Table 1. The initial mineral nitrogen (N) (0-30 cm), potentially mineralisable N (PMN) (0-30 cm) and in-field N mineralisation predicted for the primary period of crop N uptake (October-December) for dryland and irrigated trials at Chertsey in 2021-22.

Irrigation	Mineral N (0-30 cm)	PMN (0-30 cm)	Predicted in-field N mineralisation (kg N/ha)
	(Kg N/ha)	(Kg N/ha/day)	(October – December)
Dryland	29	1.28	75
Irrigated	18	1.26	85

Fertiliser N was applied in the form of SustaiN® (45.9% N) evenly by hand across each plot (as per Table 2), during or preceding rainfall or irrigation. The dryland trial was windrowed on 3 January 2022 and the irrigated trial on 7 January 2022 with a modified 1.8 m John Deere windrower cutting the entire plot. Prior to harvest dry-matter cuts were taken from a 0.225 m^2 quadrat within each plot to test for above ground biomass and N content (%) of the straw. Harvest was conducted with a Wintersteiger nursery master elite plot combine on 10 January 2022 for the dryland trial and 14 January 2022 for the irrigated trial. A small (500g) subsample was retained for machine dressing and analysis of the seed for N content (%) and thousand seed weight (TSW). Post-harvest soil samples were conducted on all plots to test for residue N.

Statistical analysis was by general analysis of variance (ANOVA), using Genstat® 22th edition (VSN International Ltd, UK).

Remaining details of the trial and its management are listed in Appendix 1.

Table 2. Treatment list and application timing for nitrogen decision trial in Nui ryegrass at Chertsey Arable Site, Mid Canterbury in the 2021-22 season.

Treatment No.	Quantity of nitrogen (kg/ha) and date of application						
	min N (0-30 cm)	late Aug	closing 1 Oct	1st week Nov	Mid Dec	Spring applied N	Total N + Min N
	Min N	**1.9.21**	**6.10.21**	**11.11.21**	**17.12.21**		
1	18	0	0	0		0	**18**
2	18	0	36	36		72	**90**
3	18	0	56	56		112	**130**
4	18	0	76	76		152	**170**
5	18	0	96	96		192	**210**
6	18	40	0	0		40	**58**
7	18	40	16	16		72	**90**
8	18	40	36	36		112	**130**
9	18	40	56	56		152	**170**
10	18	40	76	76		192	**210**
11a[1]	18	40	56		20	116	**134**
11b[2]	18	40	56	30[1]		126	**144**
12	No N control (destructive harvest plot).						

[1] Irrigated trial only
[2] Dryland trial only

Results and Discussion

The application of 170 kg total N provided the optimum balance between maximising ryegrass seed yield and minimising N input (i.e. 170 kg total N was the optimum N input), when applied as a three-way split with 40 kg N applied post winter (Treatment 9, Table 3). Above 170 kg total N (supplied using a three-way split in Treatments 10 and 11), no increase in seed yield was observed resulting in either no difference in MONC or a reduction.

The post winter application of 40 kg N on 1 September 2021 increased irrigated seed yield (170 total N, Treatment 9) by 13 % (1580-1815 kg/ha) compared with the equivalent treatment where the 170 kg/ha N was applied only across the latter two dates (Treatment 4) (Table 3). This response was not found in the dryland trial. When total N was applied as a two-programme split on 6 October and 11 November, the crop needed an extra 40 kg N/ha (Treatment 5) to reach the same yield as Treatment 9.

Table 3. Machine-dressed yield and margin-over-nitrogen cost for ryegrass cv. Nui under irrigation or dryland conditions at Chertsey Arable Site, Mid Canterbury in the 2021-22 season.

Treatment No.	Quantity of nitrogen (kg/ha)		Yield (kg/ha)		Margin-over-nitrogen cost (MONC) ($/ha)	
	Total N + Min N	Spring applied N	Irrigated MD Yield	Dryland MD Yield	MONC[1] Irrigated	MONC[1] Dryland
1	18	0	697	455	0	0
2	90	72	1259	1142	2249	2751
3	130	112	1397	1400	2800	3780
4	170	152	1584	1524	3547	4276
5	210	192	1734	1706	4146	5005
6	58	40	1030	740	1330	1143
7	90	72	1406	1131	2835	2706
8	130	112	1559	1458	3445	4013
9	170	152	1815	1581	4473	4507
10	210	192	1668	1690	3885	4940
11	144	126	1627	1366	3720	3644
		P value	**<.001**	**<.001**	**<.001**	**<.001**
		LSD (p=0.05)	**195**	**148**	**816**	**584**
		CV (%)	**9.8**	**8.4**	**17.3**	**11.0**

Note: Yellow indicates the treatments which had the greatest ryegrass seed yields and margin-over-nitrogen cost (MONC). [1] MONC, Treatment 1 excluded from the ANOVA. MONC was calculated with a N cost of $1289/t SustaiN®. Seed price for ryegrass cv. Nui was calculated as $4/kg with an application cost of $25 per application.

Figure 1 illustrates the relationships between seed yield and total N supply in both the dryland and irrigated trials.

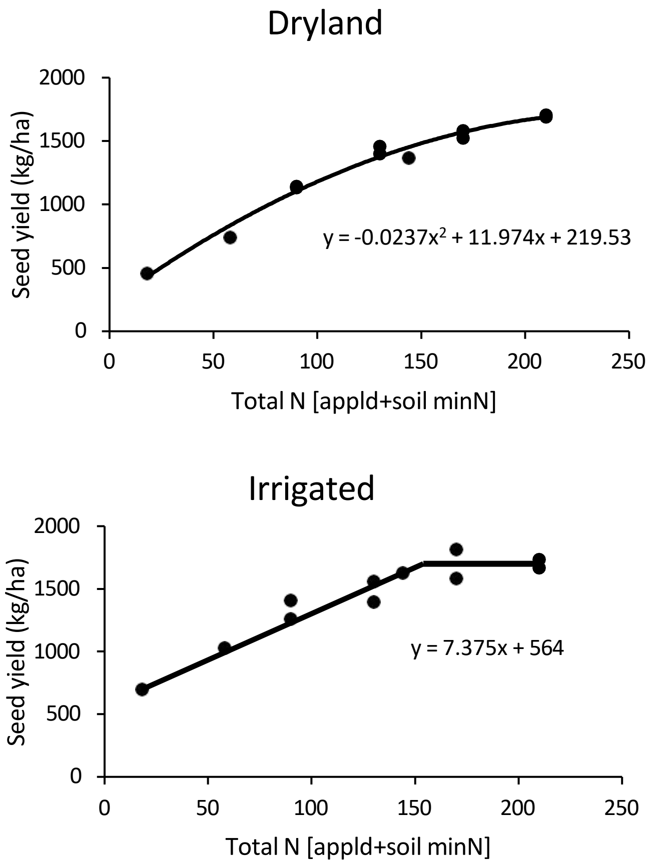

Figure 1. Seed yield for ryegrass cv. Nui grown at the Chertsey Arable Research Site in the 2021-22 season under dryland (Top) and irrigated (bottom) conditions following different nitrogen (N) treatments.

Summary

This trial confirmed the industry standard N application rate of 172 kg total N (applied N + soil mineral N) remained the most effective for balancing economic returns and environmental risk when applied using a three-way split. Applying additional N neither improved seed yield nor improved economic returns.

As N inputs are a large proportion of the cost of production for ryegrass seed and continue to fluctuate significantly, it is imperative to rationalise N use to man maximise profitability. In addition good N management decreases the N losses as greenhouse gases and the potential costs associated with emission pricing.

Future work will investigate the use of the PMN test to predict mineralisable N, which can be incorporated into N supply calculations to further reduce N application rates.

Appendix 1
Trial details

Planting:	8 April, 2021 - Cultivar Nui at 8 kg/ha, drilled with a 9-row research cone seeder disc drill. 12 kg/ha mix of SuSCon® green (Chlorpyrifos, 100 g/kg) and Diazinon 20g (200g/L Diazinon) were applied in the drill row at sowing.
Fertiliser:	22 September 2021 - 200 kg/ha 15% Potash sulphur super (N:0, P:6.8, K:7.5, S:17.5 and CA:15.3)
	N fertiliser was applied as per treatment list.
Heavy Roll	22 September 2021 - The trial was heavy rolled with a tractor mounted tow behind roller.
Herbicide:	14 April, 2021 – 4 L/ha Nortron® (Ethofumesate, 500 g/L, Group 15).

	2 June, 2021 – 1.75 L/ha Image® (Bromoxynil 120 g/L, Group 6, Ioxynil 120 g/L, group 6, Mecoprop-P 360 g/L, Group 4).
	22 September, 2021 – 65 g Perside™ (flumetsulam 800 g/Kg, Group 2).
Plant growth Regulator:	27 October, 2021 – 1.6 L/ha Moddus® Evo (Trinexapac-ehtyl 250 g/L).
Fungicide:	27 October, 2021 – 400 mL/ha Proline® (Prothioconazole, 250 g/L, Group 3).
	29 November, 2021 - 400 mL/ha Proline® (Prothioconazole, 250 g/L, Group 3), Seguris flexi® - Isopyrazam 125 g/L, Group 7)
Windrowed:	3 January 2022 (Dryland), 7 January 2022 (Irrigated)
Harvest:	10 January 2022 (Dryland), 14 January 2022 (Irrigated)

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Herbicide programmes to manage Vulpia hairgrass in ryegrass seed crops

Project code X18-35-05

Duration Years 4 and 5 of 5 (Seasons 2021-22 and 2022-23)

Authors Matilda Gunnarsson, Owen Gibson, Richard Chynoweth and Sean Weith (FAR) and Phil Rolston (SIRC)

Location Kowhai FAR Research Farm, Lincoln and St Andrews, South Canterbury.

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Richard Porter (trial host); NZ Arable (trial operator)

Key points

- Vulpia hairgrass (*Vulpia* sp.) is a common and problematic grass weed in ryegrass.
- Pre-emergence herbicide treatments, especially a tank mix of Nortron® (active ingredient (a.i.) 500 g/L ethofumesate, Group 15 herbicide) and Quantum® (a.i. 500 g/L diflufenican, Group 12 herbicide) showed the best control of Vulpia hairgrass in trials conducted between 2021 and 2023.
- Invado® (a.i. 400 g/L flufenacet, Group K3 herbicide) treatments provided acceptable control as an alternative to Nortron®.
- Treatments applied at early or late post-emergence stages provided less control of Vulpia hairgrass.
- The 2022-23 trial had lower Vulpia hairgrass infestation than the 2021-22 trial, but all treatments significantly reduced weed incidence compared with the untreated control.
- Early intervention is crucial in managing Vulpia hairgrass, but late germination and multiple flushes pose challenges through the growing season.

Background

Vulpia hairgrass (*Vulpia* sp.) is a common and problematic grass weed in ryegrass (*Lolium perenne*) seed production, impacting both seed yield and quality. The common term "hairgrass" in New Zealand denotes the combination of three distinct *Vulpia* species, namely *Vulpia bromoides* (*V. bromoides*) (squirrel-tail), *V. myuros* (rat's-tail) (Wallace, 1997), and *V. megalura* (Edgar & Connor, 2010).

The primary herbicide used to control Vulpia hairgrass in ryegrass seed crops is Nortron® (active ingredient (a.i.) 500 g/L ethofumesate, Group 15 herbicide). However, its use in crops like ryegrass poses a significant risk of resistance developing in the weed, especially if applied following cereal crops treated with Firebird® (a.i. 400 g/L flufenacet + 200 g/L diflufenican, Group 15 herbicide + Group 12 herbicide), which shares the same mode-of-action (Group 15).

To combat resistance, it is essential to incorporate herbicides with diverse modes of action and integrate them with other effective weed management practices. Therefore, it is crucial to identify the suite of alternative herbicides capable of effectively controlling Vulpia hairgrass at various growth stages in grass seed crops. Previous trials conducted by the Foundation for Arable Research (FAR) in the 2018-2019 growing season showed that Nortron® was moderately effective when applied at the 2-leaf stage (Zadoks growth stage (GS) 12) (Zadoks *et al.*, 1974) of Vulpia hairgrass, but less effective when applied at later growth stages (Smith *et al.*, 2019). Additionally, other herbicides such as Simatop™ (a.i. 500 g/L simazine, Group 5 herbicide), Asulox® (a.i. 400 g/L asulam, Group 18 herbicide) and Quantum® (a.i. 500 g/L diflufenican, Group 12 herbicide) showed similar or better efficacies than Nortron® when applied by themselves or in a tank mix together.

This study reports on the results from two trials that were conducted independently in the 2021-22 and 2022-23 growing seasons. The purpose of these trials was to investigate alternative herbicides for controlling Vulpia hairgrass in ryegrass seed crops. The main objectives were.

- To assess the effectiveness of various pre- and post-emergence herbicides for Vulpia hairgrass control in ryegrass seed crops.
- Identify herbicides that could be used as potential alternatives to Nortron® for controlling Vulpia hairgrass at different application timings.

Methods
Two small plot trials were established independently in two growing seasons (2021-22 and 2022-23) in perennial ryegrass. The first trial was established during the 2021-22 growing season at FAR's Kowhai Research Site near Lincoln (Column 1; -43.638863, 172.469796) in a block of ryegrass, cultivar (cv.) Nui, that was sown at a rate of 8 kg/ha on the 10 May 2021. Within the trial site, Vulpia hairgrass seed was hand spread at a rate of 10 kg/ha on the 4 May 2021 and incorporated using a roller. The trial had 15 treatments arranged in a complete randomised complete block design with three replicates (total 45 plots). Treatment plots were 1.65 m wide and 10 m long (18.15 m^2). The second small plot trial was established during the 2022-23 season in a non-irrigated commercial turf ryegrass, cv. Intence, seed crop in Esk Valley close to St Andrews, South Canterbury (- 44.533278, 171.088167). The trial had 10 treatments arranged in a randomised complete block design with three replicates (total 30 plots). Treatment plots were 2.5 m wide and 11 m long (27.5 m^2).

During both trials, no other grass weed herbicides were applied within the trial site. At Kowhai Research Site, during sowing on the 10 May 2021, a 50/50 mix of suSCon®Green (a.i. 100 g/kg chlorpyrifos, Group 1 insecticide) and Diazinon 20G (a.i. 200 g/kg diazinon, Group 1 insecticide) were drilled with the seeds at rates of 7.5 kg/ha. On the 17 May 2021, 10 kg/ha of SlugOut® bait (18 g/kg metaldehyde) was applied across the trial site. On the 10 August 2021 the trial site was sprayed with 3 L/ha of Saxon® (a.i. 200 g/L mecoprop-P + 200 g/L MCPA + 70 g/L fluroxypyr, Group 4 herbicide) to control broadleaf weeds within the trial site. On the 18 October 2021, nitrogen (N) was applied as Urea (NPKS = 46-0-0-0) at a rate of 70 kg/ha.

The 2022-23 trial was sown early April and received 2 L/ha of Pasture Guard® 2,4-D 680 (a.i. 680 g/L 2,4-D, Group 4 herbicide) and 1.2 L/ha of Platoon® (a.i. 25 g/L diflufencian + 250 g/L bromoxynil, Group 12 herbicide + Group 6 herbicide) post-emergence for broadleaf weed control on the 10 June 2022. During the duration of the trial, 80 units of N were applied on the 8 October 2022 and 10 November 2022.

In the 2021-22 trial, a total of six different herbicides (Asulox®; Firebird; Invado®, a.i. 400 g/L flufenacet, Group K3; Nortron®; Quantum®; Simatop) were evaluated to determine their efficacies when they were applied by themselves to control common grass weeds. In the 2022-23 trial, the same herbicides were used, but Twister® (a.i. 500 g/L isoproturon, Group 5) was added and Invado® was omitted. A list of the products and application rates are included in each of the 2021-22 and 2022-23 trials are shown Table 1 and Table 2, respectively.

Treatments were applied at three different timings in both trials, either at pre-emergence of ryegrass (GS 00-07) (T1), when 50% of plants were at two-leaf stage (GS 12) (T2) or when 50% of plants had two tillers (GS 22) (T3). In the 2021-22 Kowhai trial, T1, T2 and T3 were applied on the 17 May, 8 June and 10 August 2021, respectively. In the 2022-23, T1, T2 and T3 were applied on the 7 April, 28 April and 2 June 2022, respectively. Conditions at the timing of all applications in both trials were calm with atmospheric air temperatures ranging from 10°C to 16°C and with the treatments being applied onto mostly damp to wet soil or foliage. All treatments at the 2021-22 Kowhai site were applied using a backpack type sprayer unit with a 12-volt Flojet pressure pump and a handheld 1.65 m spray boom with 6 x 110 015 Teejet® nozzles delivering a water rate of 250 L/ha at a boom operating pressure of 210 kPa. At the 2022-23 trial site, all treatments were applied using a backpack type sprayer unit with a 12-volt Flojet pressure pump and a handheld 2.5 m spray boom with 5 x 110 02 Teejet® nozzles at a 50 cm spacing delivering a water rate of 200 L/ha at a boom operating pressure of 210 kPa.

The number of Vulpia hairgrass plants per square metre was determined by counting all Vulpia hairgrass plants present between two drill rows by 0.5 m in length on the 25 June 2021 in the Kowhai trial or between two drill rows by 0.5 m in length on 18 October 2022 in 2022-23 trial site.

Seed yield was not collected in these trials due to the high levels of Vulpia hairgrass infestation and the potential to return unacceptable levels of viable seed to the soil at both sites.

All analyses of trial data were conducted using R software programming language (R Core Team, 2022). Data were analysed using a one-way analysis of variance (ANOVA) with a linear model with treatment and replicate as factors using the R packages 'stats' and 'lme4' (Bates *et al.*, 2015). The means, least significant difference (LSD) and coefficient of variation (CV) were generated using the R package 'predictmeans' (https://cran.r-project.org/web/packages/predictmeans/index.html). The percentage of control relative to untreated control was calculated for all treatments using Abbott's formula for corrected efficacy described by Abbott (1925).

Results and Discussion

In the 2021-22 trial at FAR's Kowhai Research site, the treatments applied at the pre-emergence timing provided the best levels of control (Table 1). This was consistent with the findings of previous trials (Smith *et al.*, 2019). Treatment 3, which was a tank mix of Nortron® (4 L/ha) with Quantum® (100 mL/ha), was the most effective, reducing Vulpia hairgrass to 7.8 plants/m^2 with 95% control relative to the untreated (165 plants/m^2) and was similar to six other treatments. Treatment 7 also showed high levels of Vulpia hairgrass control (18 plants/m^2; 88% control), however, this treatment would carry higher risks of generating resistance in Vulpia hairgrass populations due to both Firebird® and Nortron® containing actives belonging to group 15 (flufenacet and ethofumesate, respectively). Treatments containing Invado® (Treatments 8 and 9) provided acceptable levels of Vulpia hairgrass control with levels of control ranging between 64 to 66% indicating Invado® may provide a promising alternative to Nortron® for pre-emergence control of Vulpia hairgrass. Generally, treatments that were applied either at early post-emergence (GS 12) or late post-emergence (GS 22), didn't perform as well. Treatment 12, using 0.75 L/ha Simatop™ (146 plants/m^2) at early post-emergence, and Treatment 10, employing 5.5 L/ha Asulox® (114 plants/m^2) applied at late post-emergence, had significantly poorer levels of Vulpia hairgrass control with 11.2% and 30.8%, respectively. Simatop™ may have exhibited reduced control in this trial because it was applied during the post-emergence stages of ryegrass development rather than as a pre-emerge. Simazine-based products are typically effective for pre-emergence weed control (Wallace, 1997). Unfortunately, Simatop™ cannot be applied pre-ryegrass emergence.

In contrast to the findings from the previous 2021-22 trial, the 2022-23 trial conducted at St Andrews had lower levels of Vulpia hairgrass infestation. Despite the lower level of infestation, all treatments applied in the trial significantly ($P \leq 0.001$) reduced the mean number of Vulpia hairgrass plants compared with the untreated control, (7.6 plants/m^2) with levels of control ranging from 73 to 95% (Table 2). Noteworthy among the treatments was Treatment 3, an early treatment that employed Nortron® at a rate of 4 L/ha and demonstrated high levels of efficacy (95% or 0.3 plants/m^2) relative to the untreated control. A later application of the same treatment (Treatment 5) did not have the same efficacy. However, given the limited severity of Vulpia hairgrass infestation in this trial, it was challenging to establish a definitive relationship between application rates or timings and their effects.

The results from both trials underscore the importance of early intervention in effectively managing Vulpia hairgrass infestations in ryegrass seed crops. However, it is important to note that late germination of Vulpia hairgrass, beyond the control of most treatments, also occurred in these trials underscoring the species' ability to produce multiple flushes throughout the growing season. In the

2022-23 trial, the late germinations aligned with the weed's natural cycle, demonstrating its potential to germinate at any time during the growing season. In contrast, the Kowhai trial exhibited more uniform emergence of Vulpia hairgrass due to the seed being hand spread across the trial site, emphasizing the contrast between artificial sowing and natural cycling. Comparing the results of both trials is challenging due to the presence of different germination flushes. The hand spreading method employed in the Kowhai trial significantly facilitated the emergence of Vulpia hairgrass throughout the trial area, potentially exceeding the control thresholds for the rates that treatments were applied. It is important to note that Vulpia hairgrass predominantly germinates from above the soil surface, with minimal germination occurring from below. For instance, the germination of *V. bromoides* and *V. myuros* seedlings is notably reduced when seeds are buried at depths of 2 cm or more (Dillon & Forcella, 1984), with the majority of buried Vulpia hairgrass seeds losing their viability after 2-3 years (Wallace, 1997). Hence, the variations in seeding methods and seed burial depths contribute to the complexity of interpreting and comparing the trial outcomes. Further work is planned to identify optimal management strategies and understand the factors influencing Vulpia hairgrass germination.

Summary
Pre-emergence treatments, particularly the Nortron® and Quantum® tank mix, provided the best control against Vulpia hairgrass in the 2021-22 trial. Treatment with Invado® also achieved satisfactory control. However, applying treatments at early (GS 12) or late post-emergence (GS 22) stages, especially Simatop™ at a later stage, resulted in poorer control. In the 2022-23 trial, despite lower Vulpia hairgrass infestation levels, all treatments significantly reduced the number of Vulpia hairgrass plants compared with the untreated control. Early intervention was crucial, but challenges arose from late germinations and multiple flushes during the growing season. Further research is necessary to identify optimal management strategies and understand factors influencing Vulpia hairgrass germination.

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Table 1. Density of Vulpia hairgrass (*Vulpia* spp.) plants and percentage control relative to untreated following 15 different herbicide treatments for Vulpia hairgrass control in a ryegrass (*Lolium perenne*) trial at the Foundation for Arable Research (FAR) Kowhai research site, Lincoln, North Canterbury in 2021-2022.

Treatment No.	**Product, Application Rate and Timing [1]**			**Vulpia hairgrass plants/m^2**	**Vulpia hairgrass Control (Abbott) (%)**
	Pre-emergence (GS 00-07) 17 May 2021	**Early post-emerge 2 leaf (GS 12) 8 June 2021**	**Late post-emerge (GS 22) 10 August 2021**		
1	Nil	-	-	165 a	-
2	Nortron® (4 L/ha)	-	-	33 ef	79.8 abc
3	Nortron® (4 L/ha) + Quantum® (100 mL/ha)	-	-	7.8 f	95.2 a
4	-	Nortron® (4 L/ha)	-	88 cd	46.3 de
5	-	Nortron® (4 L/ha) + Quantum® (100 mL/ha)	-	89 cd	45.7 de
6	Firebird® (150 mL/ha)	-	-	32 ef	80.4 abc
7	Firebird® (150 mL/ha)	Nortron® (4 L/ha)	-	18 ef	88.6 ab
8	Invado® (150 mL/ha)	-	-	55 def	66.3 abcd
9	Invado® (150 mL/ha)	Nortron® (4 L/ha)	-	58 def	64.4 bcd
10	-	-	Asulox® (5.5 L/ha)	114 abc	30.8 ef
11	-	Nortron® (4 L/ha) + Simatop™ (0.5 L/ha)	-	67 cde	59.2 ef
12	-	Simatop™ (0.75 L/ha)	-	146 ab	11.2 f
13	-	Nortron® (4) + Simatop™ (0.75 L/ha)	-	58 def	64.4 bcd
14	-	Nortron® (4 L/ha)	Simatop™ (0.75 L/ha)	95 bcd	42.2 de
15	-	Nortron® (4 L/ha)	Asulox® (5.5 L/ha)	94 bcd	43 de
			LSD ($P \leq 0.05$)	**55**	**28.9**
			***P* value**	**<0.001**	**<0.001**

Letters indicate significant difference at $P \leq 0.05$ according to Least Significant Difference (LSD)

[1] Asulox® (a.i. 400 g/L asulam, Group 18 herbicide); Firebird® (a.i. 400 g/L flufenacet + 200 g/L diflufenican, Group 15 herbicide + Group 12 herbicide); Invado® (a.i. 400 g/L flufenacet, Group K3 herbicide); Nortron® (a.i. 500 g/L ethofumesate, Group 15 herbicide); Quantum® (a.i. 500 g/L diflufenican, Group 12 herbicide); Simatop™ (a.i. 500 g/L simazine, Group 5 herbicide)

Table 2. Density of Vulpia hairgrass (*Vulpia* spp.) plants and percentage control relative to untreated following ten different herbicide treatments for Vulpia hairgrass control in a ryegrass (*Lolium perenne*) trial at St Andrews, South Canterbury in 2022-2023.

Treatment No.	Product, Application Rate and Timing [1]			Vulpia hairgrass plants/m^2	Vulpia hairgrass control (Abbott) (%)
	Pre-emergence May 2022	**Early post-emerge 2 leaf (GS 12) June 2022**	**Late post-emerge (GS 22) August 2022**		
1	Nil	-	-	7.6 a	-
2	Nortron® (2 L/ha)			1.3 b	82.6 a
3	Nortron® (4 L/ha)			0.3 b	95.6 a
4		Nortron® (4 L/ha)		2 b	73.9 a
5	Nortron® (2 L/ha)	Nortron® (2 L/ha)		0.3 b	95.6 a
6		Nortron® (4 L/ha) + Quantum® (100 mL/ha)		1 b	86.9 a
7		Nortron® (4 L/ha) + Simatop™ (500 mL/ha)		1 b	86.9 a
8		Nortron® (4 L/ha)	Simatop™ (0.75 L/ha)	1 b	86.9 a
9		Nortron® (4 L/ha)	Asulox® (5.5 L/ha)	1.3 b	82.6 a
10		Nortron® (4 L/ha) + Twister® (0.75 L/ha) + Quantum® (100 mL/ha)		0.6	91.3 a
			LSD (P≤0.05)	**2.2**	**25.6**
			***P* value**	**<0.001**	**>0.05**

Letters indicate significant difference at P≤0.05 according to Least Significant Difference (LSD)

[1] Asulox® (a.i. 400 g/L asulam, Group 18 herbicide); Nortron® (a.i. 500 g/L ethofumesate, Group 15 herbicide); Quantum® (a.i. 500 g/L diflufenican, Group 12 herbicide); Simatop™ (a.i. 500 g/L simazine, Group 5 herbicide); Twister® (a.i. 500 g/L isoproturon, Group 5 herbicide)

Management of diseases in cocksfoot seed crops

Project code H19-03-01

Duration Year 3 of 4 (season 2021-22)

Authors Richard Chynoweth, Sean Weith (FAR) and Phil Rolston (SIRC)

Location Methven and Wakanui, Mid. Canterbury, New Zealand

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Mark Braithwaite (Plant Diagnostics)

Key points

- The most probable cause of head bleaching and seed yield losses in cocksfoot crops (*Dactylis glomerata*) was identified as the oomycete pathogen *Sclerophthora cryophile*, which causes a disease called downy mildew.
- *Sclerophthora cryophile* was undetected in New Zealand until this season, although it was known to cause downy mildew in other countries.
- Seed yields where downy mildew caused significant loss of green leaf and stem area were increased three-fold with fungicide treatments that included either Phoenix® (a.i. 500 g/L folpet, Group M4) or the experimental fungicide Bravo®WeatherStik® (a.i. 720 g/L chlorothalonil, Group M5).
- The addition of the triazole fungicide Proline® (a.i. 250 g/L prothioconazole, Group 3) as a mixing partner with Bravo® resulted in an increase in the seed yield, likely through control of additional diseases.
- These data suggest that downy mildew is part of the disease complex responsible for recent seed yield losses in cocksfoot.

Background

Over the past four years, above average rainfall during the growing season has led to substantial head bleaching and seed yield losses in cocksfoot (*Dactylis glomerata*) crops, with some growers in the Methven area of Canterbury reporting yield losses of up to 70%. This seed yield loss represents a significant threat to the viability of the industry, but the cause has remained unknown.

Symptoms in the field have included small white lesions on the reproductive stems a few days after flowering (GS 60-69) (Zadoks et al. 1974), which grow larger and eventually result in the upper stem becoming bleached. Growers have reported that the severity of these symptoms is exacerbated during seasons where damp/wet conditions prevail late in the crop lifecycle. As a result, the Seed Industry Research Centre (SIRC) has conducted field surveys in the last two years in the Methven area to identify a possible pathogen or pathogen complex responsible for the observed symptoms. A range of potential causative pathogens were identified including soil-borne fungi from the *Fusarium* complex and *Gaeumannomyces graminis* var. *tritici* (Ggt), the causal agent of Take-all, along with common bacterial pathogens such as *Pseudomonas* and *Xanthomonas*.

The objective of this study was to confirm the symptoms described by growers and to identify possible casual agents by limiting infection of certain pathogens by using fungicides and bactericides targeted to strategic timings in the crop's lifecycle.

Methods

Two small plot trials were established during the 2021-22 season. One trial was located in Methven (-43.570983;171.676764) and the other was located near Wakanui (-43.978349; 171.796883), Mid Canterbury, New Zealand. A total of six fungicides (Amistar®, active ingredient (a.i.) 250 g/L azoxystrobin; Bravo®WeatherStik®, a.i. 720 g/L chlorothalonil; Phoenix®, a.i. 500 g/L folpet; Proline®, a.i. 250 g/L prothioconazole; SEGURIS®Flexi, a.i. 125 g/L isopyrazam and Tri-Base Blue®, a.i. 190g/L copper as tribasic copper sulphate), one bactericide (KeyStrepto™, a.i. 170 g/kg streptomycin), one bio-bactericide (AUREO®GOLD, a.i. 4 x 10^9 cfu/g of *Aureobasidium pullulans*) and one plant activator (Actigard®Plant Activator, a.i. 500 g/kg acibenzolar-s-methyl) were evaluated in each trial to determine their efficacies when they were applied either by themselves or tank-mixed together to control foliar diseases in cocksfoot. Each trial had eleven treatments arranged in a complete randomised block design with four replicates (total 48 plots per trial). Treatment plots were 3.2 m wide and 10 m long (32 m^2). A list of the products included in each treatment is shown in Table 1. Treatments were applied at four different timings, either at the second plant growth regulator timing (GS 32) (T1; 22 October 2021), head emergence (GS 40-49) (T2; 23 November 2021), pre-flowering (T3; 1 December 2021) or at flowering (GS 60-69) (T4; 9 December 2021). Treatment plots were assessed on the 13th December 2020 for crop greenness and at time of harvest for seed yield.

Results and Discussion

During preliminary baseline sampling prior to the GS 32 fungicide applications, *Sclerophthora cryophile* (Jones 1955), the causative agent of downy mildew, was identified as present at Methven, but not as causing widespread disease symptoms. Downy mildew was not found at Wakanui.

At Methven, treatments that contained Bravo® and Phoenix® remained green at flowering (13 December 2021), while plots treated with other fungicide and bactericide treatments experienced substantial loss of leaf greenness (Table 1). Seed yield was also greatest when Bravo® was applied with Proline® at 790 kg/ha as a tank mix, followed by a solo application of Bravo® (640 kg/ha) and as a tank mix (620 kg/ha) with Proline® plus Phoenix®. All other treatments produced lower seed yield results, some of which were similar to the untreated control at 220 kg/ha (Table 1). *Sclerophthora cryophile* is not a fungus, but an oomycete. Oomycetes are not controlled by standard fungicides, however, both Bravo® and Phoenix® are known to target oomycete pathogens suggesting *S. cryophile* could be responsible or part of a complex repsonsible) for the seed losses in cocksfoot.

At Wakanui, disease severity and final seed yield responses were lower than obtained at the Methven trial site. Downy mildew was not identified as present until mid December in the trial, whereas leaf and stem rust (caused by *Uromyces dactylidis*) and leaf fleck (caused by *Mastigosporium rubricosum*), were more common. Generally, seed yield was increased by treatments that included two fungicide mode-of-action groups with activity against the pathogens present. For example: Proline® applied alone did not increase seed yield (790 kg/ha) above the untreated control (720 kg/ha), but when mixed with either Phoenix® (930 kg/ha), Bravo® (890 kg/ha) or SEGURIS®Flexi (880 kg/ha), the programme provided adequate disease control to increase seed yield, potentially through the control of a number of different pathogens. This interpretation is based on the fact that, as an example, SEGURIS®Flexi is unlikely to provide control of downy mildew but has activity against rusts whereas Phoenix® likely controlled downy mildew but has no activity against rusts. No treatments targeting bacteria increased seed yield above the untreated control, suggesting bacteria were not the cause of seed yield loss.

The observation of downy mildew and subsequent disease control by products with activity against oomycete diseases suggested that the previously observed seed head bleaching symptoms are likely caused by *S. cryophile* alone or in a complex. Downy mildew has primary and secondary infection stages which are spread by rain splash. The primary infection likely occurs each year, but wet weather and rain splash enables the damaging secondary infection to take hold during spring and summer. The manifestation of the disease begins with the appearance of small white spots on the seed heads, which then turn lighter in color (Jones 1955). From the Methven trial, the application timing suggests that stopping secondary infection of *S. cryophile* can be linked to large seed yield increases.

It is crucial to note that the use of Bravo® is either prohibited or being phased out in Europe and New Zealand with the grazing of pastures and crops not allowed post application. Bravo® was used as a trial treatment in this study only in an attempt to identify the causal agent of seed loss in cocksfoot crops.

Summary

An oomycete, *Sclerophthora cryophile*, the casual agent of downy mildew in cocksfoot, has been identified as the likley primary cause of head bleaching and subsequent seed yield loss in cocksfoot. This oomycete was undetected in New Zealand until now, but known to cause downy mildew elsewhere. Given many standard fungicides do not control oomycetes, the detection of this pathogen likely explains why commercial fungicide and bactericide programmes previously trialled did not prevent the disease and the associated seed yield losses. Two products with activity on oomycetes gave large seed yield increases.

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Table 1. Green crop score and seed yield for cocksfoot (*Dactylis glomerata*) plots treated with 12 different fungicide programmes in trials conducted near Methven and Wakanui in Canterbury during the 2021-22 growing season. Green crop score (0=dead and 10=maximum green).

Trt No.	Fungicide rates (L/ha) and timing				Methven	Methven	Wakanui
	2nd PGR timing (5 November)	Head emergence (GS 40-49) (24 November)	Pre-Flowering (3 December)	Flowering (GS 60-69) (13 December)	Green Score (13-Dec)	Seed yield* (kg/ha)	Seed yield* (kg/ha)
1	Untreated	Untreated	Untreated	Untreated	2.8	220	720
2	Bravo® (1.4 L/ha)	Bravo® (1.4 L/ha)	-	Bravo® (1.4 L/ha)	9.0	640	830
3	Proline (0.4 L/ha)	Proline (0.4 L/ha)	-	Proline (0.4 L/ha)	3.5	340	790
4	Bravo® (1.4 L/ha) + Proline® (0.4 L/ha)	Bravo® (1.4 L/ha) + Proline® (0.4 L/ha)	-	Bravo® (1.4 L/ha) + Proline® (0.4 L/ha)	9.0	790	890
5	Phoenix® (1.5 L/ha) + Proline® (0.4 L/ha)	Phoenix® (1.5 L/ha) + Proline® (0.4 L/ha)	-	Phoenix® (1.5 L/ha) + Proline® (0.4 L/ha)	9.5	620	930
6	Proline® (0.4 L/ha)	Proline® (0.4 L/ha) + Amistar (0.75 L/ha)	-	Proline® (0.4 L/ha L/ha) + SEGURIS®Flexi (0.6 L/ha)	5.3	450	880
7	Proline® (0.4 L/ha)	Proline® (0.4 L/ha) + Amistar® (0.75 L/ha) + Tri-base Blue® (3.0 L/ha)	Tri-base Blue® (3.0 L/ha)	Proline® (0.4 L/ha) + SEGURIS®Flexi (0.6 L/ha) + Tri-base Blue® (3.0 L/ha)	5.5	470	780
8	Proline® (0.4 L/ha)	Proline® (0.4 L/ha) + Amistar® (0.75 L/ha) + Keystrepto (200 g/ha)	Keystrepto (200 g/ha)	Proline® (0.4 L/ha) + SEGURIS®Flexi (0.6 L/ha) + Keystrepto (200 g/ha)	5.5	480	890
9	Proline® (0.4 L/ha)	Proline® (0.4) + Amistar® (0.75) + AUREO®GOLD (170 g/ha)	AUREO®GOLD (170 g/ha)	Proline® (0.4) + SEGURIS®Flexi (0.6) + AUREO®GOLD (170 g/ha)	5.0	480	840
10	-	Tri-base Blue® (3.0 L/ha)	Tri-base Blue® (3.0 L/ha)	Tri-base Blue® (3.0 L/ha)	4.5	370	730
11	-	Keystrepto (200 g/ha)	Keystrepto (200 g/ha)	Keystrepto (200 g/ha)	4.0	260	730
12	AUREO®GOLD (170 g/ha) + Actigard® (7 g/ha)	AUREO®GOLD (170 g/ha) +Actigard® (7 g/ha)	AUREO®GOLD (170 g/ha) + Actigard® (7 g/ha)	AUREO®GOLD (170 g/ha) + Actigard® (7 g/ha)	3.8	230	730
				LSD (*P*≤0.05)	**1.4**	**101**	**90**
				***P* value**	**<0.001**	**<0.001**	**<0.001**

Actigard®Plant Activator (a.i. 500 g/kg acibenzolar-s-methyl); Amistar® (a.i. 250 g/L azoxystrobin, Group 11 Fungicide); AUREO®GOLD (contains not less than 4 x 10^9 cfu/g of *Aureobasidium pullulans* (YBCA5) bactericide for *Pseudomonas* control, Group NC Bactericide); Bravo = Bravo®WeatherStik® (a.i. 720 g/L chlorothalonil, Group M5 Fungicide); KeyStrepto™ (a.i. 170 g/kg streptomycin); Phoenix = Phoenix®Fungicide (a.i. 500 g/L folpet, Group M4 Fungicide); Proline® (a.i. 250 g/L prothioconazole, Group 3 Fungicide); SEGURIS®Flexi (a.i. 125 g/L isopyrazam, Group 7 Fungicide); Tri-Base Blue® (a.i. 190g/L copper as tribasic copper sulphate). Cells highlighted in yellow indicate treatments that were amongst the highest yielding group or the group with the greatest green score.

Evaluating the efficacy and selectivity of Group 3 propyzamide herbicide Kerb™ in cocksfoot

Project code H19-11-00

Duration Year 1 of 2 (season 2021-22)

Authors Phil Rolston (SIRC), Sean Weith, Owen Gibson (FAR)

Location Methven, Mid Canterbury (GPS: -43.561632, 171.660576)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Hamish Marr (trial host); NZ Arable (trial operator)

Key points

- All chemical treatments controlled the assessed grass weeds present in the trial site relative to the untreated plots.
- All treatments containing Kerb™500F caused varying levels of phytotoxicity and biomass reduction damage.
- The differences in seed yields between treatments could be linked to plots treated with the highest rates of Kerb™500F (1.3 and 1.45 L/ha) having lower seed yield due to poor seed filling caused by herbicide damage.
- Kerb™500F could be used in cocksfoot crops up to a rate of 1.15 L/ha: there was no clear benefit in either weed control or seed yield above this rate.
- However, Kerb™500F should not be applied in cocksfoot seed crops at any rate higher than 1 L/ha due to risks of unacceptable levels of seed yield losses.

Background

Cocksfoot (*Dactylis glomerata*) is a hardy grass species that is valued for its drought tolerance and high productivity during the summer months (Charlton & Stewart, 2006). Since 2019, the area of cocksfoot seed production in New Zealand has increased rapidly, with many new cultivars now being multiplied for re-export.

Managing grass weeds in established cocksfoot seed crops is challenging. Grass weeds can compete with the crop for light, water and nutrients whilst also affecting seed quality via contamination of the seed lot. Some of the most common weeds that can infest cocksfoot seed crops include annual (*Lolium multiflorum*) or perennial ryegrass (*Lolium perenne*), annual poa (*Poa annua*), rough meadow-grass (*Poa trivialis*), hairgrass (*Vulpia* sp.) and wild oats (*Avena fatua*) as well as volunteer seedling cocksfoot. At present, growers commonly apply products such as NuTrazine™900DF (active ingredient (a.i.) 900 g/L atrazine, Group 5 Herbicide), Karmex®900 (a.i. 900 g/kg diuron, Group 5 Herbicide) and/or Hussar® (a.i. 50g/kg iodosulfuron-methyl-sodium, Group 2 Herbicide) for controlling common grass weeds in second-year cocksfoot crops.

Over the last three years, the Foundation for Arable Research (FAR) and Seed Industry Research Centre (SIRC) have conducted two trials on 11 cocksfoot cultivars at Chertsey as first-year sowing (Rolston *et al.*, 2019) and second-year crop (Rolston & Chynoweth, 2020) focused trials. In a separate trial at FAR's Kowhai research site, Rolston & Chynoweth (2021) found that Kerb™500F (a.i. 500 g/L propyzamide, Group 3 Herbicide) was a promising option for grass weed control in cocksfoot where herbicide resistance to Hussar® was an issue. Furthermore, products such as Foxtrot® (a.i. 69 g/L fenoxaprop-P-ethyl, Group 1 Herbicide) and Stratos® (a.i. 200 g/L flamprop-M-isopropyl, Group 0 Herbicide) were also shown to be ideal follow-up products for products such as Kerb™500F in spring if wild oat control was needed.

The effects of products like Kerb™500F, Puma®S and Stratos® on the crop safety of various cocksfoot cultivars grown in New Zealand are not well known to growers. The trial reported here evaluated the weed control and crop safety of different rates of Kerb™500F in a commercial cocksfoot seed crop.

Methods

A small plot trial was established during the 2021-22 season in a five-year-old unirrigated commercial cocksfoot (*Dactylis glomerata*) (cv. Elise) seed crop that was sown on the 4 October 2016 in Methven, Mid Canterbury (-43.561632, 171.660576). Table 1 presents the trial's 9 treatments, which were arranged in a complete randomised experimental design with four replicates (total 36 plots). Treatment plots were 3.3 m wide and 11 m long (36 m^2). Due to supply issues, Foxtrot® (a.i. 69 g/L fenoxaprop-P-ethyl, Group 1 Herbicide) was substituted for Puma®S (a.i. 69 g/L fenoxaprop-P-ethyl, Group 1 Herbicide) which also contains fenoxaprop-P-ethyl. Puma®S was applied with 0.5 L/ha Hasten™ spray adjuvant (704 g/L ethyl and methyl esters of canola oil fatty acids with 196 g/L non-ionic surfactants).

During the year of the trial there were no grass weed control products applied to the trial site. The grower applied fungicides and plant growth regulators at two timings. In September 2021, a tank mix consisting 4 g/ha Metsulfuron (600 g/kg metsulfuron methyl, Group 2 Herbicide) and 1.5 L/ha Agritone®750 (750 g/L MCPA, Group 4 Herbicide) was applied. At stem elongation (GS 31-39), 1.5 L of Cycocel®750 (750 g/L chlormequat-chloride) was applied in two separate applications. Fertiliser nitrogen (N) was applied as urea (NPKS = 46-0-0-0) in August 2021 at 100 kg/ha, September at 150 kg/ha and October 2021 at 100 kg/ha.

All treatments were applied onto mature cocksfoot plants with some tiller post-harvest re-growth before normal plant growth regulator application timings, either on the 8 July or the 16 September 2021. Conditions at the timing of first application on the 8 July 2021 were cold with an atmospheric temperature of 5°C and soil temperature of 13°C with constant drizzle during application of treatments. Conditions on day of application on the 16 September 2021 were dry with calm winds. All Kerb™500F treatments (Treatments 2-9) were applied using a hand-held 3 m spray boom with a 12-volt electric pump with the boom fitted with 6 x 110 015 AIXR Teejet® nozzles delivering a water rate of 165 L/ha at a boom operating pressure of 250 kPa. Treatments containing Puma®S (treatment 8) and Stratos® (Treatment 9) were applied using a 3 m spray boom fitted with 6 x 110 002 XR Teejet® standard fan nozzles delivering a water rate of 200 L/ha at a boom operating pressure of 210 kPa.

The re-growth of all grass weeds post application was recorded on a plot basis on the 26 August 2021 using a scale of 0% to 100%, where 0% = no control and 100% = full control. Crop safety assessments involved treatments being assessed on a plot basis for phytotoxicity and biomass reduction on 26 August 2021 and 27 September 2021, respectively. Cocksfoot plants within each plot were assessed for visible phytotoxicity damage (bleaching or chlorosis) using a scale of 0% to 100%, where 0% = no damage and 100% = all plants dead with no green leaf. Each plot was assessed for reduction in crop biomass using a scale of 0% to 100%, where 0% = no damage and 100% = all cocksfoot plants dead. Seed head density (seed heads per square meter) was determined by recording the number of cocksfoot and grass weed (*Poa annua* and brome grasses) seed heads within a representative 0.48 m x 0.48 m (0.23 m^2) quadrat for each treatment plot on the 8 December 2021. Seed yield was obtained by windrowing plots using a modified John Deere plot windrower with a 1.8 m cut width on the 24 February 2022 and harvesting all treatment plots with a Sampo 2010 plot harvester on the 1 February 2022. Machine dressed yield, percentage dressing yield and thousand seed weight (TSW) were all determined post-harvest.

All analyses were conducted using R software programming language (R Core Team, 2022). Data were analysed using a one-way analysis of variance (ANOVA) with a linear model with treatment and replicate as factors using the R packages 'stats' and 'lme4' (Bates et al. 2015). Least significant difference (LSD) and coefficient of variation (CV) were generated using the R package 'predictmeans' (https://cran.r-project.org/web/packages/predictmeans/index.html). To calculate the margin-over-cost (MoC), the treatment cost per hectare and cost per application were subtracted from the revenue generated per hectare for each plot. This calculated amount was then further subtracted from the cost per hectare of the untreated control. Calculations were based on a grower's seed price of $5.25/kg.

Results and Discussion

There were moderate to high numbers of *Poa* grass weed species including smooth meadow-grass (*Poa pratensis*), annual meadow-grass (*Poa annua*) and rough meadow-grass (*Poa trivialis*) within the trial site. All applied treatments controlled the assessed grass weeds with 100% reduction in the number of seed heads relative to the untreated plots. As a result of the high levels of grass weed control, it was not possible to identify any obvious rate effects from the treatments containing differing rates of Kerb™500F. All grass weed efficacy results are presented in Appendix Table A1.

Plots treated with Kerb™500F at rates of 0.70 L/ha (1080 kg/ha) and 0.85 L/ha (1075 kg/ha) had significantly higher seed yields than most treatments including the control (Table 1). Interestingly, plots where these treatments were applied did not have the highest number of seed heads per square metre suggesting their actual seed yields may have been associated with other seed yield parameters.

All treatments containing Kerb™500F resulted in some degree of crop damage due to phytotoxicity and biomass reduction (Figure 1; Table 1). However, only treatments 2-5 had levels of biomass reduction below 30%. This could be related to several factors affecting the herbicidal activity of Kerb™500F, such as soil temperature, soil moisture and rainfall. Kerb™500F should be applied when the soil temperature is below 13°C and when there is sufficient rainfall (at least 35 mL) to move the herbicide into the root zone. If the soil temperature is too high or the rainfall is insufficient, the herbicide may not be effective or may cause excessive crop damage.

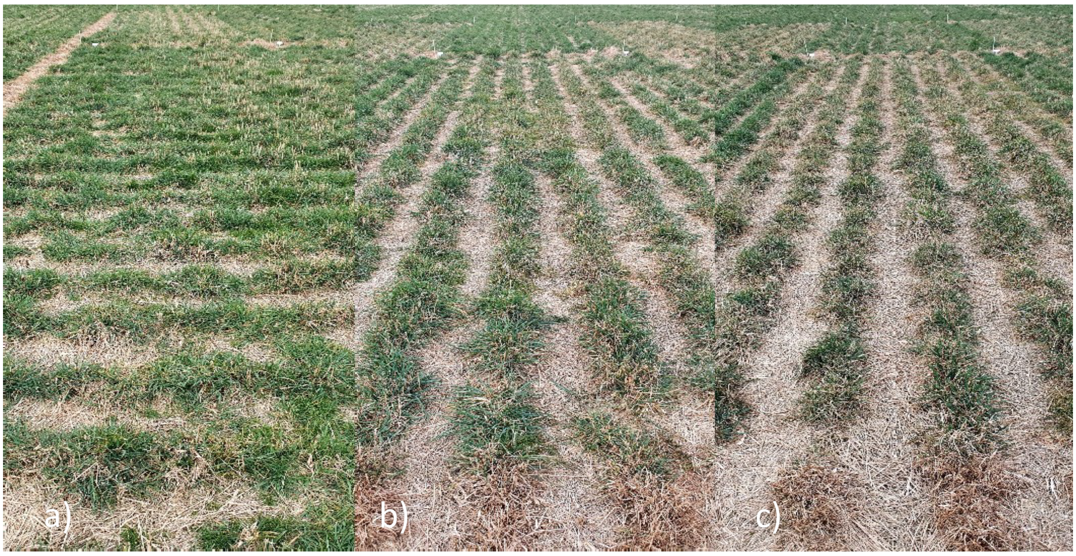

Figure 1. Examples of phytotoxicity and biomass reduction effects observed on the 26 August 2021 in cocksfoot (*Dactylis glomerata*) (cv.Elise) plots that were a) left untreated (nil) or treated with either b) 1.15 L/ha or c) 1.45 L/ha of Kerb™500F (propyzamide).

There was a large economic response (as measured by margin-over-herbicide cost) to herbicide in cocksfoot seed yield relative to the untreated control (Table 1). The profitability of seed yield was significantly ($P \leq 0.001$) decreased by Kerb™500F applied at rates of either 1.45 L/ha (Treatment 7) (-$1098) or at 0.85 L/ha followed by 0.75 L/ha Puma®S (Treatment 8) (-$1053) in comparison to plots treated with lower rates of Kerb™500F.

A Pearson's pairwise correlation coefficient matrix (not presented) of all measured responses indicated that the differences in seed yields between treatments could be linked to plots treated with the highest rates of Kerb™500F (1.3 and 1.45 L/ha) having lower seed yield due to poor seed filling caused by physiological herbicide damage from propyzamide. For example, there were significant strong positive correlations between phytotoxicity and biomass reduction of treatments with thousand seed weight (r= 0.90 and 0.92, respectively, $P \leq 0.001$). Furthermore, the significant moderate inverse correlation (r= - 0.63, $P \geq 0.05$) between machine-dressed yield and crop biomass reduction suggested that seed yield decreased with an increase in the level of biomass reduction caused by Kerb™500F treatments.

Overall, from a seed yield perspective, Kerb™500F could be used in cocksfoot crops up to a rate of 1.15 L/ha: there was no clear benefit in either weed control or seed yield above this rate. However, when the crop safety of the treatments was considered, it is clear that Kerb™500F should not be applied in cocksfoot seed crops at any rate higher than 1 L/ha due to the risks of significant crop damage. In this trial, the effects caused by this damage did not flow through to actual yield. Further trials are recommended to assess if the 1 L/ha rate of Kerb™500F can provide adequate grass weed control under more challenging conditions.

Summary

The results from this trial showed that Kerb™500F effectively controlled all grass weeds at all rates, but also caused phytotoxicity and biomass reduction at higher rates. Plots that received the highest doses of Kerb™500F (1.3 and 1.45 L/ha) had lower seed yields because of physiological damage from the herbicide that affected seed-filling. There is no advantage in using Kerb™500F above 1.15 L/ha in terms of weed control or seed yield in cocksfoot crops. However, applying Kerb™500F at more than 1 L/ha in cocksfoot seed crops is not recommended as it could result in unacceptable reductions in seed yield. More research is needed on effects of Kerb™500F under different seasonal conditions.

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Table 1. Phytotoxicity, biomass reduction, cocksfoot heads per square metre (m^2), machine dressed seed yield, percentage dressing yield, thousand seed weight (TSW) and margin-over-cost (MoC) from cocksfoot (*Dactylis glomerata*) (cv.Elise) plots treated with nine different chemical treatments in a trial conducted at Methven, Mid Canterbury during the 2021-22 season. Seed yields are estimated machine-dressed yields based on field-dressed seed yields and assuming a 20% dressing loss.

Treatment No.	Product, Application Rate and Timing [1] 8 July 2021	16 September 2021	Phytotoxicity (0-100%)	Biomass Reduction (0-100%)	Cocksfoot Seed Heads per m^2	Machine Dressed yield (kg/ha)	Dressing Loss (%)	TSW [2] (g)	MoC * ($/ha)
1	Untreated	Untreated	0 a	0 a	424 a	862 ab	20.4 a	1.11 a	NA
2	Kerb™ 500F (0.70 L/ha)		23 b	5 ab	495 a	1080 c	12.5 b	1.15 ab	1047 a
3	Kerb™ 500F (0.85 L/ha)		30 bc	13 abc	388 a	1075 c	12.3 b	1.16 abc	1011 a
4	Kerb™ 500F (1 L/ha)		35 bc	22 cde	535 a	949 a-c	13.0 b	1.15 abc	339 ab
5	Kerb™ 500F (1.15 L/ha)		42 c	28 de	482 a	988 a-c	12.1 b	1.15 ab	530 ab
6	Kerb™ 500F (1.3 L/ha)		58 d	48 f	406 a	889 a	14.1 b	1.20 bc	-2.1 b
7	Kerb™ 500F (1.45 L/ha)		68 d	68 g	448 a	682 d	14.8 b	1.22 c	-1098 c
8	Kerb™ 500F (0.85 L/ha)	Puma®S (0.75 L/ha) + Hasten™ (0.5 L/ha)	33 bc	33 d	405 a	699 b-d	13.7 b	1.19 bc	-1060 c
9	Kerb™ 500F (0.85 L/ha)	Stratos® (4 L/ha)	33 bc	15 b-e	416 a	872 a	10.9 b	1.17 abc	-264 bc
		Range	**0-7**	**0-8**	**282-760**	**542-1353**	**7.1-32.9**	**1.0-1.2**	**-1836-2483**
		LSD (P≤0.05)	**12**	**14**	**199**	**169**	**5.0**	**0.06**	**936**
		CV	**56**	**89**	**29**	**20**	**28**	**4.5**	**-**
		P value	**<0.001**	**<0.001**	**>0.05**	**<0.001**	**<0.05**	**>0.05**	**<0.001**

Letters indicate significant difference at *P*≤0.05 according to Least Significant Difference (LSD)

[1] Kerb™500F (500 g/L propyzamide, Group 3 Herbicide); Puma®S (69 g/litre fenoxaprop-P-ethyl, Group 1 Herbicide); Stratos® (200 g/litre flamprop-M-isopropyl, Group 0 Herbicide)

[2] TSW = Thousand Seed Weight

* MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $5.25 per kg (effective June 2022). MoC for treatments were calculated based on product price per litre with Hasten™ at $13.9/L, Kerb™ 500F at $82.5/L, Puma®S at $80.78/L and Stratos® at $45.52/L

Appendix

Table A1. Number of *Poa* species and brome species heads and heads per square meter (m^2) and percentage grass weed regrowth from cocksfoot (*Dactylis glomerata*) (cv. Elise) plots treated with nine different chemical treatments in a trial conducted at Methven, Mid Canterbury during the 2021-22 season.

Treatment No.	**Product, Application Rate and Timing** [1]		***Poa sp.* heads**	***Poa* sp. heads/m²**	**Percentage Grass Weed Re-growth (0-100%)**
	8 July 2021	16 September 2021			
1	Untreated	Untreated	46 a	200 a	22
2	Kerb™ 500F (0.70 L/ha)		0.0 b	0.0 b	67
3	Kerb™ 500F (0.85 L/ha)		0.0 b	0.0 b	65
4	Kerb™ 500F (1 L/ha)		0.0 b	0.0 b	60
5	Kerb™ 500F (1.15 L/ha)		0.0 b	0.0 b	85
6	Kerb™ 500F (1.3 L/ha)		0.0 b	0.0 b	68
7	Kerb™ 500F (1.45 L/ha)		0.0 b	0.0 b	75
8	Kerb™ 500F (0.85 L/ha)	Puma®S (0.75 L/ha) + Hasten (0.5 L/ha)	0.0 b	0.0 b	75
9	Kerb™ 500F (0.85 L/ha)	Stratos® (4 L/ha)	0.0 b	0.0 b	68
		Range	**0-99**	**0-430**	**0-9**
		LSD (*P*≤0.05)	**19**	**83**	**2.8**
		CV	**365**	**365**	**38**
		***P* value**	**<0.001**	**<0.001**	**>0.05**

Letters indicate significant difference at *P*≤0.05 according to Least Significant Difference (LSD)

[1] Puma®S (69 g/L fenoxaprop-P-ethyl, Group 1 Herbicide); Kerb™500F (500 g/L propyzamide, Group 3 Herbicide); Stratos® (200 g/L flamprop-M-isopropyl, Group 0 Herbicide)

The effect of *Trichoderma* bio-inoculants on soil-borne disease and seed yields in peas

Project Code B21-02-01

Duration Year 1 of 3 (season 2021-22)

Authors Diwakar (Wadia) Kandula, John Hampton (Lincoln University) and Phil Rolston (FAR)

Location Lincoln University Iversen Field 9 (43° 38′ 59.94″ S; 172° 28′ 00.71″ E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Staff of the Field Research Centre (Lincoln University); Alistair Pullin and Dylan Coleman (Agrimm Technologies); Greg Noller, Nigel Rowe-Lucas, and Gavin Snelson (Watties); Richard Chynoweth and Alice Ridgen (FAR); Bede McCloy (NZ Arable).

Key points

- *Aphanomyces* and other soil-borne pathogens are a major limitation to pea production.
- *Trichoderma* and fungicide seed treatments reduced the incidence of *Aphanomyces* and *Fusarium* root rots in a crop of Pea cultivar Ashton grown in Lincoln, Canterbury in 2021-22.
- All seed treatments resulted in a higher yield than in the no treatment control.
- A combination of a fungicide and *Trichoderma* treatment produced a higher seed yield than using a fungicide alone.
- Plant counts were greater when using a seed treatment than in the no treatment control, suggesting seed treatments support early establishment of the pea crop.

Background

Plant pathogens, especially those that are soil-borne, are a major limitation to the frequency that vegetable and seed pea crops can be grown in the same paddock. The host range of the soil-borne pathogens, *Aphanomyces euteiches* in particular, includes other legumes (white clover, lucerne). Common arable weeds and crops including spinach, field pansy, chickweed and shepherd's purse can also host this pathogen. The breadth of these host associations makes control challenging.

Aphanomyces can be assessed with a soil test, which gives a predicted Disease Severity Index (DSI) ranging from 0 to 100. Vegetable pea yields are predicted to decline when the DSI is greater than 50 and when DSI is >69 peas should not be sown (PIDG 2008). Seed growers consider a DSI <40 as a threshold for growing high grade seed. Typically, peas should not be sown more frequently than on a 5-year rotation to ensure sufficient time for the inoculum of these pathogens to drop to acceptable levels.

Seed treatments, including fungicides and biologicals such as *Trichoderma*, have been shown to improve the tolerance of crop species to fungal (root and foliar) diseases. This project offered the opportunity to test if pea seeds treated with fungicides and/or *Trichoderma* can provide sufficient protection from soil-borne pathogens to be sown in an *Aphanomyces*-infected field without affecting pea production as well as seed quality and yield. Results pertinent to seed production are provided in the report.

Methods

Pea cultivar Ashton was sown into a Templeton silt loam soil with a pre-sowing *Aphanomyces euteiches* root rot rating of 30 (despite not having grown peas for 10 years but has had lucerne in recent years), with a Flexiseeder on 21 September 2021. Prior to planting, the seed was treated with one of six seed treatments: Wakil-XL (Metalaxyl-M + fludoxonil + cymoxanil) fungicide coating (fungicide standard), two *Trichoderma* (PBI, ACB58W) seed coatings, a combination of Wakil-XL plus one of the *Trichoderma* treatments or a bare seed control. The trial consisted of six replicates of each treatment in a complete randomized design. Each plot was 12.6 m^2. Apart from two (a pre- and a post-emergence) herbicide applications, no chemicals were applied to the growing crop.

Seedling establishment (28 DAS) and root disease incidence (35 DAS) were assessed. Root assessments for incidence of *Aphanomyces* were based on oospore presence in root tissue and *Fusarium* spp. as calculated from 20 root-bits plated on Potato Dextrose Agar amended with chloromphenicol.

Weekly monitoring of the crop canopy was carried out from 3 November to 13 Dec 2021 using a RapidSCAN CS-45 handheld crop sensor (Holland Scientific) to record Normalized Difference Red Edge (NDRE) and Normalized Difference Vegetation Index (NDVI) parameters. NDRE and NDVI are indicators of biomass and/or plant stress.

Final seed harvest took place on 5 January 2022 (106 Days afrer sowing (DAS)).

Results and Discussion

At 28 DAS, all plots with a seed treatment had a higher established plant population (by 15-24 %) than the bare seed control treatment (Table 1). At 35 DAS, the plots with a *Trichoderma* treatment or a combination of fungicide and biological seed treatment had a significantly lower incidence of *Aphanomyces* and *Fusarium* root rots than the fungicide treatment or bare seed control (Table 1).

Table 1. A summary of establishment, disease severity, seed yield and seed quality (100 seed weight) for a pea cultivar Ashton crop grown at Lincoln University, Canterbury in the 2021-22 season following different treatments of the seed prior to sowing.

Treatment	Establishment (No. of plants/m^2)	*Aphanomyces* (% infected plants)	*Fusarium* spp. (% infected roots)	Seed Yield (kg/ha)*	100 Seed Wt. (g)
Bare Seed	110 a[1]	37 a	52 a	3192 a	14.50
WAKIL Coated	127 b	24 b	42 a	3843 b	15.10
Bare + PBI	126 b	10 c	13 b	4052 bc	15.02
Bare + ACB58W	135 b	12 c	22 b	3886 b	15.24
WAKIL + PBI	136 b	12 c	17 b	4345 c	15.03
WAKIL + ACB58W	129 b	13 c	20 b	4291 c	14.72
LSD (P=0.05)	**14.9**	**10.0**	**10.5**	**398**	**0.90**
P value	**<0.017**	**0.029**	**<0.001**	**<0.001**	**NS**

[1]Treatments that share a common letter do not differ at the 5% significance level.

Canopy assessments using NDVI showed that all the plots with seed treatments had a higher vegetation index than the untreated plots during the early phase of growth (vegetative growth and into reproductive growth (Table 2). However, vegetation index at later assessment times were not different. Similar data was obtained using NDRE (data not shown).

At final seed harvest on 5 January 2022 (106 DAS), all seed treated with a fungicide, biological or a combination of the two produced a greater yield than untreated seed (by between 20 to 36%). Seed treated with a combination of the fungicide and either *Trichoderma* treatment produced the greatest yield (Table 1). None of the treatments increased 100 seed weight (Table 1).

Despite observing differences between crops treated with seed treatments, because of the very wet season, the incidence and intensity of foliar diseases was unexpectedly high. This meant foliar disease became a significant factor across the trial and may have influenced the overall seed yields and quality in the trial. Foliar diseases identified during crop growth were predominantly leaf blotch (*Septoria pisi*), powdery mildew (*Erysiphe pisi*), and downy mildew (*Peronospora viciae*).

Table 2. Normalized Difference Vegetation Index values obtained by scanning a pea cultivar Ashton crop grown at Lincoln University, Canterbury in the 2021-22 season following different treatments of the seed prior to sowing.

Treatment	3 Nov	10 Nov	16 Nov	26 Nov	30 Nov	8 Dec	13 Dec
Bare Seed	0.37 a[1]	0.51 a	0.63 a	0.73 a	0.76 a	0.80 a	**0.80 a**
WAKIL coated	0.44 b	0.58 b	0.69 b	0.75 ab	0.77 ab	0.81 ab	**0.81 a**
Bare + PBI	0.43 b	0.57 b	0.68 b	0.75 b	0.77 ab	0.80 ab	**0.80 a**
Bare + ACB58W	0.43 b	0.55 b	0.66 ab	0.74 ab	0.77 b	0.81 b	**0.80 a**
WAKIL + PBI	0.45 b	0.58 b	0.69 b	0.75 b	0.77 b	0.80 a	**0.80 a**
WAKIL + ACB58W	0.44 b	0.56 b	0.68 b	0.74 ab	0.77 ab	0.80 ab	**0.80 a**
LSD (p=0.05)	**0.035**	**0.046**	**0.039**	**0.021**	**0.010**	**0.007**	**0.013**
P value	**0.002**	**0.035**	**0.040**	**0.236**	**0.173**	**0.210**	**NS**

[1]Treatments that share a common letter do not differ at the 5% significance level. Data used at four decimal places, but rounded up for the table.

The increase in plant counts and lower soil-borne disease in treated plots compared to the untreated plots was consistent with early differences in the vegetative indices across the plots observed by NDVI (and NDRE) imaging, with plots sown with bare seed having a lower index value than plots sown with treated seed. Differences in the vegetative index as a result of fungicide or biological seed treatment became less distinct at later scanning dates.

Early protection afforded by the seed treatments appeared to result in greater pea seed yields, but did not change the 100 seed weight of the seed, suggesting seed fill was consistent across all treatments.

Overall, these data suggest that fungicide and *Trichoderma* seed treatments provided protection or stimulated improved growth early in the season (prior to establishment) rather than later, which directly influenced yield but not quality. This was consistent with a lower incidence of both *Aphanomyces* and *Fusarium* root rots in crops sown with treated seed.

Summary

Trichoderma seed treatments reduced the incidence of both *Aphanomyces* and *Fusarium* root rots and increased yield over the untreated control. Alone, the *Trichoderma* treatments did not significantly out-yield the fungicide treatment, but the treatments with both *Trichoderma* and Wakil-XL produced significantly higher yield than the fungicide alone. All seed treatments had better establishment than the control.

Further trials will be required to confirm the observations in this trial.

Desiccation options for white clover seedcrops

Project code H19-07-00

Duration Year 5 of 5 (season 2022-23)

Authors Sean Weith, Owen Gibson and Richard Chynoweth (FAR)

Location Barrhill, Mid Canterbury (GPS: -43.691105, 171.8444416)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Grant Maw (trial host); NZ Arable (trial operator)

Key points

- Products such as Buster® (a.i. 200 g/L glufosinate-ammonium, Group 10 Herbicide), Gramoxone®250 (a.i. 250 g/L paraquat, Group 22 Herbicide) and Versatill™PowerFlo™ (600g/L clopyralid, Group 4 Herbicide) can be used as alternative desiccants to Reglone® (active ingredient (a.i.) 200 g/L diquat, Group 22 Herbicide) in white clover seed crops, but at the expense of post-harvest re-growth for grazing.
- Among the various desiccant options, the most cost-effective treatment was mixing Gramoxone®250 with Reglone®. The most expensive options were treatments containing either Buster® or the commercial standard program of Agritone®750, followed by Reglone®.
- None of the treatments had any adverse effects on dry matter, seed yield or seed germination.

Background

White clover (*Trifolium repens*) seed crops in New Zealand must be desiccated to ensure efficient harvest. Currently, growers rely heavily on diquat by using products such as Reglone® (active ingredient (a.i.) 200 g/L diquat, Group 22 Herbicide) for this purpose. In a normal season, where total dry matter (DM) production does not exceed approximately 4000 kg/ha, growers use single or double applications of diquat to desiccate their white clover crops. However, in wetter seasons or situations of high soil fertility, when crops can have up to 9000 kg/ha DM, this method does not always achieve satisfactory dry down due to canopy penetration being difficult. As a result, some growers use MCPA-based products like Agritone®750 (750 g/L MCPA, Group 4 Herbicide) as a pre-desiccant treatment, which can help to fold leaves and facilitate the penetration of diquat. While this approach can be effective, it can also lead to clover plants twisting and canopy collapse, making desiccation from subsequent applications difficult. Furthermore, if applied too early, MCPA can also disrupt seed fill which can reduce seed yield and thousand seed weight (TSW).

The European ban on diquat, means that white clover seed lines intended for export must be free of diquat residues. Furthermore, diquat is among the chemicals being evaluated by the New Zealand Environmental Protection Agency (EPA), necessitating the exploration of alternative chemical options to desiccate white clover crops. White clover seed crops are commonly used for lamb grazing on many New Zealand farms, and therefore any substitute for diquat must be able to desiccate the crop effectively whilst still permitting a degree of re-growth to support livestock grazing.

In the past four years, the Foundation for Arable Research (FAR) has conducted numerous trials to evaluate pre-desiccants and alternatives to diquat. Greenman™ (a.i. 650 g/L fatty acids, Group 0) has shown promise, but was effective at desiccating white clover only at higher concentrations (8% v/v) than recommended (2-4% v/v). A trial conducted during the 2021-22 season reported that Buster® (a.i. 200 g/L glufosinate-ammonium, Group 10 Herbicide), Granstar® (a.i. 750 g/kg tribenuron-methyl, Group 2 Herbicide), and Deal 510 (a.i. 510 g/L glyphosate, Group 9 Herbicide) were effective options for desiccation of white clover crops, especially in situations where the crops are bulky or where re-growth from a Reglone® treatment is problematic under damp conditions (Gibson & Rolston, 2021). However, the limited post-harvest re-growth from these treatments was identified as an issue if grazing or second-year crops were important.

This trial was the fifth in a series of trials that were established to explore alternative desiccation options for white clover seed crops to facilitate the development of new programmes that are suitable for use in future New Zealand white clover seed system.

Methods

A small plot trial was established in a commercial white clover (cv. Romena) seed crop during the 2022-23 season in Barrhill, Mid Canterbury (-43.691105, 171.8444416) prior to desiccation of the commercial paddock. Table 1 presents the trial's 15 treatments, which were arranged in a complete randomised experimental design with four replicates. The design incorporated two blocking factors (replicate and block) and featured doubly resolvable rows and columns. This arrangement resulted in a total of 60 plots, distributed across 30 rows and two columns. Treatment plots were 2.5 m wide and 10 m long (25 m^2). All treatments containing either Reglone® or Deal 510 were applied with either 25 mL/ 100 L of Contact™Xcel surfactant (980 g/L linear alcohol ethoxylate) or 1 mL/L Pulse®Penetrant (800 g/L organosilicone modified polydimethyl siloxane), respectively, as per label instructions. Treatments were applied at three different timings, either 21 days before harvest (DBH) (2 February 2023), 12 DBH (9 February 2023) or 4 DBH (17 February 2023). Treatments were applied using an electric pump pressurised backpack sprayer with a 2.5 m spray boom fitted with 5 x 03 Flat Fan Teejet® nozzles delivering a water rate of 300 L/ha at a boom operating pressure of 210 kPa.

Treatment plots were assessed for time to brown off (greenness) using a Crop Circle™ (Holland Scientific, Lincoln, NE, USA) normalised difference vegetation index (NDVI) scanner at 21, 16, 13, 10, 7 and 1 day before harvest. Due to an accidental application of Reglone® by the grower on the 12 February 2023, plots 101, 102, 301 and 302 were excluded from the NDVI dataset. Harvest fresh and dry weights were determined for each treatment plot by collecting a representative cut using a 0.3 m x 0.3 m quadrat on the 21 February 2023. Samples were weighed using a precision balance with two decimal places before and after drying in paper bags at 105°C to determine fresh and dry weight, respectively. Percentage dry matter (DM) was calculated post-weighing of samples by dividing the fresh weight by the amount of dry weight. Seed yield was obtained by harvesting all treatment plots with a Wintersteiger Classic Plus plot harvester on 21 February 2023. The ease of harvest for each plot was recorded using a scale of 1 to 10, with 1 indicating easy and 10 indicating difficult, as reported by the trial contractors at the time of harvest. Seed germination tests were completed by New Zealand Seedlab on 29 May 2023 using a 4-day pre-germination chilling period at 5-10°C and a final germination count after 10-days at 20-30°C. The percentage seed germination per treatment was calculated as the percentage of germinated seed + percentage hard seed. To calculate the margin-over-cost (MoC), the treatment cost per hectare and cost per application were subtracted from the revenue generated per hectare for each plot. Calculations were based on a grower's seed price of $6.50/kg. The analyses were performed using the R software programming language (R Core Team, 2022). All data, excluding MoC, were analysed using a one-way linear mixed model analysis of variance (ANOVA) using the residual maximum likelihood (REML) procedure with treatment as a fixed effect and replicate, column and row as random effects.

Results and Discussion

The percentage DM results, presented in Table 1, show that there were no significant differences ($P \geq 0.05$) between any of the desiccation treatments. The seed yields of white clover plants in the 15 direct-headed treatments averaged 452 kg/ha, with no significant differences ($P \geq 0.05$) between them (Table 1), which was comparable to the findings from a trial conducted in the 2019-20 season (Chynoweth *et al.,* 2020). Overall, these results suggested that none of the active ingredients contained in any of the applied treatments had any adverse effects on the DM partitioning in white clover plants.

The quickest time to brownout was achieved by treatments containing either Buster® (Treatments 8 and 9), Versatill™PowerFlo™ (Treatment 13) or Gramoxone®250 (Treatments 14 and 15), compared with the commercial standard of Agritone®750 applied at 2 L/ha followed by Reglone® applied 12 and

4 DBH (Figure 1). While Reglone® applied at 21 DBH and 4 DBH (Treatment 5) resulted in rapid brownout after application, it also greened up quickly. Gramoxone®250 tank mixed with Reglone® (Treatment 15) provided the most cost-effective desiccant option, costing $164 per hectare, whilst Buster® followed by a separate application of Reglone® (Treatment 9) was the most expensive, costing $391 per hectare (Table A1). However, it is important to note that the level of desiccation achieved by products such as Buster® and Versatill™PowerFlo™ was achieved at the expense of post-harvest re-growth for grazing. It should also be noted that this study's findings apply solely to a dry season climate. As a result, it is difficult to anticipate how these findings might change in a wet season (defined as receiving more than 100 mm of rainfall per month).

Seed germination tests following desiccant application showed that none of the translocation herbicide treatments (e.g. Deal 510 and Versatill™PowerFlo™), had any negative effects on germination (Table 1). The margin-over-herbicide cost (Table 1) showed there was a negligible economic response in white clover seed yields.

Summary

This field trial showed that there are several alternative chemical options available for pre-desiccating or desiccating white clover seed crops. Products such as Buster®, Gramoxone®250 and Versatill™PowerFlo™ offer promising options for application prior to Reglone® on white clover seed crops, however, post-harvest re-growth for grazing was compromised. None of the treatments had any adverse effects on DM, seed yield or seed germination. The quickest time to brownout was achieved with Buster®, Versatill™PowerFlo™ and Gramoxone®250 relative to the commercial standard treatments of Agritone®750 followed by Reglone®. Among the various desiccant options, the most cost-effective was mixing Gramoxone®250 with Reglone®, while the most expensive options were treatments containing either Buster® or the commercial standard program of Agritone®750, combined with Reglone®. The findings of this study were obtained under optimal harvest conditions, and as such, additional research is necessary to ascertain the impact of wetter climate conditions on the evaluated desiccation options.

References

Chynoweth, R, Washington, H, Gunnarsson, M, and Rolston, R (2020). Desiccation options for white clover seed harvest. *FAR Research Results 2019/20*: 20-24.

Gibson, O, and Rolston, P. (2021). White clover harvest management *SIRC Annul Research Report 2020/21*.

R Core Team (2022). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Table 1. Harvest fresh and dry weight, percentage dry matter (DM) and seed yield from white clover (*Trifolium repens*) (cv. Romena) plots treated with 15 different chemical desiccation treatments in a trial conducted at Barrhill, Mid Canterbury during the 2022-23 season. Seed yields are estimated machine dressed based on field dressed seed yields assuming a 20% dressing loss.

Treatment No.	**Product, Application Rate and Timing[1,2]**			**Percentage DM (%)**	**Seed yield (kg/ha)**	**Seed Germination[3] (%)**
	21 days before harvest 2 February 2023	**12 days before harvest 9 February 2023**	**4 days before harvest 17 February 2023**			
1			Reglone® (4 L/ha)	26.2 a	497 a	97.7 a
2			Reglone® (5 L/ha)	23.4 a	479 a	96.5 ab
3		Reglone® (2 L/ha)	Reglone® (3 L/ha)	26.2 a	466 a	93.6 ab
4		Reglone® (3 L/ha)	Reglone® (2 L/ha)	23.9 a	448 a	96.8 ab
5	Reglone® (2 L/ha)		Reglone® (4 L/ha)	23.3 a	403 a	93.7 ab
6	Agritone®750 (2 L/ha)		Reglone® (4 L/ha)	23.4 a	440 a	97.1 ab
7	Agritone®750 (2 L/ha)	Reglone® (3 L/ha)	Reglone® (2 L/ha)	27.0 a	487 a	98.2 a
8	Buster® (5 L/ha)			27.2 a	410 a	96.1 ab
9		Buster® (5 L/ha)	Reglone® (4 L/ha)	23.6 a	436 a	97.5 a
10	Granstar® (40 g/ha)		Reglone® (4 L/ha)	27.7 a	390 a	91.7 b
11	Agritone®750 (2 L/ha)	Deal 510 (2.1 L/ha)	Reglone® (4 L/ha)	21.9 a	520 a	98.0 a
12	Deal 510 (2.1 L/ha)		Reglone® (4 L/ha)	24.5 a	414 a	96.9 ab
13	Versatill™PowerFlo™ (0.35 L/ha)		Reglone® (4 L/ha)	29.0 a	480 a	93.7 ab
14		Reglone® (3 L/ha)	Gramoxone®250 (1.5 L/ha)	28.3 a	438 a	96.6 ab
15		Gramoxone®250 (1.5 L/ha) + Reglone® (3 L/ha)		21.9 a	471 a	95.9 ab
			LSD ($P \leq 0.05$)	**10.3**	**191.7**	**5.6**
			***P* value**	**0.68**	**0.26**	**0.21**

Letters indicate significant difference at $P \leq 0.05$ according to Least Significant Difference (LSD)

[1] All product applied with additives as per label recommendations.

[2] Agritone®750 (750 g/L MCPA, Group 4 Herbicide); Buster® (a.i. 200 g/L glufosinate-ammonium, Group 10 Herbicide); Gramoxone®250 (a.i. 250 g/L paraquat, Group 22 Herbicide); Granstar® (a.i. 750 g/kg tribenuron methyl, Group 2 Herbicide); Reglone® (a.i. 200 g/L diquat, Group 22 Herbicide); Deal 510 (a.i. 510 g/L glyphosate, Group 9 Herbicide); Versatill™PowerFlo™ (600g/L clopyralid, Group 4 Herbicide).[3] Seed germination = percentage of germinated seeds + percentage hard seed.

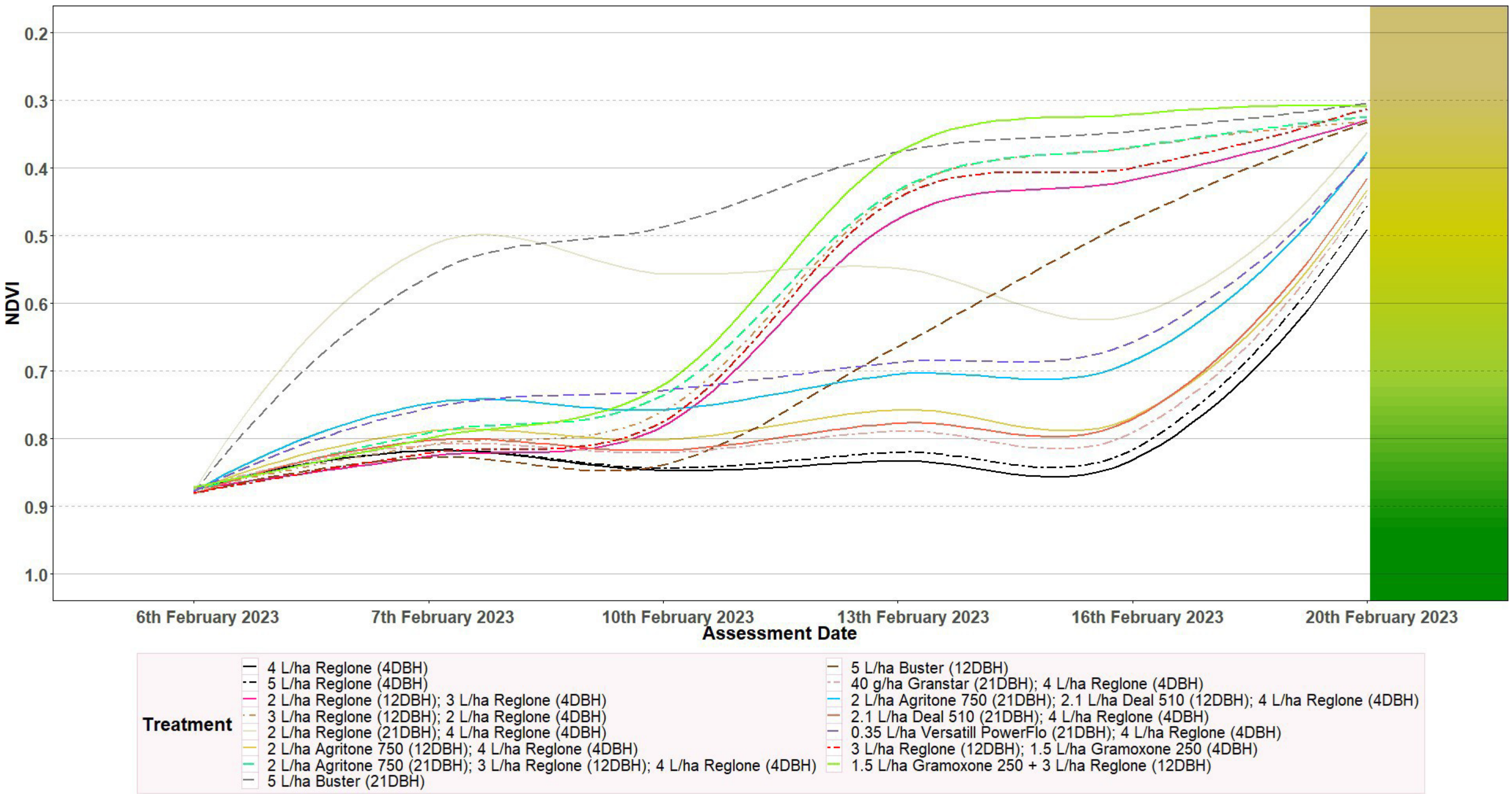

Figure 1. Time to brown off indicated by greenness (NDVI) of white clover (*Trifolium repens*) (cv. Romena) plots treated with 15 different chemical desiccation treatments at six assessment timings in a trial conducted at Barrhill, Mid Canterbury during the 2022-23 season. Application timings of treatments are indicated as 21 days before harvest (DBH) (2 February 2023), 12DBH (9 February 2023) or 4DBH (17 February 2023).

Appendix

Table A1: Cost per hectare per chemical, cost per application, cost per hectare and margin-over-cost (MoC) for 15 different chemical desiccation treatments.

Treatment	21 days before harvest	12 days before harvest	4 days before harvest	*$/ha Chem*	*$/app**	Cost/ha	MoC** ($/ha)
1			Reglone® (4 L/ha)	138	30	168	3020 ab
2			Reglone® (5 L/ha)	172	30	203	2901 abc
3		Reglone® (2 L/ha)	Reglone® (3 L/ha)	172	60	233	2770 abc
4		Reglone® (3 L/ha)	Reglone® (2 L/ha)	172	60	233	2675 abc
5	Reglone® (2 L/ha)		Reglone® (4 L/ha)	207	60	267	2346 c
6	Agritone®750 (2 L/ha)		Reglone® (4 L/ha)	187	60	248	2631 abc
7	Agritone®750 (2 L/ha)	Reglone® (3 L/ha)	Reglone® (2 L/ha)	222	90	312	2901 abc
8	Buster® (5 L/ha)			192	30	223	2429 abc
9		Buster® (5 L/ha)	Reglone® (4 L/ha)	330	60	391	2458 abc
10	Granstar® (40 g/ha)		Reglone® (4 L/ha)	165	60	226	2308 c
11	Agritone®750 (2 L/ha)	Deal 510 (2.1 L/ha)	Reglone® (4 L/ha)	215	90	306	3073 b
12	Deal 510 (2.1 L/ha)		Reglone® (4 L/ha)	166	60	226	2426 abc
13	Versatill™PowerFlo™ (0.35 L/ha)		Reglone® (4 L/ha)	180	60	240	2893 abc
14		Reglone® (3 L/ha)	Gramoxone®250 (1.5 L/ha)	134	60	194	2675 abc
15		Gramoxone®250 (1.5 L/ha) + Reglone® (3 L/ha)		134	30	164	2899 abc

Product Name	Cost per Litre or gram ($) ***
Reglone®	34.5
Buster®	38.5
Gramoxone	20.4
Agritone®750	24.8
Deal 510	13.4
Versatill™PowerFlo™	120.7
Granstar®	0.69

LSD (P≤0.05)	635
P value	<0.001

Letters indicate significant difference at P≤0.05 according to Least Significant Difference (LSD)

* Price per application is based on standard FAR operating costs

** MoC, margin-over-herbicide cost was calculated based on average cocksfoot seed price at harvest of $6.50 per kg (effective April 2023).

***MoC for treatments were calculated based on product price per litre including adjuvant prices of $25.3/L for Contact™Xcel or $39.55/L for Pulse®Penetrant.

Plantain response to spring nitrogen

Project Code H19-16-00

Author Owen Gibson, Phil Rolston (FAR)

Duration Year 2 of 3 (season 2021-22)

Location Southbridge (43°47'28.5"S 172°14'54.4"E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator)

Key points

- Spring applied nitrogen (N) had no effect on plantain seed yield, dry matter or seed head number.
- The absence of a N response in this trial was caused by a high background fertility in the paddock compounded by the application of N fertiliser, which led to a minimum N supply in excess of 177 kg/ha N.
- Plantain did show a strong and persistent uptake of N in response to increasing N supply, despite showing no response in seed yield or dry matter. This confirmed that plantain can act as an effective reservoir of N even in highly fertile environments.
- An estimate of potentially mineralizable N would have enabled a more accurate measure of N supply in this trial, which would have helped to gain a more accurate understanding of the optimum N supply required for plantain seed production.

Background

Plantago, is a versatile and widely distributed plant genus that includes several species. In New Zealand, *Plantago lanceolata* is the most common species found in both agricultural and natural ecosystems. These plants have gained significant attention in recent years because of their potential to aid nitrogen (N) management and environmental sustainability in pasture-based systems.

N is an essential nutrient for plant growth, but its excessive use in agriculture can lead to environmental pollution, including water contamination and greenhouse gas emissions. Therefore, finding effective strategies for N management is crucial to more sustainable farming practices. Plantain has shown potential for nitrogen management because its thick fibrous root system as well as its tap root allowing access to N in deeper soil layers. This ability to capture N further down in the profile has the potential to reduce leaching and run-off.

In New Zealand, where N and nitrous oxide emissions are increasingly regulated, incorporating plantain into farming systems has become of interest. This project aims to improve the agronomy of plantain seed production by identifying optimal biological and economic N application rates.

Methods

A randomised complete block trial was established in a commercial paddock of first-year 'Boston' plantain near Southbridge (43°47'28.5"S 172°14'54.4"E) in the 2021-22 season. The trial consisted of six nitrogen treatments and four replicates (Table 1).

Soil samples were collected from the trial area to test for mineral N at 0-30 cm (27 kg N/ha available in 0-30 cm) and at 30-60 cm (74 kg/N/ha) at the start of the trial (just prior to 1 September). All agronomic inputs except N were applied by the farmer as standard paddock management. Prior to the start of the trial, the farmer applied 200 kg/ha Cropzeal 16N (15% N, 8% P, 10% K and 8.6% S) to the paddock including the trial area. The additional 30 kg/N was added to the total available N (Mineral N and soil N) for all subsequent interpretation. N was applied in the form of SustaiN® by individually spreading a set amount evenly over each plot by hand. Mineralisable N was not measured.

Plant biomass was measured on two occasions during the season: at flowering on 13 December 2021 and pre-harvest on 25 February 2022. A 50 cm x 50 cm (0.25 cm^2) quadrat was cut from the centre of each plot. At each cut, seed head numbers were counted and converted to heads/m^2. The samples were dried for 48 h at 70°C in Contherm 2000 ovens to calculate dry matter per hectare before being sent to Hill Laboratories for N concentration (%) testing.

Plots were windrowed on 4 March 2021 by a modified John Deere small plot windrower, and the trial was machine-harvested on 11 March 2021 using a Wintersteiger nursery master elite plot combine. A small sub-sample of harvested seed was retained for quality testing.

Statistical analysis was by general analysis of variance (ANOVA) and regression, using Genstat® 19th edition (VSN International Ltd, UK) and Microsoft excel 2019 (version 1808).

Table 1. Spring nitrogen treatments and application dates in a plantain cv. Boston crop grown at Southbridge in the 2021-2022 season.

Treatment No.	Date and quantity of Nitrogen (kg/ha) applied or in the soil			
	18.10.21	**11.11.21**	**Total spring applied N**	**Total N* (soil MinN plus applied N)**
1	0	0	0	131
2	20	20	40	171
3	40	40	80	211
4	60	60	120	251
5	80	80	160	291
6	100	100	200	331

*Total N supply was the sum of soil MinN supply at 0-60 cm, 30 kg/N/ha applied by the farmer prior to the commencement of the trial and various Spring N treatments applied as SustaiN® (45.9% N).

Results and Discussion

Seed yield did not respond to increasing N supply because of high background fertility across the trial.

The seed yield ranged from 1541 to 1782 kg/ha for a first-year plantain crop grown in 2021-22 (Table 2). The application of spring N resulted in no difference in seed head counts or seed yield. The lack of response to spring fertiliser N was likely a result of the high fertility background in the trial as a result of the high quantity of pre-trial N (131 kg/ha) in the system plus the additional 46 to 92 kg/ha mineralisable N that became available during the season. We estimate the mineralizable N to have been between 46 to 92 kg/ha, as total N uptake in the crop not supplied with additional fertiliser N was 177 kg N/ha (Table 2) suggesting 46 kg/h mineralizable N was taken up in the plants. In addition, the intercept of the line in N dose response curve in Figure 2 indicates that the untreated crop had access to 92 kg/ha mineralisable N during the season.

The lack of a response to fertiliser N in this trial was in contrast to the increase in seed yield in a similar trial in a second-year plantain crop the previous year, when N was supplied up to a total N of 139 kg/ha (mineral plus fertiliser supply) (Rolston et al. 2020). The different response can be explained based on the calculations above, which suggest that even the untreated control crop had access to between 177 and 269 kg/N, a level of background fertility above the ceiling for a response in plantain seed yield.

There was no effect of applied fertiliser N on margin-over-cost despite there being no seed yield response to applied N (Table 2). This was unexpected, but was probably a result of the very high variability within treatments (as demonstrated by the high coefficient of variation for this trial (CV%=212) resulting from high background N supplies, which caused noticeable lodging across the trial.

Biomass did not respond to increasing N supply

The application of spring fertiliser N also resulted in no difference in biomass (Table 2). Again, this was in contrast to the response in dry matter the previous year, which continued even when a maximum of 310 kg/ha total N was supplied (Rolston et al. 2020). The 2021-22 season meant that plantain was harvested one month later than it would otherwise have been harvested. During this time, the crop probably continued to uptake N and increase in biomass, which may have resulted in the response being saturated (reaching a maximum biomass, which was not constrained by differences in N supply).

Table 2. Total Nitrogen (N) supply, herbage mass at mid-seed fill, seed head density, pre-harvest N-uptake (25 February) seed yield and margin-over-cost for plantain 'Boston' grown at Southbridge in the 2021-22 season following application of different amounts of N fertiliser.

Treatment No.	Total N supply[1] (kg N/ha)	Mass (DM kg/ha)	Seed heads (m^2)	N uptake[2] (kg N/ha)	Seed yield (kg/ha)	MOC[2] ($/ha)
1	131	19850	1170	177	1657	0
2	171	19950	1035	205	1782	360
3	211	18650	1205	215	1541	-680
4	251	20300	1210	271	1591	-570
5	291	18980	1315	253	1639	-450
6	331	20720	1170	316	1564	-840
	P value	**0.965**	**0.925**	**0.174**	**0.561**	**0.285**

[1] Total N supply was the sum of soil MinN supply at 0-60 cm, 30 kg/N/ha applied by the farmer prior to the commencement of the trial and various Spring N treatments applied as SustaiN® (45.9% N). [2] N uptake is calculated by percent plant nitrogen content of dry matter (DM kg/ha) (data not shown). [2] MOC, margin-over-cost calculated using a plantain seed price = $4/kg, SustaiN® price = $929/t.

Plantain showed increasing N uptake even in response to high N supply

Plantain did show a strong and persistent uptake of N in response to increasing N supply (up to the maximum of 331 kg/ha N in this trial) (Table 2; Figure 1), despite showing no response in seed yield or dry matter. This result was consistent with previous research, including FAR's N response trial in the experimental second-year plantain crop the previous year, which had a maximum N supply of 310 kg/ha N (Rolston et al. 2020). The linear response to N supply in these two trials confirmed that plantain can act as an effective reservoir of N even in highly fertile environments, its capacity to uptake N providing an opportunity to reduce nitrate leaching and run-off from pastoral and arable systems. The only challenge with this scenario is if the crop is grazed then the animals may return the N to the soil.

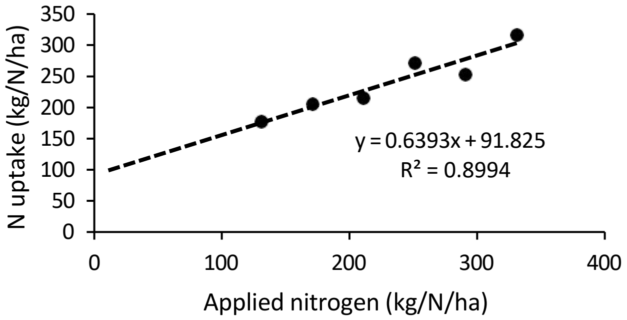

Figure 1. Pre-harvest nitrogen (N) uptake as measured on 25 February 2022 in a plantain 'Boston' seed crop grown at Southbridge following application of different quantities of N.

Summary

Plantain seed yield did not respond to the high N supply in this trial, consistent with the optimum total N of 139 kg N/ha (MinN plus fertiliser) observed in a previous trial. Given the previous trial also had mineralisable N become available (predicted to be approximately 40 kg/ha N) (Rolston et al. 2020), the likely optimum for total N sits somewhere close to 180 kg/ha N above which seed yield will plateau.

Despite seed yield plateauing at less than 200 kg/ha N, plantain has the capacity to act as a reservoir for much greater quantities of N, providing opportunities to use this crop to manage environmental risks associated with N leaching and run-off. However, grazing animals on the crop may return the N to the soil.

Further research will be needed to need to be conducted under lower fertility conditions and will also need to include an estimate of potentially mineralisable N to calculate accurately the optimum N required for seed production.

Reference

Rolston P, Gibson O, and Chynoweth R (2021). Plantain grown for seed: response to spring nitrogen, *SIRC Research Results 2020/21*: Pp 54-56.

Appendix 1

Trial management details

Sowing date:	5 February 2021 at 5 kg/ha
Soil mineral N:	1 September – 101 kg/ha N (27 kg/ha N (0-30 cm) 74 kg/ha N (30-60 cm))
Post Winter N:	5 September – 30 kg/ha N (200 kg Crop Zeal 16N (33 kg/N) + 10 kg Borox + 7 kg Copper)
Spring N:	As per Table 1
Windrowing:	4 March 2022
Harvest:	11 March 2022

Control of Phomopsis stalk disease in plantain grown for seed

Project Code H19-16-00

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

Duration Year 4 of 4 (season 2021-22)

Location Southbridge, Mid Canterbury (GPS: 43°47'25.8"S 172°14'55.1"E)

Funding Seed Industry Research Centre (SIRC)

Acknowledgements NZ Arable (trial operator), Aaron Lill (trial host)

Key points

- All fungicide treatments reduced Phomopsis stalk disease and increased yields and profitability compared to the untreated control.
- Prothioconazole (e.g. Proline®, Group 3) applied alone provided equivalent disease control and yield increases to applications where Prothioconazole was included in a mix with other mode-of-action fungicides.

Background

Phomopsis stalk disease, caused by *Phomopsis subordinaria* (Figure 1), results in the collapse of stems below the seed head of plantain (*Plantago lanceolata*) and commonly seed heads that produce no saleable seed. Disease control by growers typically relies on the active ingredient (a.i.) prothioconazole (e.g. Proline® or Prosaro®, Group 3). This project was developed to understand the impact of Phomopsis stalk disease on seed yield of plantain and to identify additional management options.

In the previous two seasons of trials, the application of Proline® either alone or in a tank mix has increased seed yield. In 2019-20, seed yields were increased by an average of 24 % (480 kg extra seed/ha) when Proline® was used either alone or in a mixture, with no differences among treatments (Gibson et al. 2021). During the 2020-21 season, a trial in a second-year plantain crop showed that seed yield was increased by 590 % with the application of Proline® (620 kg extra seed/ha) (Gibson et al. 2021).

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

The trial was established in an irrigated commercial first-year plantain seed crop, cultivar Boston, located near Southbridge, Canterbury. The trial was a randomised complete block design with five treatments and four replicates (Table 1) on a Flaxton deep silt soil type.

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, Group 11), Proline® (a.i. 250 g/L prothioconazole, Group 3), Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3), and Seguris® flexi (a.i. 125 g/L isopyrazam, Group 7) applied twice either alone or in mixtures at mid-flowering on 19 November 2021 and repeated 14 days later (Table 1). Disease assessments were made by sampling 50 heads per plot on 17 January 2022, and separating them into those with disease, non-diseased and immature heads. The data presented on percent diseased heads excluded the immature heads.

Thousand seed weight (TSW) was measured by counting 200 seeds and multiplying by five. The machine-dressed sample was further cleaned by using a Dekota blower to remove light seed. The sample was then weighed on a Vibra HT balance capable of 0.0001 g accuracy and converted to grams per thousand seeds. Results were analysed using Genstat®19th Edition (VSN 2019).

Margin-over-cost (MoC) relative to the untreated control yield was calculated for each treatment, based on a grower's price of $4.00/kg for seed, the fungicide costs and $30/ha per application cost.

Results and Discussion

The application of a two fungicides 14 days apart increased seed yield above the untreated control. There was no difference among fungicide treatments applied. All fungicide treatments resulted in an increase in MOC compared with the untreated (Table 1). Disease scores conducted 27 January 2022 indicated that Phomopsis stalk disease influenced seed yield (Figure 2). However, the variation within treatments and relatively low levels of *Phomopsis* (4-14%) did not allow the seed yield between fungicide treatments to be separated.

Table 1. Seed yield of plantain, cultivar Boston following treatment with five fungicide programmes grown near Southbridge, Mid Canterbury in the 2021-22 season.

	Fungicide treatment applied mid flowering + 14 days [1]	Seed yield (Kg/ha)	Mature infected heads (%)	TSW mean (g)	MoC[3] ($/ha)
1	nil	828	27	1.46	0[2]
2	Proline® (0.8 L/ha)	1075	4.0	1.46	720
3	Proline® (0.8 L/ha) + Seguris® Flexi (0.6L/ha)	1184	13.5	1.56	1060
4	Proline® (0.8 L/ha) + Amistar® (0.5 L/ha)	1296	13.5	1.56	1610
5	Prosaro® (1 L/ha) + Amistar® (0.5 L/ha)	1191	6.5	1.54	1210
	Mean	**1115**	**12.8**	**1.52**	**1155**
	LSD (p=0.05)	**228**	**8.87**	**0.078**	**(992)**
	P value	**0.008**	**<0.001**	**0.018**	**0.301**
	CV (%)	**13.2**			

Note: Yellow indicates the treatments with greatest disease suppression, yield, thousand seed weight (TSW), and margin-over-cost (MoC).

[1]Mid flowering application dates – 19 November 2021, +14 days application date – 3 December 2021.

[2] Treatment 1 was excluded from the MOC analysis. LSD in brackets is unsupported.

[3] Plantain seed price: $4 kg, Proline® – $100/L, Seguris® Flexi - $100/L, Amistar® - $54/L, Prosaro® - $63/L.

All fungicide treatments resulted in an increase in MOC compared with the untreated (Table 1).

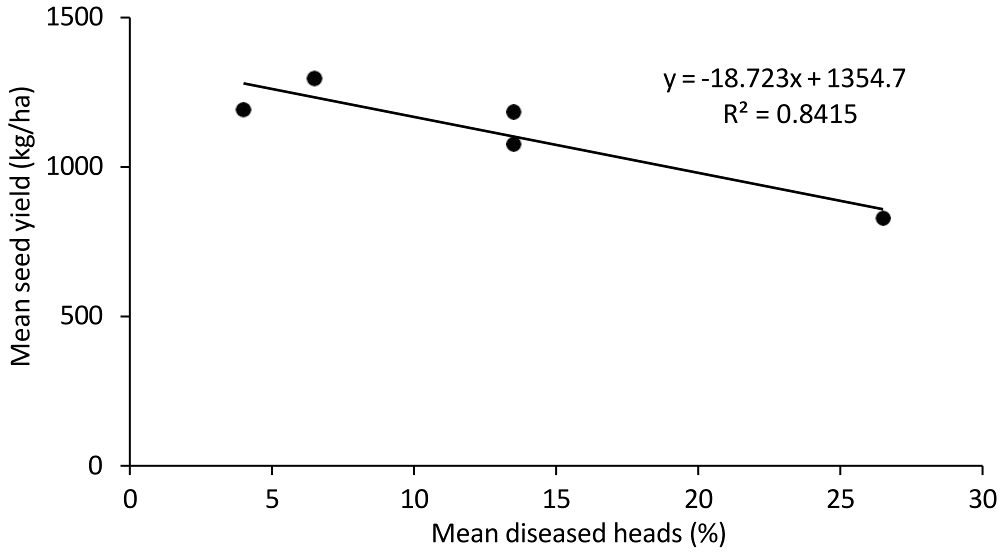

Figure 2. Mean diseased mature heads (%) infected in plantain cv. Boston with *Phomopsis* stalk disease following the application of five different fungicide treatments to a crop at Southbridge, Mid Canterbury in the 2021-2022 growing season.

Summary

Fungicide treatment reduced stalk disease and increased seed yields. Prothioconazole applied on its own or combined with a different mode-of-action resulted in a yield increase of 30 to 57 % compared with the untreated crop yield.

Appendix 1.

Trial Details

Sowing date	28 February 2021
Irrigation	3 applications: 42 mm total
Nitrogen	5 September 2021: 200 kg/ha Cropzeal 16N 3 November 2021: 100 kg/ha Sustain®
Windrowing	4 March 2022: with a modified 1.8 m John Deere windrower
Harvest	11 March 2022

References

Gibson, O, Rolston, P, and Chynoweth, R (2021). Control of Phomopsis stalk disease on two plantain cultivars grown for seed. *SIRC Research Results 2020/2021*. https://assets.far.org.nz/All-herbage-and-vegetable-seed-reports_2023-08-01-010315_rrom.pdf

The effects of late clopyralid applications on red beet seed crops

Project code B20-01-00

Duration Year 1 of 3 (season 2021-22)

Authors Matilda Gunnarsson, Ben Harvey, Phil Rolston and Owen Gibson (FAR)

Location Southbridge, Mid-Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Rowan McFadden (trial host), James Taylor (South Pacific Seeds), NZ Arable (trial operator)

Key points

- Clopyralid (Mode-of-Action Group 4) herbicide was applied to a red beet seed crop at three different timings (11 or 21 October or 1 November 2021) at three rates (200, 350 or 500 mL/ha).
- No statistically significant differences were observed in seed yield, plant height, plant numbers or germination rate between the ten treatments, including those with late timings.

Background

New Zealand is the world's eighth largest exporter of vegetable seeds, of which red beet is a significant proportion. Clopyralid herbicide (Versatill™ PowerFlo™ and generics) is registered for use in beets (fodder beet) and is used in seed crops to control late emerging spring weeds including Californian thistle, other thistle species and yarrow. There is no information on late timing of application and the impacts on seed yield and seed quality.

Methods

The trial was conducted to quantify crop tolerance and effects of clopyralid (Mode-of-Action Group 4) on seed yield and seed quality**.** The trial was set up as a randomized complete block design with four replicates. Each plot had 16 rows, (one female bed (8 m) x 3.6 m wide). The trial included three rates of Versatill™ PowerFlo™ (200 mL, 350 mL and 500 mL/ha) with three application timings, 10 days apart, starting 11 October 2022.

Plant counts were undertaken in November 2021, plants heights were measured at flowering. Field-dressed yields as well as germination rates were recorded. Plots were harvested on 1 March, 2022 using a Sampo plot combine with vertical side knives cutting 2.1 m x 8 m plots. Seed yields were adjusted to 12 % seed moisture (Table 1).

Results and Discussion

No statistically significant differences were observed in plant numbers, field-dressed seed yield, plant height, or germination rate after application of the clopyralid herbicide at different rates and application timings, including those considered later in the season.

The seed yields presented were before machine-dressing and so are potentially higher than would be achieved in a commercial setting (Table 1). Furthermore, germination tests were conducted on a bulk sample rather than following the commercial standard, which involves separating the seed by size and testing only the larger seeds for germination. To assess the impact of late applications of clopyralid on seed yield and quality more accurately, the trial will be repeated, incorporating changes in the recording and testing procedures to reflect commercial practice.

Table 1. Field-dressed (FD) seed yield, adjusted to 12 % seed moisture content, in a red beet seed crop grown near Southbridge in the 2021-22 growing season following three different treatments of Clopyralid (Versatill™ Powerflo™, 600 g/L) (Group 4) at three different timings.

Treatment No.	Herbicide application rate and timing			FD Seed yield (kg/ha)
	11 October 2021	21 October 2021	1 November 2021	
1	nil			1094
2	Versatill™PowerFlo™ (200 mL)			1114
3	Versatill™PowerFlo™ (350 mL)			1027
4	Versatill™PowerFlo™ (500 mL)			1076
5		Versatill™PowerFlo™ (200 mL)		1115
6		Versatill™PowerFlo™ (350 mL)		1107
7		Versatill™PowerFlo™ (500 mL)		1178
8			Versatill™PowerFlo™ (200 mL)	1216
9			Versatill™PowerFlo™ (350 mL)	1221
10			Versatill™PowerFlo™ (500 mL)	1188
			LSD (p=0.05)	**215**
			P value	**Not Significant**
			CV (%)	**13.1**

Alternatives to diquat for pre-harvest seed crop desiccation of red beet

Project code	B20-02-01
Duration	Year 2 of 3 (season 2021-22)
Authors	Ben Harvey, Matilda Gunnarsson, Phil Rolston and Owen Gibson (FAR)
Location	Southbridge, Mid-Canterbury
Funding	Agmardt and Seed Industry Research Centre (SIRC)
Acknowledgements	Nigel Greenwood (trial host), James Taylor (South Pacific Seeds), NZ Arable (trial operator)

Key points

- Five alternatives to diquat for pre-harvest desiccation of red beet (*Beta vulgaris*) seed crops were tested.
- Diquat remained the fastest desiccant of those tested, but alternative chemical desiccants did not reduce seed yield in the trial.
- Organic bioherbicide GreenMan™ was also effective, but remains prohibitively expensive as a desiccant when compared with other alternatives.

Background

New Zealand is the world's eighth largest exporter of vegetable seeds, which includes Red beet seed. Current practice for Red beet seed growers in New Zealand is to desiccate the crop before harvest with a chemical desiccant, diquat dibromide (Mode-of-Action Group 22). Desiccation with diquat improves seed harvest operations.

Diquat has been withdrawn from approval in the European Union amid concerns surrounding its human and ecological toxicity (O.J. 2020). There also remain fears that diquat reduces seed quality, particularly germination (Miller 2002; Trivedi *et al.* 2010). If withdrawal occurred in New Zealand as a result of these challenges, Red beet seed growers would have no viable alternatives.

In Year 1 of this project, a trial was conducted to compare the efficacy of different chemical desiccants in beet seed crops and the impacts on seed yield (Rolston & Gibson, 2021). This trial identified potential alternatives to diquat, although they all had lower rates of "brown-out". This trial followed up on some of the more promising treatments, while also including "windrowing" as a non-chemical alternative.

Methods

A trial was conducted near Southbridge, Mid-Canterbury in a commercial hybrid red beet seed crop. All crop inputs, including pre-trial weed control, disease control, fertilisers and irrigation were managed by the grower.

All desiccant treatments (Table 1) were applied on February 28, 2022, using a 3 m hand-held boom sprayer fitted with six 110 02xr teejet nozzles at a water rate of 200 L/ha, except for GreenMan®, which was applied in 400 L/ha of water. The plot size was 8 m x 3 m, with treatments replicated four times in a randomised block design. The windrow treatment was simulated by cutting the entire plot by hand with hedge cutters the day before the desiccation treatments were applied.

Desiccation rates were taken by sampling plant stems by hand. Samples were taken by cutting the top 50 cm of the plant stem, including any branches, and oven-drying for 48 h at 70°C to calculate stem and seed moisture (Table 1). These samples were taken three- and six days post desiccation.

Plots were harvested on March 6, 2023 using a Sampo plot combine with vertical side knives cutting 2.1 m x 8 m plots. Seed yields were adjusted to 12 % seed moisture and to account for the absent male rows (Table 1).

Results and Discussion

The trial area was relatively uneven, with patches of bare ground in between plants. This, combined with the small plot size, led to a high amount of variability in the results as evidenced by the high CV (>20%) for seed yields. Nevertheless, results were very similar to those for the previous year's trial. In particular, diquat continued to provide the most rapid desiccation, with stem moisture down to 13.6 % after six days, compared with around 25 % for the second most effective desiccant (and 22.1% for the windrow treatment). Seed yields (p=0.178) and moisture contents (p=0.61) were comparable for all desiccant treatments.

Windrowing gave the lowest seed yield of all treatments (636 kg/ha), although it was not significantly different from the yield following diquat treatment. Windrowing also gave the lowest seed yield in the previous year's trial, which suggests that across seasons this may be a less effective approach to pre-harvest desiccation.

GreenMan™ was an effective organic desiccant for pre-harvest management of red beet seed in our trials. However, it is currently sold at a price that precludes its use in non-organic arable systems, so we will continue to monitor its price point.

Summary

If future use of diquat is restricted in New Zealand, FAR trials suggest effective chemical alternatives exist that are currently on the market. These alternatives do not compromise seed yield, but are not as rapid in their rate of desiccation as diquat.

References

Miller, T W (2002). Diquat used as a preharvest desiccant affects seed germination of spinach, table beet, and coriander. *HortScience* 37:1032-1034.

O. J. (2020). L234, 21.7.2020 Regulations. *Official journal of the European Union* (accessed from https://eur-lex.europa.eu/oj/direct-access.html on 13/06/2023).

Rolston, P, and Gibson, O (2021). Alternatives to diquat for pre-harvest seed crop desiccation of beets and radish. *SIRC Herbage and vegetable seed reports 2020-2021,* pp14-17.

Trivedi, R S, Townshend, J M, and Hampton, J G (2010). Can desiccant application improve carrot seed quality? *Agronomy New Zealand* 40: 187-196.

Table 1. Machine-dressed seed yield, stem moisture and seed moisture content for a red beet seed crop grown near Southbridge in the 2021-22 growing season following various pre-harvest desiccation treatments.

Treatment No.	Desiccant* and rate of application (applied 28 February 2023)	Stem moisture (%)		[1]Seed moisture (%)	Seed Yield (kg/ha)
		3 March 2023	6 March 2023		
1	Reglone® (3L/ha) + Contact™ XCEL	35.7	13.6	11.7	955
2	Buster® (5 L/ha)	40.6	25.4	11.6	1018
3	Buster® (5 L/ha) + Sharpen® (25 g/ha)	49.2	25.2	12.0	846
4	Hammer® Force (250 mL/ha) + Uptake™ (1 L/ha) + Contact™ XCEL	47.1	39.4	12.4	820
5	GreenMan™ (8% in 400 L/ha) + Expedient® (2 L/ha)	44.2	28.8	13.2	809
6	Windrow	23.3	22.1	12.2	636
	LSD (p=0.05)	**14.3**	**12.4**	**2.1**	**299**
	P value	**0.035**	**0.031**	**0.61**	**0.178**
	CV (%)	**-**	**-**	**-**	**23.4**

*Product active ingredients, concentrations and Mode of Action groups: Reglone® (200 g/L diquat, Group 22); Buster® (200 g/L glufosinate, Group 10); Sharpen® (700 g/kg salfufenacil, Group 14); Hammer® Force (240 g/L carfentrazone-ethyl, Group 14); GreenMan™ (650 g/L fatty acids, Group 0).

[1]seed yield adjusted to 12 % seed moisture content.

Nutrient uptake and nitrogen loss of seed crops

Project code B19-09-00

Duration Year 3 of 3 (season 2021-22)

Authors Alastair Wolfe (Ravensdown), Dirk Wallace, Richard Chynoweth, Turi McFarlane (FAR)

Location Mid Canterbury, South Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements Phil Rolston (SIRC), Ivan Lawrie (FAR), Jo Townshend (Midlands Seeds) and Keith Gundry (Pure Oil NZ).

Key points

- Crop-specific Overseer models modified the N loss number compared to the original proxy.
- Modified N loss numbers are to be expected as the crop-specific models control water and nitrogen uptake from the soil.
- Future work is needed to measure nitrate leaching under specific seed crops to validate the new crop models.

Background

Many Overseer users currently use proxies to model seed crop losses, as OverseerFM (at the time of project initiation) lacks seed crop-specific models. Yet, many seed crops are physiologically very different to the proxy selected and this may be under or over-estimating nitrate (and nutrient) losses from the rotation. The hypothesis for this project was that the use of a ryegrass seed proxy in Overseer under-estimates nitrate leaching compared to a crop-specific model.

Work in Year 2 of this project brought together industry experts and crop modellers to develop seed crop-specific models for Overseer. In Year 3, these new crop models were compared with the historic proxy.

Methods

Blocking and File Structure: The twelve crop types of interest were each modelled in their own Overseer Sci analysis file. Each file contained four blocks, two representing the old proxy modelling setting and the other two blocks representing the new crop input setting. Each crop type was modelled based on its place within a typical crop rotation and within both the Reporting Year and Year 1. Blocks were assigned an arbitrary area of 10ha each. All crops (new and proxy) that are normally grazed were modelled as grazed utilising 'Non farm animals -Sheep' within Overseer. All crops except Oilseed Rape were modelled with the location/climate data of the FAR, Chertsey site. Oilseed Rape was modelled with the St Andrews location/climate data. Yield outcomes and residue management from these blocks are presented in Table 1. Model input details including irrigation and nutrient input information are reported in the Appendix.

Soils: Soil types modelled were chosen as representative of common arable soils that the crops would be grown on. The soils chosen were Templeton silt loam at the Chertsey site and a Claremont at the St Andrews Site.

Stock management: Where crops would typically be grazed by stock (e.g. defoliation of ryegrass seed crop), this was modelled as 'Non farm animals', 'Sheep and/or deer' rather than entering specific stock numbers under the Animals tab. This approach was used in order to standardise modelling and reduce unintended interactions related to animal grazing.

***Block History**:* For the ten-year period prior to the reporting year, the number of years a block is in pasture needs to be entered into Overseer®FM. This provides an indication of how much nitrogen has accumulated in the soil under a grazed pastoral system, grass seed crops and from clover N fixation. A block history of 4 years in pasture was modelled for all crops, in order to represent a typical arable farm system. All crops were established with minimum tillage.

Table 1. Time to sowing, yield, harvest date and residue management for crops used to collect nutrient data.

Crop	Month Sown	Month Harvested	Yield (t/ha)	Residue management
Linseed	October	March	3	Baled
Radish seed	September	March	1.5	Retained
Red beet seed	March	April	1	Retained
Plantain seed	April	February	1.8	Grazed
Carrot seed	April	March	0.8	Retained
Oilseed Rape (Autumn sown)	April	February	4	Retained
Oilseed Rape (Spring sown)	September	February	4	Retained
Cocksfoot seed	February	January	1	Removed
Pak choi	October	February	2.5	Retained
Sunflowers	October	March	2.5	Retained
Rape seed	September	March	2.5	Grazed
Hemp fibre	November	March	10	Baled
Hemp seed	November	March	1	Baled
Autumn Wheat	April	February	1.1	Baled
Ryegrass seed	March	January	2.2	Baled/Grazed

Results and discussion

The application of crop-specific models rather than a proxy had an effect on the estimate of nitrogen leached when we considered the first-year planting data (Table 1). In some instances, this increase in leaching was significant, for example when the red beet seed model was used instead of the ryegrass seed proxy, leaching increased by 43% (modelled leaching increased from 56 kg N/ha to 80 kg N/ha) and 130% (modelled leaching increased from 23 kg N/ha to 53 kg N/ha) in the irrigated and dryland scenarios, respectively. Similarly, declines in N leaching were also observed, with losses from autumn sown oilseed rape being 48% and 53% less when the crop specific model was used instead of the proxy for irrigated and dryland scenarios, respectively. Table 2 and 3 detail the crop-specific outcomes for each of the new crop models tested in a year 1 and year 2 planting scenario respectively.

The changes in N loss were to be expected as the new crop models take account of canopy closure rates which impact transpiration and therefore drainage potential and nitrogen uptake which will alter the amount of N available to be leached. This study was a simple comparison and did not investigate the specific reasons why N loss increased or decreased when using the new crop-specific model or the previous crop proxy.

There are limited validation data sets available which have measured nitrate leaching from seed crops and therefore it is difficult to comment on the relative accuracy of the Overseer generated N loss numbers.

Table 2. First year planting data. Crop Rotation is the sequence of crops sown where AW = Autumn wheat, and RGS = Ryegrass seed. Old proxy N loss represents the modelled N leaching loss from the proxy that would be used prior to the development of a crop specific model. New crop N loss represents the modelled N leaching data from the newly developed crop specific model. Change from proxy represents an increase (+%) or decrease (-%) in N leaching loss when the new crop model is used.

		Old Proxy N loss (kg N/ha/yr)		New Crop N loss (kg N/ha/yr)		Change from Proxy (%)		Increase/Decrease in N loss	
Crop	**Crop Rotation***	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**
Linseed	Linseed>AW>RGS	39	20	47	24	21	20	Increase	Increase
Radish seed	Radish Seed>AW>RGS	64	29	61	36	-5	24	Decrease	Increase
Red beet seed	Redbeet seed>AW>RGS	56	23	80	53	43	130	Increase	Increase
Plantain seed	Plantain seed>AW>RGS	43	41	38	20	-12	-51	Decrease	Decrease
Carrot seed	Carrot seed>AW>RGS	67	29	74	52	10	79	Increase	Increase
Hemp seed (Oct sown)	Hemp seed>AW>RGS	76	61	86	57	13	-7	Increase	Decrease
Hemp seed (Nov sown)	Hemp seed>AW>RGS	71	52	83	47	17	-10	Increase	Decrease
Oilseed Rape (Aut sown)	Oilseed Rape>RGS	29	17	15	8	-48	-53	Decrease	Decrease
Oilseed Rape (Spr sown)	Oilseed Rape>AW>RGS	50	31	39	28	-22	-10	Decrease	Decrease
Cocksfoot seed	AW>Cocksfoot Seed	16	14	37	30	131	114	Increase	Increase
Pak choi seed	Pak Choi Seed>AW>RGS	71	40	56	34	-21	-15	Decrease	Decrease
Sunflower seed	Sunflower seed>AW>RGS	53	25	70	41	32	64	Increase	Increase
Rape seed	Rape seed>AW>RGS	61	48	49	26	-20	-46	Decrease	Decrease
Hemp fibre (Oct sown)	Hemp fibre>AW>RGS	31	31	54	54	74	74	Increase	Increase
Hemp fibre (Nov sown)	Hemp fibre>AW>RGS	45	31	79	49	76	58	Increase	Increase

Table 3. Second year planting data. Crop Rotation is the sequence of crops sown where AW = Autumn wheat, and RGS = Ryegrass seed. Old proxy N loss represents the modelled N leaching loss from the proxy that would be used prior to the development of a crop specific model. New crop N loss represents the modelled N leaching data from the newly developed crop specific model. Change from proxy represents an increase (+%) or decrease (-%) in N leaching loss when the new crop model is used.

		Old Proxy Input (kg N/ha/yr)		New Crop Input (kg N/ha/yr)		% Change from Proxy		Increase/Decrease	
Crop	**Crop Rotation**	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**
Linseed	RGS>Linseed	5	3	6	3	20	0	Increase	NC
Radish seed	RGS>Radish Seed	5	3	10	3	100	0	Increase	NC
Red beet seed	RGS>Redbeet Seed	5	4	47	30	840	650	Increase	Increase
Plantain seed	RGS>Plantain seed	11	5	14	5	27	0	Increase	NC
Carrot seed	RGS>Carrot Seed	8	5	40	20	400	300	Increase	Increase
Hemp seed (Oct sown)	RGS>Hemp seed	7	4	19	4	171	0	Increase	NC
Hemp seed (Nov sown)	RGS>Hemp seed	7	5	7	4	0	-20	NC	Decrease
Oilseed Rape (Aut sown)	RGS>Oilseed Rape	61	30	54	27	-11	-10	Decrease	Decrease
Oilseed Rape (Spr sown)	RGS>Oilseed Rape	2	1	6	1	200	0	Increase	NC
Cocksfoot seed	Cocksfoot>Kale	4	3	4	3	0	0	NC	NC
Pak choi seed	RGS>Pak Choi Seed	4	3	5	3	25	0	Increase	NC
Sunflower seed	RGS>Sunflower seed	4	3	11	3	175	0	Increase	NC
Rape seed	RGS>Rape seed	10	4	8	5	-20	25	Decrease	Increase
Hemp fibre (Oct sown)	RGS>Hemp fibre	3	3	3	3	0	0	NC	NC
Hemp fibre (Nov sown)	RGS>Hemp fibre	5	3	7	3	40	0	Increase	NC

Summary
The introduction of crop-specific models to Overseer has altered the modelled N loss number compared to the previous approach of using a proxy. The crop-specific model gives an appropriate rate of crop canopy closure and N uptake, thus providing a more accurate modelled estimate. However, that "more accurate" doesn't always mean a lower N loss estimate. To provide further confidence in these models, future work is needed to measure nitrate leaching under specific seed crops of interest.

Reference

Wolfe, A. 2022 Nutrient Budget Report: Comparison modelling exploring Overseer crop proxies. Published by Ravensdown. Report number 60232763.

Appendix

Additional information from report which provides extra detail on inputs to the modelling

Soils - Soil types modelled were chosen as representative of common arable soils that the crops would be grown on. The soils chosen were similar to, but may have not been the actual soil sibling present at the climate site.

Soils

Sibling Name	Location	Soil Order	Texture	Drainage	PAW 0100cm	PAW 060cm	PAW 030cm
Temp_1a.1	Chertsey	Pallic	Silt	Moderately well drained	157	101	56
Clar_1a.1	St Andrews	Pallic	Silt	Poor	96	95	54

Information sourced from S-Maps

Soil Fertility

Overseer default soil fertility was modelled for all crop blocks. Overseer only requires Organic-S values for crop blocks.

Soil Fertility

Block	Olsen P	K	Ca	Mg	Na	Org-S
All blocks	-	-	-	-	-	7

Other crops in rotation

Crop Information - Other Crops in Rotation

Crop	Cultivation	Month Sown	Month Harvested	Yield (T/ha)	Residue Management
Autumn Wheat	Min Till	April*	February**	11	Baled
Ryegrass Seed	Min Till	March	January	2.2	Baled/Grazed

Fertiliser inputs

Crop	Month Applied	Fertiliser Type	Rate (kg/ha)
Linseed	September	30% Pot. Sul. Super	300
	October	Cropmaster 15	250
	November	Urea	125
Radish seed	September	Potash Gold 14-7-14	200
	November	Cropmaster 15	300
Red beet seed	February	Cropmaster 15	250
		Kieserite	150
	August	Cropmaster 15	200
	September	Urea	150
Plantain seed	April	Triple Superphosphate	550
		Muriate of Potash	50
		Magnesium Oxide	50
	August	Ammo 36	160
	October	Urea	140
	November		150
	February		120
Carrot seed	October	SustaiN	100
	December	SustaiN	100
Oilseed Rape (Autumn Sown)	April	Superphosphate	200
		Mag Oxide	20
		Cropmaster DAP	110
	August	Sulphate of Ammonia	170
	September	Urea	200
	October		180
Oilseed Rape (Spring Sown)	September	Superphosphate	200
		Mag Oxide	20
		Cropmaster DAP	110
	October	Urea	200
	November		180
Cocksfoot seed	April	SustainN	150
		Superphosphate	400
		Potassium Chloride	50
	September	SustaiN	250
Pak choi	October	YarMila 12-10-10	250
Sunflowers	November	Urea	50
	December	SustaiN	120
Rape seed	November	Potash Gold 14-7-14	200
	September	Cropmaster 15	300

Crop	Month Sown	Month Applied	Fertiliser Type	Rate (kg/ha)
Hemp Fibre	October	October	Urea	250
	November	November	YaraMila Actyva S 15-7-12.5	300
		December	Urea	160
Hemp Seed	October	October	Urea	250
	November	November	YaraMila Actyva S 15-7-12.5	300
		December	Urea	110

Crop	Month Applied	Fertiliser Type	Rate (kg/ha)
Autumn Wheat	August	Sulphate of Ammonia	200
	September	SustaiN	300
	October		200
Ryegrass Seed	August	SustaiN	80
	September		100
	October		100

Irrigation input

All Irrigation was modelled using pivot scheduled using soil moisture sensors: probes/tapes with 'Trigger point; fixed depth applied' strategy. Trigger point, minimum return period and depth per application are detailed below.

The approach chosen was selected to represent common arable practice consistent with Good Management Practice expectations.

Pivot Irrigation – Crop Types of Interest

Irrigation Method		Oct	Nov	Dec	Jan	Feb	Mar	OLD Proxy Input Overseer®FM estimated annual volume (mm/ha/yr)	New Crop Input Overseer®FM estimated annual volume (mm/ha/yr)
Linseed	Depth/appl	30	30	30	30	30		300	240
	Min Return	7	7	7	7	7			
	Trigger Point	35	35	35	35	35			
Radish seed	Depth/appl	30	30	30	30	30		330	270
	Min Return	7	7	7	7	7			
	Trigger Point	35	35	35	35	35			
Red beet seed	Depth/appl	30	30	30	30			300	210
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Plantain seed	Depth/appl	30	30	30	30			300	300
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				

Carrot seed	Depth/appl	30	30	30	30			300	240
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Oilseed Rape	Depth/appl	30	30	30	30			210 Spr sown 240 Aut sown	210 Spr sown 240 Aut sown
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Cocksfoot seed	Depth/appl	30	30	30	30			300	300
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Pak choi seed	Depth/appl	30	30	30	30			240	270
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Sunflower seed	Depth/appl	30	30	30	30			240	270
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Rape seed	Depth/appl	30	30	30	30			240	270
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Hemp fibre (Oct sown)	Depth/appl	30	30	30	30			150	240
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Hemp fibre (Nov sown)	Depth/appl	-	30	30	30			150	240
	Min Return	-	7	7	7				
	Trigger Point	-	35	35	35				
Hemp seed (Oct sown)	Depth/appl	30	30	30	30			180	210
	Min Return	7	7	7	7				
	Trigger Point	35	35	35	35				
Hemp seed (Nov) sown)	Depth/appl	-	30	30	30			150	210
	Min Return	-	7	7	7				
	Trigger Point	-	35	35	35				

Irrigation Method		**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Overseer®FM estimated annual volume (mm/ha/yr)**
Autumn Wheat	Depth/appl	30	30	30	30			150
	Min Return	7	7	7	7			
	Trigger Point	35	35	35	35			
Ryegrass Seed	Depth/appl	30	30	30	30			240
	Min Return	7	7	7	7			
	Trigger Point	35	35	35	35			

Open field drone fly rearing: Protecting developing larvae and pupae from rodents and birds through a modified rearing system

Project code B21-03-00

Duration Year 4 of 4 (season 2021-22)

Authors Brad Howlett, Franziska Schmidlin, Sam Read (Plant & Food Research) and Phil Rolston (SIRC)

Location Plant & Food Research, Lincoln and Darfield, North Canterbury

Funding Seed Industry Research Centre (SIRC)

Acknowledgements South Pacific Seeds (NZ) Limited and Bianca Wohlers, David Pattemore, Warrick Nelson, Carol Dolman and Nicolas Bordes (Plant & Food Research)

Key points

- Drone flies can be reared using modified Intermediate Bulk Containers, but they are susceptible to predation by rodents and birds.
- In this study a modified rearing system for drone flies was developed that supported several thousand pupae with no evidence of predation by rodents or birds.
- Pupal chambers positioned outside the container resulted in higher pupal counts than chambers located inside the container.
- Pupal counts were lower than estimated larval numbers, possibly due to larvae pupating within drying substrate, larval escapes, and mortality.
- Rearing systems located under irrigation produced few larvae and pupae, with strongly odorous substrate attracting European Green Blow Flies.

Background

Drone flies are efficient pollinators of a range of crops in New Zealand and their successful management would offer growers opportunity to diversify their pollinator options (Howlett & Gee 2019). Recent research found drone flies to be more efficient pollinators than honey bees for hybrid seed crops, largely due to their greater frequency of movement between the hybrid cultivar lines resulting in more frequent pollen deposition (Howlett et al. 2021a; Howlett et al. 2021b).

Drone flies can be reared utilising modified Intermediate Bulk Containers (IBC) (1000 L) that contain rearing substrates suitable for drone fly development. These containers are transportable by farmers allowing placement in field as required. The costs for preparation of IBCs are largely purchase and modification. Howlett et al. (2021b) verified that each container is capable of rearing several thousand drone flies. However, the researchers identified that further modifications of pupal rearing containers were needed to protect larvae from predation. They found rodents were able to access the pupal containers from the ground, and birds from the top of the IBC containers. Although larvae largely migrate from substrates to find pupal sites, restricting and protecting these sites would ensure optimal survival of larvae, pupae and emerging adults.

In this study, we trialled IBC 1000 L containers with modifications that were specifically focussed on protecting drone flies through all life stages, particularly pupae.

Methods

To improve pupal survival, two new pupal chamber designs were proposed and investigated. These were built from epoxy varnished plywood and designed to be supported by the metal frame of an IBC1000 L container. In the first design, larvae seeking a pupation site were required to migrate over a flat ledge, before entering a slot into a chamber containing wood-shavings positioned on the outside of the IBC container. In the second design, the larvae were required to migrate via the outside of the chamber structure to an entry slot into the pupal chamber. In this latter case the chamber was positioned overhanging the IBC container.

The two plywood pupae chamber designs were built to be supported by the metal frame of each modified 1000 L IBC container in which drone fly larvae were reared. Figure 1 shows the dimensions of each of the pupal container designs. Plywood (12 mm thick) was coated with marine clear epoxy resin to protect it from moisture generated from the drone fly rearing substrate, overhead irrigation and rainfall. For both designs, each pupae chamber was covered with a hinged lid to allow easy access to collect or count pupae. Larvae searching for pupation sites exit the rearing substrate by climbing the inner wall of the plywood pupae container and enter the chamber via a slot. Six litres of untreated pine wood-shavings were placed within each pupae chamber as substrate to support pupation.

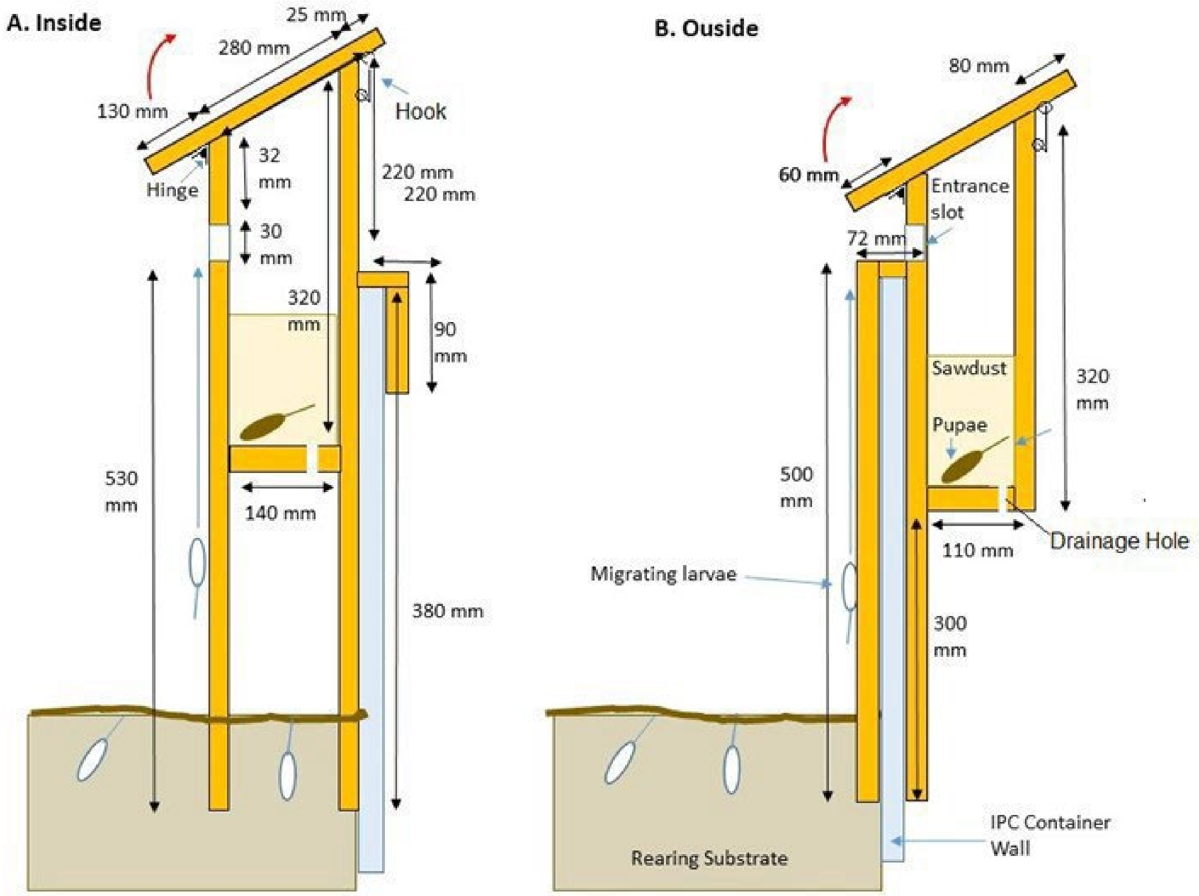

Figure 1. Two designs of drone fly pupae chambers that fit on the inside (left) and outside (right) of IBC 1000 L rearing containers. The length of both chambers was 1000 mm. Note larvae pupae are not drawn to scale.

A detailed description of the modification of IBC 1000 L containers has been provided by Howlett et al. (2021b). In summary, a circular saw was used to reduce container height and to alter the holding cage to a height 5 cm above the modified container (Figure 2). Final dimensions were 96 cm width x 115 cm length x 68 cm height.

Figure 2. Converted 1000-L bulk containers with two drone fly pupae chambers attached on opposite sides. The rearing substrate for the drone fly larvae was grass clippings submerged in water.

To test the modified container designs, two trials were conducted in two separate arable fields in North Canterbury, New Zealand. The first was located in a hybrid carrot (*Daucus carota* subsp. *sativus*) vegetable seed crop at Clintons Road, Darfield (-43.539550, 172.107060). The second was located at Plant & Food Research's Lincoln arable farm site (-43.631607, 172.476613). Eight IBC containers were established for the trial, four at each location. At the Lincoln site on the 29 October 2021, four IBC containers were filled with grass clippings and spaced approximately 5 m apart along the edge of a grass field. This site had a poplar shelterbelt. The grass added was a mix of one part 1-month-old grass clippings to four parts fresh clippings. On the 25 November 2021, pupal chambers (one of each design) were fitted on each container after larvae were observed in the substrate. At the Darfield site, Clinton Road, two IBC containers were set up on 23 October and two on 6 November 2021. Two containers were placed approximately 20 m apart, with each located equidistantly between a conifer hedgerow and the crop (approximately 5 m from each). The other two containers were placed approximately 100 m from the first two at the edge of the same carrot seed crop but adjacent to an arable field, with these containers being fully exposed to overhead irrigation. The grower added long grass cut from the roadside as a substrate to rear drone flies on the 25 November 2021. To help prevent migrating larvae from escaping over the container edges without pupae chambers, all tanks were fitted with a piece of aluminium strip (115 cm x 10 cm) that was bent to an angle of approximately 30° from each exposed inner container side. All containers were filled to within 20 cm of the top with substrate and then water added and stirred.

The containers were monitored fortnightly and were stirred each time to break up drying material on the substrate surface. Bird netting was placed over each container, including the pupal chambers, and frequently examined for movement or damage. Larval numbers were estimated from the 1000-L bulk containers, on seven occasions beginning on the 3 December 2021 and finishing on 2 March 2022. Estimations involved sampling 750 mL of the substrate across three sub-samples of 250 mL each. The sub-samples were collected diagonally across the substrate, with two collected approximately 10 cm from opposite corners and one from the centre. Grass clippings/cut grass occupied the top 30 cm of the containers with water below (220 L). Larvae were sampled from the grass layer. Pupae from the pupal chambers were counted on seven occasions at both locations beginning on 3 December 2021 and finishing on 2 March 2022. Counts were made on five occasions by subsampling 2 L of wood-shavings (total 6 L/chamber). One 1 L sub-sample was taken from the chamber edges and one 1 L sub-sample from the centre. Sub-samples were sifted through and pupal cases of non-emerged and emerged flies were counted. Full pupal counts within each chamber were conducted on the 25 January and 2 March 2022. On the 25 January 2022, original wood shavings in each of the boxes were replaced with fresh wood shavings (6 L).

Descriptive statistics (figures, tables, total and estimated counts) were used to present and compare trial results. Student t-tests were used to determine whether counts of pupae varied significantly between the two pupal chamber designs. To correct for skewness, the data were $\log_{10}(n=1)$ transformed prior to conducting the t-tests.

Results and Discussion

The modified rearing systems for drone flies supported several thousand pupae with no evidence of predation by rodents or birds. However, a very small number (n = <10) of pupae had been caught in spider webs and we did find evidence of significant spider predation. Both the bird netting and pupal chambers remained undamaged throughout the trials and we did not observe vertebrate disturbance of the rearing substrate as noted in earlier trials (Howlett et al. 2021b).

When not placed directly under overhead irrigation lines, the contents of pupal chambers remained dry throughout the 4-month period they were exposed to field conditions. Under overhead irrigation, a small amount of water was found to enter the pupal chambers irrespective of the design. Despite this, larvae still pupated in the chambers but at relatively low numbers. Minor modifications of the lid should prevent this issue from occurring in future (e.g. a rim underneath the lid that when closed prevents water flowing into the chamber).

The estimated numbers of larvae varied substantially between containers throughout the sampling period, particularly at the Clinton Road site. Most containers recorded high peak larval populations, with median estimated counts exceeding >20,000 for six out of the eight containers, consistent with findings by Howlett et al. (2021b). Peak larval populations occurred at different times for each container at the PFR Lincoln site. At Clinton Road, containers closer to conifer hedgerows had significantly higher larval numbers than those between crops. There was a significant difference between the estimated number of larvae developing in the containers and the pupal counts in the chambers. This could be attributed to larvae pupating within the container substrate itself, larvae escaping the container without entering the pupal chambers (potentially near uncovered corners), or a high mortality rate among developing larvae. Understanding larvae fate within containers and whether the chambers reflect the true number of developed pupae per container could help guide further improvements to designs that optimise drone fly numbers.

Pupal numbers varied between containers. At PFR Lincoln, all containers had over 1000 pupae in each chamber. At Clinton Road, containers near the conifer hedgerow yielded approximately 4000 larvae each (container 1: 3916; container 2: 4118) at the final count, while those in the open field under irrigation had very low numbers (container 3: 367, container 4: 97). Pupae numbers increased substantially from late December 2021 to early March 2022 at both sites, despite a decrease in larval counts starting from early February 2022. The overall trend across all containers indicated a steady rise in pupae from early December 2021 to early March 2022. The data indicated that the pupal chamber design influenced the number of larvae that successfully pupated. Chambers located on the outside of the container, except for one container, had a higher number of pupae than internally located containers, with statistical ($P\leq0.05$) significance (or close) observed at three out of seven sampling times (Table 1).

Out of the eight rearing containers, six demonstrated high larval populations (tens of thousands) and pupal numbers (mostly thousands). However, the two containers fully exposed to overhead irrigation exhibited fewer observed egg batches and supported only a small number of larvae and pupae. Notably, these containers displayed distinct differences in fermentation, including a strong odour, the presence of small bubbles across the substrate surfaces, and the substrate being submerged under water instead of floating. Additionally, a significant number of European Green Blow Flies (*Lucilia sericata*), which are typically attracted to decomposing meat, were observed around these containers but not the others. The causes behind these observations were not investigated. Previous research noted a significant reduction in drone fly larval numbers when containers were topped up with a large volume of water (more than 50% of the volume) (Howlett 2021b). The overhead irrigation in this study may have had a similar impact by introducing high volumes of water over short periods.

Table 1. Paired t-tests comparing pupal counts within two pupal chamber designs positioned inside or outside IBC 1000 L containers. Six containers were assessed, each having one set of both chamber designs. Mean counts are actual values with log10 transformed means in brackets.

Date	Mean count inside	Mean count outside	t statistic	P value
3-Dec-21	12 (0.8)	24 (0.9)	-0.430	**0.681**
17-Dec-21	14 (1.0)	66 (1.7)	-3.817	**0.006**
30-Dec-21	57 (1.6)	162 (2.1)	-5.120	**0.001**
12-Jan-22	78 (1.8)	387 (2.2)	-2.184	**0.065**
25-Jan-22	347 (2.4)	917 (2.7)	-2.236	**0.061**
11-Feb-22	506 (2.6)	1214 (2.9)	-2.316	**0.053**
2-Mar-22	**655 (2.7)**	**14083 (3)**	**-2.687**	**0.031**

Based on the comparison of the two pupal chamber designs, the design with the chamber supported on the outside of the IBC container appeared advantageous. The reason for this design collecting higher pupal numbers is unclear, but it showed statistical significance or near significance on most occasions for pupal counts.

Summary

This study demonstrated the successful support of large pupal populations in the new container designs, with no predation by rodents or birds. However, a degree of spider predation was observed with some pupae caught in spider webs. Larval populations varied among containers, with most containers experiencing high peaks in larval numbers. Containers near conifer hedgerows had significantly higher larval numbers than those clear of such hedgerows.

A significant difference was found between estimated larval counts and pupal counts in the chambers, potentially due to factors including larvae pupating in the container substrate, escaping the containers, or high larval mortality. Pupal numbers varied between the different chambers, with higher numbers in chambers positioned outside the container than chambers inside the container.

Containers exposed to overhead irrigation had fewer observed egg batches and supported fewer larvae and pupae, indicating a potential impact of water volumes on larval development.

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Herbicide resistant weed survey in Southland in the 2020-2021 season

Project code	X18-35-01
Duration	Year 3 of 5 (season 2021-22)
Authors	Ben Harvey, Matilda Gunnarsson, Phil Rolston, Richard Chynoweth (FAR) Chris Buddenhagen and Trevor James (AgResearch)
Location	Southland
Funding	MBIE-funded programme with FAR and SIRC support
Acknowledgements	Zachary Ngow (AgResearch), Fiona Anderson, Harry Washington, Lauren McCormick and Alice Ridgen (FAR)

Key points

- A survey of two representative paddocks from 27 randomly-selected arable farms in the Southland region was carried out pre-harvest in January 2021. This represented 21% of arable farms in the region.
- The most common weeds were grass weeds, with *Poa* species the most prevalent grass weed identified.
- Cases of herbicide-resistant grass weeds were detected on eight of the 27 farms. Herbicide-resistant broadleaf weeds (all of which were chickweed) were identified on six farms.
- The prevalence of herbicide-resistance was lower in Southland than in South Canterbury or the Selwyn district of Mid-Canterbury.
- The most common resistant weeds on farms in Southland were grass weeds resistant to Mode-of-Action Groups 1 and 2, in particular haloxyfop, fenoxaprop, iodosulfuron and pyroxsulam.

Background

Herbicide resistance is an increasing problem worldwide (Heap n.d.) and in New Zealand (Buddenhagen et al. 2021). Since 2018, AgResearch has been leading an MBIE-funded Herbicide Resistance programme with FAR as a major industry partner. Surveys conducted as a part of this programme in the Selwyn district (2018-19) and South Canterbury (2019-20) identified herbicide resistance on 62% of the farms surveyed over the two-year period (Gunnarsson et al. 2020). The surveys continued for a third year, with arable farms in Southland surveyed in January 2021. This report summarises the results of a survey undertaken in 2021 throughout the Southland region.

Methods

The FAR database identified 130 suitable arable farms in the Southland region. Growers were randomly selected from this list and contacted to assess their suitability for inclusion in the survey; a final list of 27 farms were visited from the 25 to 29 January 2021. Two paddocks (mostly cereals) on each of the 27 farms were selected after consultation with the grower. Following inspection of each paddock, seed was collected from weeds that appeared to have survived normal herbicide application. Mature seed was collected, placed in paper bags (one bag per plant), and the bags labelled with the weed species, site and date of collection. The seeds were stored at 5°C for three months or more, then soaked in 0.1% KNO_3 solution for 24 hours to break seed dormancy. Seeds were then planted into trays and herbicide was applied once seedlings had reached the desired growth stages. Seeds from known herbicide-susceptible controls were sown alongside tested seeds. Herbicides tested are summarised in Table 1.

Table 1. Product name, active ingredient and mode-of-action group for herbicides included in the resistance screening of plants collected during a survey of 27 farms in Southland in January 2021.

Product	Active Ingredient	Mode-of-Action Group
Glean®	750 g/kg Chlorsulfuron	2
SeQuence™	240 g/L Clethodim	1
Banvel®	200 g/L Dicamba	4
Puma® S	69 g/L Fenoxaprop	1
Preside™	800 g/kg Flumetsulam	2
Starane™ XTRA	333 g/L Fluroxypyr	4
Crucial™	600 g/L Glyphosate	9
Ignite®	100 g/L Haloxyfop	1
Hussar®	50 g/kg Iodosulfuron	2
Mesoflex®	480 g/L Mesotrione	27
Latro®WG	750 g/kg Nicosulfuron	2
Twinax®	100 g/L Pinoxaden	1
Rexade™ GoDRI™	150 g/kg Pyroxsulam	2
Gardoprim®	500 g/L Terbuthylazine	5

Plant mortality was assessed 3-6 weeks after herbicide application. Where greater than 10% of plants survived (or ≥3 plants when total number of plants was less than 30), the mother plant was considered to have been resistant to that herbicide.

Results and Discussion

A total of 339 herbicide/species interactions were tested on seed gathered from the 27 farms surveyed. The majority of these weeds were grasses, with species of *Poa* (*Poa annua* and *P. trivialis*) and *Lolium* (*Lolium multiflorum* and *L. perenne*) the most prevalent (Table 2). In all, 12 farms (45%) had at least one weed with some form of herbicide resistance; eight farms had resistant grass weeds, six had resistant broadleaf weeds, and two farms had both. The most common case of grass weed resistance was iodosulfuron-resistant winter grass (*P. annua*), while chickweed (*Stellaria media*) was the most common resistant broadleaf weed. Southland recorded the first known New Zealand case of Group 2-resistant chickweed in 1995 (Bourdôt 1996); the cases recorded in the survey were all in the Lumsden area, which was also where this case was recorded. Growers in the Lumsden area of Southland should be aware of this issue and consider alternative herbicide mode-of-action (MoA) groups. All of the resistant chickweed samples tested were susceptible to fluroxypyr (Group 4).

The percentage of farms with grass weed resistance to Groups 1 and 2 active ingredients (30%) was lower than in the previous two years' surveys (62% across both years, Gunnarsson et al. 2020). Southland also had *Poa* species as the most common weed; Canterbury farms were more likely to have a problem with ryegrass. One explanation for this could be that ryegrass seed crops are common in Canterbury rotations, while they are not often included in Southland.

While herbicide resistance in Southland does not appear to be as urgent an issue as in other parts of New Zealand, it is still present and care must be taken to prevent the development of resistant weed populations. Rotating between different herbicide MOA groups, rotating crops to allow different MOA groups to be used, and including non-chemical weed control techniques as part of an integrated weed management strategy are all important components of a robust herbicide resistance management strategy.

Table 2. Herbicide resistance cases, highlighted in red, identified on 27 randomly-selected arable farms located in Southland when samples were collected during January 2021.

Species	Active Ingredient	No. plants tested	No. plants surviving	No. of farms	Farms with resistance
Avena fatua (wild oat)	chlorsulfuron	6	6	1	0
	fenoxaprop	181	16	6	1
	fluroxypyr	6	0	1	0
	glyphosate	126	0	4	0
	pinoxaden	162	0	6	0
	pyroxsulam	180	0	6	0
Bromus diandrus (ripgut brome)	clethodim	233	0	8	0
	glyphosate	227	0	8	0
	haloxyfop	257	0	8	0
Lolium multiflorum (Italian ryegrass)	clethodim	122	1	3	0
	glyphosate	133	1	3	0
	haloxyfop	105	6	3	1
	iodosulfuron	97	22	3	1
	pinoxaden	133	6	3	0
	pyroxsulam	144	24	3	1
Lolium perenne (perennial ryegrass)	clethodim	16	0	1	0
	glyphosate	16	0	1	0
	haloxyfop	20	0	2	0
	iodosulfuron	22	13	2	1
	pinoxaden	20	0	1	0
	pyroxsulam	20	15	1	1
Poa annua (annual bluegrass)	dicamba	10	0	1	0
	glyphosate	157	0	8	0
	haloxyfop	170	0	8	0
	iodosulfuron	171	59	8	3
	mesotrione	8	0	1	0
	nicosulfuron	14	0	1	0
Poa trivialis (Kentucky bluegrass)	glyphosate	27	0	1	0
	haloxyfop	29	0	1	0
	iodosulfuron	26	26	1	1
Persicaria maculosa (redshank)	fluroxypyr	19	0	2	0
	haloxyfop	20	0	1	0
	iodosulfuron	5	0	1	0
	terbuthylazine	22	0	2	0
Stellaria media (chickweed)	chlorsulfuron	218	218	6	6
	flumetsulam	113	113	4	4
	fluroxypyr	182	0	6	0

Summary

Southland arable farms were shown to have a lower level of herbicide resistance than farms previously surveyed in South Canterbury and Selwyn. *Poa* and *Lolium* species were the most common resistant grass weeds, while chickweed plants resistant to Group 2 herbicides were identified on several farms in the Lumsden area. This work continues; surveys have been carried out in Manawatu, Wairarapa and Hawkes Bay (January 2022), and Mid-Canterbury (January 2023). These will be reported separately.

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Grass weed herbicide screening trial

Project code X18-35-04

Duration Year 2 of 5 (season 2021-22)

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

Location Chertsey, Mid Canterbury. GPS - 43°47'26.4"S 171°57'39.9"E

Funding SIRC

Acknowledgements NZ Arable (trial operator)

Key points

- A range of grass weed herbicides were investigated by spraying weeds at different rates using a log-sprayer.
- Results showed several promising options, including two new coded products for management of grass weeds.
- Using the most effective herbicide possible within the crop grown reduces the risk of herbicide resistance emerging to an active ingredient. It is also important to use a range of herbicide mode-of-action groups against a target weed.

Background

Herbicide resistance is a hot topic at present. Work conducted by AgResearch and FAR has identified that herbicide resistance is widespread across New Zealand in many industries, including arable farming. With limited new herbicide chemistry available it is imperative to use the existing chemistry to its full potential. Mixing old chemistry with new can give increased protection against herbicide resistance, especially when using different mode-of-action (MoA) chemicals which target the same weed species.

This trial compares the new industry standards against the old. New unregistered products can be visually evaluated against standard herbicides available to the New Zealand farmer. The trial is designed to determine the relative strengths and weaknesses of different herbicides applied at a range of application rates, from 200% commercial rates down to 25% doses. Whilst target grass weeds have been sown with no cover crop, the trial should still allow growers and researchers to determine relative herbicide performance from one trial. The herbicide screening trial using a log-sprayer can identify the relative efficacy of different herbicides, at different product rates, over a range of typical grass weeds encountered on arable farms across New Zealand.

Methods

A non-replicated trial was set up at the FAR Arable Site, Chertsey (43.79065 N; 171.961130 E) on a Templeton_9a.1 silt-loam soil. Twelve species were sown on 7 May 2021 in 18 m long strips (Table 1). Fourteen different herbicide treatments (Table 2) were tested over each species using a log sprayer using four 110 015xr teejet® nozzles at 250 kPa pressure applying 250 L water/ha. This applies a concentration gradient down the length of the plot. Rates began at twice the 'full rate' diluting down to 10% of the full rate at the end of each 18 m plot. A score (10 = dead; 0 = no effect) representing percentage kill at the 2x full, full (label), half and quarter rates is reported. The Avadex® Xtra® treatments were applied pre-drilling, then incorporated by a hoe coulter drill at full depth setting (70 mm). The trial was drilled with four rows per species, with two species per plot. Due to the nature of the seed, some species were hand sown and then raked in to the plot (see Appendix).

In the Avadex®-Sakura® 850WG treatment, Avadex® was applied on 7 May at a fixed rate of 2.8 L/ha then incorporated pre-drilling.

The pre-emergence applications were applied across all species on 13 May. Post-emergence timings were applied once the cereals reached two leaves (Zadok's Growth Stage 12) on 8 July. The trial was scored at 45 days (data not shown) after application and repeated at 70 days after final herbicide application (whether pre- or post-emerge).

Table 1. Herbicides, active ingredients, label (1x) rates, MOA groups and cost of herbicides used in the herbicide screening trial sown at Chertsey, 2021.

TRT. NO.	Chemical Name	Active Ingredient	Application Rate (1x)	MoA Group	Cost $/ha[1]
1	Avadex®	tri-allate	2.8 L/ha	15	42
2	Gardoprim® fb Glean®[2]	Terbuthylazine + Chlorsulfuron	1.5 L/ha fb 20 g/ha	5 + 2	26
3	Firebird®	flufenacet + diflufenican	0.5 L/ha	15 + 12	65
4	Firebird® + Gardoprim®	flufenacet + diflufenican + terbuthylazine	0.5 L/ha + 1.5 L/ha	15 + 12 + 5	79
5	Firebird® + Karmex®	flufenacet + diflufenican + diuron	0.5 L/ha + 1.5 kg/ha	15 + 12 + 5	116
6	Sakura®	pyroxasulfone	150 g/ha	15	96
7	Sakura® + Gardoprim®	pyroxasulfone + terbuthylazine	150 g/ha + 1.5 L/ha	15 + 5	111
8	Othello®[2]	diflufenican + mesosulfuron-methyl + iodosulfuron	1 L/ha	12 + 2 + 2	58
9	Rexade™[2] GoDRI™	halauxifen-methyl + pyroxsulam	100 g/ha	4 + 2	66
10	Twister®[2]	isoproturon	3 L/ha	5	54
11	Asulox®	asulam	3 L/ha	18	109
12	H21/01[2]	-	0.65 L/ha	30	NA[4]
13	AG590	-	2.5 L/ha	5 + 3 + 12	NA[4]
14	Avadex® + Sakura®	tri-allate + pyroxasulfone	2.8[3] L/ha + 150 g/ha	15 + 15	139

[1]Cost at label rate
[2]Applied post emerge on 8 July 2021.
[3]Avadex applied at a fixed rate, Sakura log sprayed at pre-emerge timing.
[4]Product not registered in New Zealand
fb = followed by, which confers a sequence of products. Always consult your agronomist when making herbicide decisions.

Results and discussion

Results in the summary below refer to the full label (1x) rate. Complete results are shown in Table 2. Interpretations are based on scores from Table 2, where 0-3 = fully tolerant, 3-5 = mostly tolerant, 5-8 = mostly susceptible and 8-10 = fully susceptible.

Tall Fescue

Tall fescue was at least partly susceptible to most products tested in this trial, with many treatments providing full control. Pre-emergence herbicides were particularly effective.

- Tolerant to: none of the treatments.
- Mostly tolerant to: none of the treatments.
- Mostly susceptible to: Avadex®, Othello®, Twister®.
- Fully susceptible to: Gardoprim® f.b. Glean®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, AG590, Avadex® f.b. Sakura®, Rexade™ GoDRI™, Asulox®.

Phalaris

Phalaris aquatica showed high susceptibility to almost all of the herbicides studied in this trial, likely due to the even emergence pattern and application timings. Even at the quarter rate, many of the herbicides were still giving close to 100% kill. Note that these results may not reflect the level of control achieved in practice.

- Tolerant to: none of the treatments.
- Mostly tolerant to: none of the treatments.
- Mostly susceptible to: Asulox®.
- Fully susceptible to: Avadex®, Gardoprim® f.b. Glean®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, AG590, Avadex® f.b. Sakura®, Othello®, Rexade™ GoDRI™, Twister®.

Annual ryegrass

Only Asulox®, a product with no label claim for grasses, showed no activity on annual ryegrass. Thus, Asulox® has potential to provide grass weed control in annual ryegrass crops. All other products had significant activity. Avadex® f.b. Sakura® in sequence was particularly effective. Note that in this treatment the Avadex® was applied at a fixed rate, with only the Sakura® being log-sprayed.

- Tolerant to: Asulox®.
- Mostly tolerant to: none of the treatments.
- Mostly susceptible to: Gardoprim® f.b. Glean®, AG590, Othello®, Rexade™ GoDRI™.
- Fully susceptible to: Avadex®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, Avadex® f.b. Sakura®, Twister®.

Perennial ryegrass

None of the herbicides were suitable for application to perennial ryegrass seed crops when used at 1x rate. Avadex® f.b. Sakura® was particularly effective at removing perennial ryegrass in this trial, as was Firebird® + Karmex®. Note that Avadex® and Sakura® are both from the Group 15 Mode of Action, which may be a consideration where herbicide resistance is concerned.

- Tolerant to: none of the treatments.
- Mostly tolerant to: Avadex®, Asulox®.
- Mostly susceptible to: AG590, Othello®, Rexade™ GoDRI™, Twister®.
- Fully susceptible to: Gardoprim® f.b. Glean®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, Avadex® f.b. Sakura®.

Hairgrass

A number of the treatments were very effective on hairgrass. Pre-emerge herbicides were the most effective. The very high levels of control achieved by some products were unexpected. Results may vary when herbicides are applied to hairgrass growing within a crop. FAR will continue to investigate in future trials.

- Tolerant to: none of the treatments.
- Mostly tolerant to: none of the treatments.
- Mostly susceptible to: Avadex®, Gardoprim® f.b. Glean®, AG590, Othello®, Rexade™ GoDRI™, Asulox®.
- Fully susceptible to: Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, Avadex® f.b. Sakura®, Twister®.

Prairie grass

Several of the herbicides in this trial did not provide acceptable levels of control of prairie grass. However, there are a number of options for dealing with prairie grass, particularly the Group 15 pre-emerge herbicides, although different sub-types may respond differently.

- Tolerant to: AG590, Othello®.
- Mostly tolerant to: Avadex®, Gardoprim® f.b. Glean®.
- Mostly susceptible to: Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura® f.b. Gardoprim®, Twister®.
- Fully susceptible to: Sakura®, H21/01, Avadex® f.b. Sakura®, Rexade™ GoDRI™, Asulox®.

Ripgut brome

Germination rates were very poor for ripgut brome in this trial, which may have led to some higher levels of control than would be seen in practice. Similar products with activity against prairie grass were effective against ripgut brome. Treatments that contained Firebird® provided more control on ripgut brome than on prairie grass. Historical FAR data has shown Firebird® is also effective against soft brome.

- Tolerant to: Avadex®, Gardoprim® f.b. Glean®, AG590, Twister®.
- Mostly tolerant to: Sakura® f.b. Gardoprim®.
- Mostly susceptible to: Firebird® f.b. Karmex®, Avadex® f.b. Sakura®, Rexade™ GoDRI™.
- Fully susceptible to: Firebird®, Firebird® f.b. Gardoprim®, Sakura®, H21/01, Othello®, Asulox®.

Wheat

Wheat showed tolerance to all products except Asulox®, which potentially opens an option for wheat control in annual ryegrass. Of particular interest are the two coded products AG590 and H21/01, which showed excellent crop safety with wheat.

- Tolerant to: Avadex®, Gardoprim® f.b. Glean®, Firebird®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, AG590, Avadex® f.b. Sakura®, Othello®, Rexade™ GoDRI™, Twister®.
- Mostly tolerant to: Firebird® f.b. Gardoprim®.
- Mostly susceptible to: Asulox®.
- Fully susceptible to: none of the treatments.

Barley
Barley showed tolerance to almost all of the herbicides tested. The coded product H21/01 was very effective at killing the barley plants despite having almost no effect on wheat. Note that several of these products are not registered for use on barley. Always check the label before application.

- Tolerant to: Avadex®, Gardoprim® f.b. Glean®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, AG590, Avadex® f.b. Sakura®, Othello®, Rexade™ GoDRI™, Twister®, Asulox®.
- Mostly tolerant to: Sakura® f.b. Gardoprim®.
- Mostly susceptible to: none of the treatments.
- Fully susceptible to: H21/01.

Wheat grass
Wheat grass was mostly tolerant to the post-emerge herbicides tested while only Asulox® gave a high level of control.

- Tolerant to: Gardoprim® f.b. Glean ®, Othello®, Rexade™ GoDRI™, Twister®.
- Mostly tolerant to: AG590, Avadex® f.b. Sakura®.
- Mostly susceptible to: Avadex®, Firebird®, Firebird® f.b. Gardoprim®, Firebird® f.b. Karmex®, Sakura®, Sakura® f.b. Gardoprim®, H21/01.
- Fully susceptible to: Asulox®.

Oats
This trial used tame oats as a proxy for wild oats. Wild oats are more difficult to control due to variable germination and emergence dates. Oat control was most effective with Avadex® followed by Sakura®. Some other products gave useful levels of control which may be adequate when grown with a competing crop. When oats are grown as a crop, grass weed control could be challenging. Firebird® was somewhat safe in this trial, but is not registered for use in oat crops.

- Tolerant to: Gardoprim® f.b. Glean®, AG590, Twister®, Asulox®.
- Mostly tolerant to: Firebird®, Firebird® f.b. Karmex®.
- Mostly susceptible to: Avadex®, Firebird® f.b. Gardoprim®, Sakura®, Sakura® f.b. Gardoprim®, H21/01, Othello®, Rexade™ GoDRI™.
- Fully susceptible to: Avadex® f.b. Sakura®.

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

Appendix 1.

Table 3. Cereal and grass species sown in the herbicide screening trial sown at Chertsey, in 2021.

Species/cultivar	Scientific name	Sowing rate (kg/ha)	Sowing method
Tall Fescue cv. Fortuna	*Festuca arundinacea*	20	Drill
Phalaris cv. Grasslands Maru	*Phalaris aquatica*	5	Drill
Annual ryegrass cv. Grasslands Tama	*Lolium multiflorum*	30	Drill
Perennial ryegrass cv. Grasslands Nui	*Lolium perenne*	20	Drill
Hairgrass	*Vulpia bromoides/myuros*	10	Hand sow
Prairie grass	*Bromus willdenowii*	5	Hand sow
Ripgut brome	*Bromus diandrus*	5	Hand sow
Wheat cv. Firelight	*Triticum aestivum*	100	Drill
Barley cv. Planet	*Hordeum vulgare*	140	Drill
Wheat grass	*Thinopyrum intermedium*	50	Drill
Oats L5 Milling	*Avena sativa*	140	Drill

Table 3. The results of 14 herbicide treatments at four different chemical rates across 11 grass and cereal species in a screening trial at Chertsey in 2021.

		Pre-emergence treatments							Post-emergence						
Species	Rate	Avadex®	Gardoprim® f.b. Glean®	Firebird®	Firebird® f.b. Gardoprim®	Firebird® f.b. Karmex®	Sakura®	Sakura® f.b. Gardoprim®	H21/01	AG590	Avadex® f.b. Sakura®	Othello®	Rexade™ GoDRI™	IPU	Asulox®
Tall Fescue	2x	7	9	9	10	10	10	10	10	9	10	8	9	10	7
	1x	6	9	9	9	10	10	10	10	9	10	8	9	8	9
	0.5x	6	8	8	9	9	9	9	10	9	10	7	8	8	5
	0.25x	2	7	4	8	5	7	5	9	7	9	7	8	8	4
Phalaris	2x	9	10	10	10	10	10	10	10	10	10	9	10	10	8
	1x	9	10	10	10	10	10	10	10	10	10	10	9	9	7
	0.5x	8	8	9	10	10	10	10	10	10	10	9	9	7	4
	0.25x	4	6	8	10	9	9	9	10	9	9	8	9	8	6
Annual ryegrass	2x	10	9	10	10	10	10	10	10	8	10	8	9	10	4
	1x	9	6	10	10	10	10	10	10	8	10	8	8	10	2
	0.5x	9	6	9	9	9	9	9	10	6	10	8	7	9	2
	0.25x	4	2	8	7	8	8	5	8	4	10	7	7	9	2
Perennial ryegrass	2x	7	10	10	10	10	10	10	10	8	10	8	8	10	9
	1x	4	9	10	10	10	9	9	10	8	10	7	8	8	4
	0.5x	4	3	8	10	9	9	9	10	7	9	7	7	6	4
	0.25x	1	3	7	7	9	8	4	7	5	9	6	6	9	5
Hairgrass	2x	9	9	10	10	10	10	10	10	9	10	8	7	10	8
	l1x	6	7	10	10	10	10	10	10	8	10	7	6	10	7
	0.5x	2	3	10	10	10	10	10	10	8	10	5	4	10	5
	0.25x	1	1	9	9	9	10	10	10	5	10	2	2	10	4
Prairie grass	2x	10	9	9	10	10	10	9	10	4	10	3	10	10	10
	1x	4	5	8	6	8	9	8	9	2	10	2	9	7	10
	0.5x	1	2	5	3	6	8	5	8	2	9	2	9	3	8
	0.25x	1	1	1	2	4	8	5	7	2	8	1	9	4	7
Ripgut brome	2x	8	6	10	10	10	10	9	10	3	10	10	9	0	10
	1x	2	2	9	9	6	9	5	10	2	8	10	8	0	10
	0.5x	2	2	5	4	6	9	5	8	4	7	10	8	0	7
	0.25x	1	1	2	2	3	7	3	3	0	7	8	10	0	5
Wheat	2x	4	0	3	4	3	3	4	3	2	0	0	0	0	6
	1x	2	0	1	4	2	0	3	3	2	0	0	0	0	7
	0.5x	0	0	0	4	0	0	0	2	0	0	0	0	0	3
	0.25x	0	0	0	2	0	0	0	0	0	0	0	0	0	3
Barley	2x	2	0	3	5	4	4	4	9	2	3	0	0	0	5
	1x	2	0	3	3	2	2	4	9	2	3	0	0	0	3
	0.5x	0	0	1	3	1	2	2	7	2	2	0	0	0	4
	0.25x	1	1	0	2	1	2	1	3	1	1	0	0	0	3
Wheat grass	2x	8	4	9	8	8	8	6	8	5	4	2	2	4	9
	1x	6	3	7	6	7	6	6	7	4	4	2	2	2	9
	0.5x	3	2	4	3	6	4	6	5	2	4	1	1	1	8
	0.25x	3	0	4	2	2	4	4	4	2	4	0	0	0	9
Oats	2x	7	2	8	8	7	9	8	8	5	9	9	9	6	4
	1x	6	0	5	8	5	7	7	8	3	9	8	9	4	3
	0.5x	7	0	3	7	5	6	5	5	2	8	8	8	3	2
	0.25x	3	0	3	5	2	4	4	2	2	8	7	7	3	3

Note: 2x = double the label rate, label rate, 0.5x = half the label rate, 0.25x = quarter label rate). 0 = no effect, 10 = full control (all plants killed). Note that “label rate” here was chosen to be a typical grassweed application rate, as many product labels suggest a range. Starting rates given in Table 2 are the 2x rates. Scores are those from 70 days after application. Avadex® was incorporated at drilling. f.b. = followed by

Investigating the potential of AGR96X to protect cereal seedlings from grass grub larval feeding during establishment

Project code X19-01-00

Duration Year 3 of 3 (seasons 2019 through to 2022)

Authors Richard Chynoweth, Owen Gibson (FAR), Mark Hurst, Sarah Mansfield (AgResearch)

Location Canterbury

Funding SFFF supported by FAR co-funding

Acknowledgements M, O'Callaghan; D Wright; L, Villamizar; A Beattie; M, Western; C van Koten; E, Garnett and L McCormick (AgResearch)

Key points

- All grass grub treatments increased the mortality and disease of grass grub larvae above the untreated control.
- Generally, treated plots had similar plant populations at the end of winter, irrespective of how they controlled grass grub larval feeding. Thus, the performance of the biological treatment, AGR96X, was similar to the organophosphate insecticide, SuSCon® Green.
- Grain yield was increased above the untreated control by SuSCon® Green and Poncho®, however these were similar to many of the other treatments.

Background

The New Zealand grass grub (*Costelytra giveni*) is one of New Zealand's major pasture and crop pests as the larval stages can cause serious damage to plants by feeding on their roots. Devastating outbreaks of grass grub frequently occur after the establishment phase. Chemical insecticides commonly used to control grass grub, including organophosphates and neonicotinoids, are in the process of being phased out overseas. The organophosphate 'diazinon' is still available in New Zealand but will be phased out by 2028. Chlorpyrifos (e.g. SuSCon® Green) is also scheduled for review (EPA 2019) and has recently been removed from use in the European Union with a zero-residue policy adopted for food crops. Neonicotinoid insecticides are viewed as potential replacements for organophosphates to control grass grub in arable crops, but neonicotinoids are also under scrutiny (EFSA 2015), so it is important to find non-chemical alternatives for grass grub control (Mansfield et al. 2017).

A bacterium active against both grass grub and manuka beetle has been identified (Hurst et al. 2018). *Serratia proteamaculans* (AGR96X) was isolated from diseased grass grub larvae and in laboratory bioassays was found to kill 90-100% of grass grub larvae within 5-12 days of ingestion. The rapid kill of grass grub larvae post ingestion of AGR96X, suggests a mode of action similar to an insecticide (Hurst et al. 2018). During the infection of grass grub 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).

This report summarises three years of research where the objective was to determine field efficacy of AGR96X for control of grass grub in autumn sown wheat and barley crops, compared with an organophosphate insecticide SuSCon® Green, and a neonicotinoid insecticide, Poncho® (a.i. 600 g/L clothianidin).

Methods

Methods were similar in all three seasons. A brief description is presented below and detailed descriptions are provided in Appendix 1 for 2019-20, Appendix 2 for 2020-21 or Appendix 3 for 2021-22.

Methods in common between years include assessing the background disease level of grass grub larvae populations by placing individual larvae in individual cells of ice cube trays with a small piece of fresh carrot (approximately 3 mm cube). After 12 days, the larvae were assessed visually for disease symptoms. Prior to planting at least ten spade squares along two transects were dug in the target paddock to determine background larvae populations. The minimum threshold was 90 larvae/m^2.

AGR96X was applied via an inert organic granule, designed to be drilled with the seed, containing 3.98×10^8 cells/gram at an application rate of 30 kg/ha. When applied in combination with AGR626 (1.81×10^9 cells/gram), 15 kg of both AGR626 and AGR96X were applied. Poncho® was applied at 60 mL/100 kg seed and SuSCon Green® was drilled with the seed at 15 kg/ha. Additional products were included in some years at rates as described by the manufacturer.

In all seasons, the cereal was pre-treated with Raxil® star (a.i. 25 g/L tebuconazole, applied at 1.0 L/t seed) and all experiments were direct drilled at a target plant population between 150 and 175 plants/m^2 using a custom built, double disc, cone seeder. Individual plots sizes ranged from 13.5 - 42 m^2 and there was a minimum of five replicates per treatment.

All experiments were irrigated, and all other crop inputs, were managed by the host farmer.

Eight weeks after planting, three spade squares were dug near the centre of 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.

Plots were harvested with a Sampo plot combine at the same time as the surrounding field, with grain yield data adjusted to 14.5% grain moisture content.

Results and Discussion

Year 1

Field collected larvae were assessed for latent signs of disease 10 days after collection (24 June 2019). The untreated control had the lowest level of mortality/disease at 19% (Figure 1). The highest mortality/disease was seen in the three bacterial treatments (58-60%) and the Poncho® (clothianidin) treatment (48%). Mortality/disease was intermediate in the SuSCon Green® and GrubZero treatments (41-42%) (Figure 1).

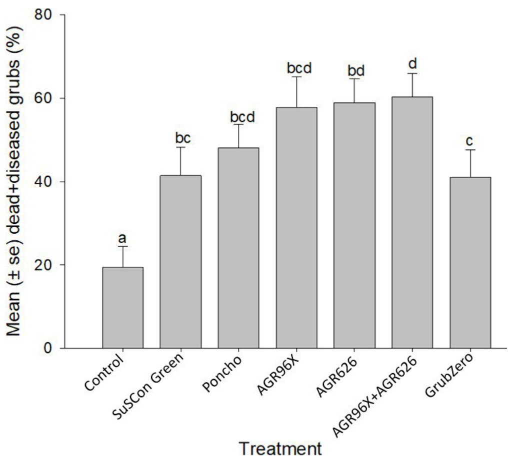

Figure 1. Mortality and disease (%) observed in grass grub larvae collected from wheat, cultivar Griffin treated with insecticides (SuSCon Green®, Poncho®), prototype biopesticides containing *Serratia* spp. (AGR96X, AGR626), or GrubZero grown near Southbridge in the 2019-20 growing season. Treatments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

For statistical analysis, plant numbers were assessed at 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. 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 in the 2019-20 season were high due to favourable environmental conditions during grain filling. Yield was, however, increased by SuSCon® Green and Poncho® above the untreated control (Table 1). 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 (27th Aug)	Heads/m^2	Grain Yield (t/ha)
Untreated	75	630	10.98 a
SuSCon® Green	75	670	12.11 b
Poncho®	93	660	11.95 b
AGR96X	70	700	11.11 ab
AGR626	79	630	10.92 a
AGR96X + AGR626	81	680	11.65 a
GrubZero	71	620	10.72 a
P value	**0.147**	**0.646**	**0.01**
LSD (p=0.05)	**NS**	**NS**	**0.87**

[1]Treatments that share a common letter do not differ at the 5% significance level

Year 2

The plant population of barley was quickly reduced due to grass grub feeding, with the untreated being one-third the population of the Poncho® based treatments (28 v 86 plants/m^2) (Table 2). The barley in the Poncho® followed by (f.b.) GrubZero treatments responded in a similar way to Poncho® alone. A similar pattern occurred in the wheat and the final plant populations were not dissimilar from each other. Plant loss was generally less severe in the wheat than the barley. The plants in the GrubZero treatment initially looked healthier than the Poncho treatments and had visibly higher dry matter than the surrounding plots, but this did not translate to a grain yield increase. Plant counts showed that grass grub larvae stopped feeding around the time of GrubZero application.

Table 2. Final plant population of wheat cultivar Discovery and barley cultivar Planet, when sown with a target plant population of 150 plants/m^2 into a population of ~350 New Zealand grass grub larvae/m^2, following seven control options. Trial sown 13th May 2020 at the FAR Arable Research Site, Chertsey. Little letters?

Treatment	Product and rate	[1]Final plant population/m^2	
		Barley	Wheat
1	Nil	28 a	82
2	15 kg/ha SuSCon® Green	75 bc	114
3	Poncho®	85 c	114
4	30 kg/ha AGR96X	61 bc	106
5	30 kg/ha *S. entomophila*	53 ab	95
6	15 kg/ha AGR96X + 15 kg/ha *S. entomophila*	60 bc	101
7	Poncho® f.b. GrubZero - 16.7.20	87 c	124
	LSD (p=0.05)	**28**	**NS**
	P value	**0.003**	**0.125 (NS)**

[1]Treatments that share a common letter do not differ at the 5% significance level

In the barley trial, Poncho®, SuSCon® Green and AGR96X treatments produced the highest grain yields at 8.0, 7.8 and 7.1 t/ha respectively (Table 3). Poncho® f.b. GrubZero responded in a similar way to Poncho® alone. Similarly, in the wheat trial Poncho®, SuSCon® Green and AGR96X producing the highest grain yields. Grain yield was closely related to final plant population in both trials (R^2>0.9, data not shown). There was a trend for treatments involving *S. entomophila* to have reduced plant numbers compared with the best chemical treatments and this difference was significant in barley (Table 3).

Table 3. Grain yield of wheat, cultivar Discovery, and barley, cultivar Planet, with a target plant population of 150 plants/m^2, following seven treatments for the control of the New Zealand grass grub, population ~350/m^2, sown 13th May 2020 at the FAR Arable Research Site, Chertsey.

Treatment	Product and rate	[1]Grain yie			
		Barley			
1	Nil	3.1	d	6.2	d
2	15 kg/ha SuSCon® Green	7.8	a	10.0	ab
3	Poncho®	8.0	ab	10.2	a
4	30 kg/ha AGR96X	7.1	ab	9.0	abc
5	30 kg/ha *S. entomophila*	5.0	c	7.8	c
6	15 kg/ha AGR96X + 15 kg/ha *S. entomophila*	6.9	b	8.6	bc
7	Poncho® f.b. GrubZero - 16.7.20	8.2	a	10.0	a
	LSD (p=0.05)	**1.2**		**1.4**	
	P value	**<0.001**		**<0.001**	

[1]Treatments that share a common letter do not differ at the 5% significance level

Year 3

The plant population was quickly reduced by larval grub feeding from ~120 plant/m^2 on 14 May towards the final populations recorded 21 August 2021. The untreated control had 54 plants/m^2, similar to the 20 kg/ha AGR96X while all other treatments produced approximately 80 plants/m^2 (Table 4). No phytotoxicity effect was recorded for any treatment.

Table 4. Final plant population of wheat, cultivar Whopper, recorded 21 August when sown at a target plant population of 150 plants/m^2 into a population of ~240 New Zealand grass grub larvae/m^2, following ten control options. Trial sown 19th April 2020 at Kowhai farm, Lincoln, New Zealand.

Treatment	Product and rate	Final plant population/m^2
1	Nil	54
2	20 kg/ha AGR96X	60
3	30 kg/ha AGR96X	71
4	Poncho®[a]	71
5	Poncho® + 20 kg/ha AGR96X	83
6	Poncho® + 30 kg/ha AGR96X	78
7	15 kg/ha SuSCon® Green	73
8	Poncho® + 15 kg/ha SuSCon® Green	83
9	Poncho® f.b. GrubZero[1]	70
10	Poncho® f.b. diazinon[2]	85
	LSD (p=0.05)	**16.0**
	P value	**0.004**

[a] Poncho® applied at 60 mL/100 kg seed.

In year 3, grass grub mortality in plots treated with AGR96X alone was significantly higher than the untreated plots and the plots treated only with Poncho® (Chi-squared statistic = 42.874, df = 9, P<0.001, Table 5). Mortality from the AGR96X treatments was similar to or greater than mortality from the combination treatments Poncho® + 15 kg/ha SuSCon® Green, Poncho® followed by

GrubZero, and Poncho® followed by diazinon. The combination of AGR96X with Poncho® did not increase mortality compared with AGR96X alone.

Grass grub mortality also differed between replicates (Chi-squared statistic = 12.411, df = 5, P = 0.030, Table 5), although it is not clear what caused these differences. Substantial rainfall (> 120 mm) from 29 May to 1 June 2021 caused a drainage ditch to overflow into the eastern side of the trial area. This may have influenced mortality in the trial either through waterlogging or possibly movement of AGR96X between plots.

Table 5. Post-trial mean (± se) grass grub mortality (%) for each treatment and each block.

Treatment		**Mean**		**SE**
1	Nil	20.4	d	5.5
2	20 kg/ha AGR96X	41.7	b	7.2
3	30 kg/ha AGR96X	63.0	a	6.6
4	Poncho®[b]	8.3	d	4.7
5	Poncho® + 20 kg/ha AGR96X	54.8	ab	7.8
6	Poncho® + 30 kg/ha AGR96X	44.4	ab	9.7
7	15 kg/ha SuSCon® Green	35.0	bc	7.6
8	Poncho® + 15 kg/ha SuSCon® Green	40.8	b	7.1
9	Poncho® f.b. GrubZero	39.6	ab	7.1
10	Poncho® f.b. diazinon	19.4	cd	7.2
replicate		Mean		SE
1		44.2	a	7.0
2		26.9	b	5.5
3		43.2	a	5.5
4		34.5	ab	5.1
5		45.2	a	5.9
6		33.3	ab	5.7

Means followed by the same letter are not significantly different (P > 0.05).

The two insecticide controls (Poncho®, 10.5 t/ha and bare seed + SuSCon® Green 10.9 t/ha ($LSD_{0.05}$ = 0.76) gave the same grain yield (Figure 2, Appendix 4 Table 8) but with different protection patterns (data not shown). Poncho® provided immediate protection and subsequently lost plants from approximately eight weeks after sowing, while SusCon® Green lost plants soon after plant emergence but provided protection from approximately five weeks after sowing. The highest grain yields were generally provided by treatment that provided both forms of protection, e.g. Poncho® + SuSCon® Green, Poncho® followed by diazinon, Poncho® + 20 kg/ha AGR96X and 30 kg/ha AGR96X.

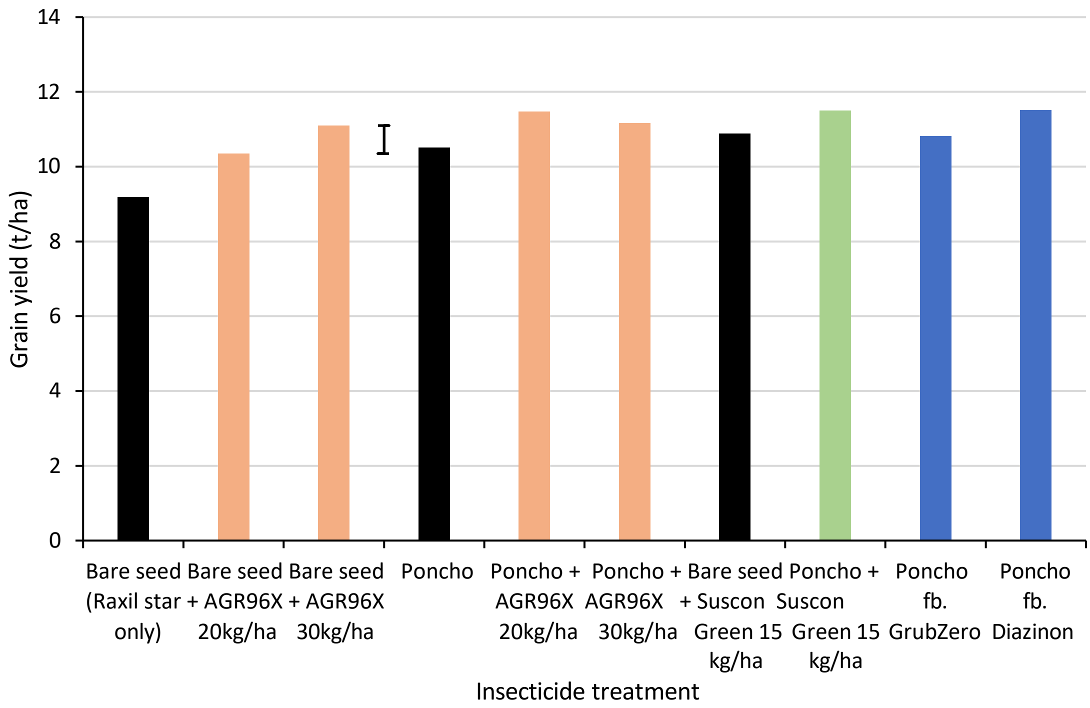

Figure 2. Grain yield of wheat, cultivar Whopper, following treatment with 10 products when sown 19 April at 150 seeds/m^2 into a population of approx. 240 grass grub larvae/m^2 at Lincoln in the 2021-22 growing season. Bar = LSD p=0.05 (0.76).

Summary

The application of 30 kg/ha of AGR96X (*S. proteamaculans*) at planting generated grain yields matching the organophosphate (e.g. SuSCon® Green) or neonicotinoid (Poncho®) treatments in all experimental years. The addition of GrubZero to Poncho® did not improve the efficacy of Poncho®.

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Appendix 1

To determine background disease levels in the grass grub populations, larvae were collected from the 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 larvae 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 larvae/spade square, indicating the field site had >180 larvae/m^2. This exceeded the minimum threshold of 90 larvae/m^2 required for AGR96X trial work.

AGR96X was applied via an inert organic granule drilled with the seed containing 3.98×10^8 cells/gram at an application rate of 30 kg/ha independently and in combination (15 kg of each) with AGR626 (1.81×10^9 cells/gram). 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 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 the product's 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.

Plots were harvested on 24 February with a Sampo plot combine with yield data adjusted to 14.5 % grain moisture content.

Appendix 2
Methods

To determine the background density of grass grub larvae pre-planting, spade squares were dug along 3 transects in the target paddock, with transects approximately 10 m apart. 10 spade squares were dug along each transect, with each sample spaced approximately 5 m apart along the transect. Sampling occurred on 30 April 2020, and there were >8 larvae/spade square on average, indicating the field site had >240 larvae/m^2. This far exceeds the minimum acceptable threshold of 90 larvae/m^2. Prior to the trial being laid down, the site had been in ryegrass pasture for two seasons. This was sprayed out with Roundup® Ultra MAX (2.5 L/ha, a.i. 570 g/L glyphosate) before direct drilling the wheat and barley.

Wheat, cv. Discovery and barley, cv. Planet, were sown on 13 May 2020 in 15 cm row spacing with 5 replicate plots (10 x 1.35 m each) used per treatment. Treatments and application rates are listed in Table 6. All seeds were pre-treated with the fungicide Raxil®Star (a.i. 25 g/L tebuconazole, applied at 1.0 L/t seed); seeds for the neonicotinoid treatment were also pre-treated with Poncho® (a.i. 600 g/L clothianidin, application rate 60 mL/100 kg seed).

Seeds were sown and treatments (except for GrubZero) applied using a custom built, double disc, cone seeder supplied by New Zealand Arable. GrubZero (formulated with BioMarinus hydrolysed liquid fish fertiliser) was applied at 10 L/ha on 16 July when the wheat had two fully expanded leaves.

Table 6. Treatments used at FAR Arable Site, Chertsey, established May 13, 2020.

Treatment No.	Treatment – 13 May 2020	Application method	Application rate
1	Nil	Drilled	Nil
2	SuSCon® Green	Drilled	15 kg/ha
3	Poncho®	Drilled	60 mL/100 kg seed
4	AGR96X	Drilled	30 kg/ha
5	*Serratia entomophila*	Drilled	30 kg/ha
6	AGR96X + *S. entomophila*	Drilled	15 kg/ha of each
7	GrubZero – 16/7/2020	Sprayed	10 L/ha

Post-establishment the trial was assessed for plant emergence, retention, compensation (tillering) and final grain yield. The grass grub larvae population and larval disease assessments were undertaken at 52 days post-application on 25 June 2020. Three spade squares were taken per plot, the soil was sorted in the field and larvae placed into individual wells in tissue culture trays before covering with a small amount of soil. Plant assessments were undertaken at approximately seven-day intervals from 14 days post sowing.

The barley crop was harvested on 2 February and the wheat on 15 February with a Sampo plot combine. All grain yields are reported at 14 % moisture content. All general application details are listed below in Appendix 3.

Appendix 3
Management inputs

Wheat

Sown: 13.05.2020

Molluscicide: 29.05.2020 – 10 kg/ha SlugOut® (18 g/kg Metaldehyde)
10.06.2020 – 10 kg/ha SlugOut® (18 g/kg Metaldehyde)

Herbicide: 18.05.2020 – 2.5L Roundup Ultra® MAX (570 g/L glyphosate as the potassium salt) + 0.5 L Firebird® (400 g/L flufenacet and 200 g/L diflufenican) + Pulse® Penetrant (Organo-silicone penetrant)
24.08.2020 – 3 L Twister® (500 g/L isoproturon) + 20 g Glean® (750 g/kg Chlorsulfuron)
21.09.2020 – 100 g Rexade™ GODRI™ (50 g/kg Arylex active, 150 g/kg pyroxsulam) + Contact™ Xcel (980g/L Linear alcohol ethoxylate)

Nitrogen: 21.08.2020 – 150 kg Nrich SOA (31 kg/N + 34.5 Sulphur)
28.09.2020 – 100 kg/Nitrogen as SustaiN® N (45.9% N)
22.10.2020 – 80 kg/Nitrogen as SustaiN® N (45.9% N)

Fungicide: 09.10.2020 – 1 L Kestrel® (160 g/litre prothioconazole and 80 g/L tebuconazole
02.11.2020 – 1 L Adexar® (Fluxapyroxad 62.5 g/L + Epiconazole 62.5 g/L) + 0.25 L Opus® (Epiconazole 125 g/L)
24.11.2020 – Prosaro® 1 L (Prothioconazole 210 g/L + Tebuconazole 210 g/L)

Irrigation:

Date	Amount (mm
12.05.2020	40
29.09.2020	20
08.10.2020	30
28.10.2020	35
04.11.2020	20
17.11.2020	20
23.11.2020	20
08.12.2020	30
15.12.2020	20
Total	**240**

Barley

Sown:	13.05.2020
Molluscicide:	29.05.2020 – 10 kg/ha SlugOut® (18 g/kg Metaldehyde) 10.06.2020 – 10 kg/ha SlugOut® (18 g/kg Metaldehyde)
Herbicide:	18.05.2020 - 2.5 L Roundup Ultra® MAX (570 g/L glyphosate as the potassium salt) + 0.5 L Firebird® (400 g/L flufenacet and 200 g/L diflufenican) + Pulse® Penetrant (Organo-silicone penetrant) 24.08.2020 – 2 L Twister® (500 g/L isoproturon) + 20 g Glean® (750 g/kg Chlorsulfuron)
Nitrogen:	21.08.2020 – 150 kg Nrich SOA (31 kg/N + 34.5 Sulphur) 10.09.2020 – 80 kg/Nitrogen as SustaiN N (45.9% N) 28.09.2020 – 60 kg/Nitrogen as SustaiN N (45.9% N)
Fungicide:	09.10.2020 - 0.4 L Pilot™ (250 g/L Prothioconazole + 0.6 L Seguris Flexi® (125 g/L Isopyrazam) and 1.5 L Phoenix® (500 g/L Folpet) 02.11.2020 – 0.4 L Pilot® (250 g/L Prothioconazole) + 0.6 L Seguris Flexi® (125 g/L Isopyrazam)
Irrigation:	As above for wheat trial.

Appendix 4
Methods

The background density of grass grub larvae was established pre-planting by digging spade squares along transects in the target area. Two transects approximately 10 m apart with 10 spade squares were dug along each transect, each sample spaced approximately 5 m apart. On average there were 8 larvae/spade square indicating the field site had ~240 larvae/m^2. This far exceeds the minimum acceptable threshold of 90 larvae/m^2. Prior to planting, the site had been in ryegrass pasture for one season preceded by Faba beans. Prior to planting the area was sprayed out with Roundup® Ultra MAX (2.5 L/ha, a.i. 570 g/L glyphosate). On the day of planting the area was mown to 5 cm and the clippings removed prior to before direct drilling on 19 April 2021. Wheat, cultivar 'Whopper', was sown in 15 cm row spacing at a target seed rate of 150 seeds/m^2 (93 kg/ha), there were 6 replicate plots (10 x 1.35 m each) per treatment. Treatments and application rates are listed in Table 7. All seeds were pre-treated with the fungicide seed treatment, Raxil® Star (a.i. 20 g/L fluopyram, 100 g/L prothioconazole and 60 g/L tebuconazole), seeds for the neonicotinoid treatment were also pre-treated with Poncho® (a.i. 600 g/L clothianidin, application rate 60 mL/100 kg seed). The same seed line was used for all treatments.

Seeds were sown and treatments applied on 15 April 2021, except for GrubZero and Dew™ 600 (a.i. 600 g/L diazinon, using a custom built, double disc, cone seeder supplied by New Zealand Arable. GrubZero (formulated with BioMarinus hydrolysed liquid fish fertiliser) was applied at 10 L/ha and Dew™ at 4 L/ha on 8 June when the wheat had 2 fully expanded leaves.

Post sowing the trial was assessed for plant emergence and retention by counting the number of alive seedings per 1m of row at two constant locations in each plot at approximately seven-day intervals from 14 days post sowing. The ability of plants to compensate (tillering) was determined by a head count at grain harvest.

The grass grub larvae population and larval disease assessments were undertaken at 54 days post-planting on 8 June 2021. Three spade squares were taken per plot, the soil was sorted in the field with all grass grub larvae placed into individual wells in tissue culture trays before covering with a small amount of soil. Larvae were taken back to AgResearch (Lincoln) and put through a standard feeding bioassay to assess mortality. Mortality (%) was determined for each plot (= dead larvae from field collection + deaths during bioassay).

Table 7. Treatments used at Kowhai farm to protect wheat seedlings from feeding by grass grub larvae when sown 19 April 2021.

Treatment	Product	Application method	Application rate
1	Nil	Drilled	Nil
2	AGR96X	Drilled	20 kg/ha
3	AGR96X	Drilled	30 kg/ha
4	Poncho®	Drilled	60 mL/100 kg seed
5	Poncho® + AGR96X	Drilled	60 mL/100 kg seed + 20 kg/ha
6	Poncho® + AGR96X	Drilled	60 mL/100 kg seed + 30 kg/ha
7	SuSCon® Green	Drilled	15 kg/ha
8	Poncho® + SuSCon® Green	Drilled	60 mL/100 kg seed + 15 kg/ha
9	Poncho® f.b. GrubZero[1]	Drilled f.b. sprayed	60 mL/100 kg seed + 10 L/ha
10	Poncho® f.b. Dew™	Drilled f.b. sprayed	60 mL/100 kg seed + 4 L/ha

[1] f.b. = followed by.

The crop was harvested on 23 February 2022 with a Sampo plot combine, grain yield is reported at 14% moisture content. All general application details are listed below in Appendix 1.

Plant and yield data were analysed via General Analysis of Variance with means separation via Least Significant Difference (LSD) test and linear regression within Genstat®19 (VSN 2019). Mortality (%) was analysed and compared using a generalised linear model (GLM) with binomial distributions through a logit link function to test for treatment and block effects using Minitab version 16.

Management inputs

Sown:	19/4/2021
Molluscicide:	20/4/2021 – 10 kg/ha SlugOut®
	4/5/2021 – 10 kg/ha SlugOut®
	5/7/2021 – 10 kg/ha SlugOut®
Herbicide:	20/4/2021 – 150 mL/ha Sakura® + 40 mL/ha Karate
	1/7/2021 – 3 L/ha Image
	9/9/2021 – 100 mL/ha Rexade™ + 250 mL/100L Contact
	2/11/2021 – 750 mL Starane™ applied
Nitrogen:	9/9/2021 – 250 kg/ha SOA
	5/10/2021 – 120 kg N/ha applied (Urea)
	11/11/2021 – 40 kg N/ha applied (Urea)
Fungicide:	20/10/2021 – 1 L/ha Prosaro® applied
	10/11/2021 – 1.5 L/ha Revystar®
	1/12/2021 – 0.7 L/ha Opus + 0.4 L/ha Comet

Table 8. Grain yield of wheat, cultivar Whopper, following treatment with 10 products when sown 19 April at 150 seeds/m^2 into a population of approx. 240 grass grub larvae/m^2 at Lincoln in the 2021-22 growing season.

Treatment	Products	t/ha	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
1	Bare seed (Raxil star only)	**9.2**[a]	10.5	9.9	9.7	8.6	7.8	8.6
2	Bare seed + AGR96X 20kg/ha	**10.4**	12.4	10.7	10.7	8.7	10.5	9.2
3	Bare seed + AGR96X 30kg/ha	**11.1**	12.1	11.3	11.6	10.6	11.7	9.4
4	Poncho	**10.5**	11.8	11.8	11.4	9.9	10.9	7.2
5	Poncho + AGR96X 20kg/ha	**11.5**	12.5	11.3	11.6	11.9	11.9	9.6
6	Poncho + AGR96X 30kg/ha	**11.2**	12.1	12.0	11.8	11.9	10.0	9.2
7	Bare seed + Suscon Green 15 kg/ha	**10.9**	11.8	11.7	11.8	10.1	10.9	8.9
8	Poncho + Suscon Green 15 kg/ha	**11.5**	12.6	12.4	11.2	11.8	12.0	9.1
9	Poncho fb. GrubZero	**10.8**	12.4	11.1	10.3	10.7	10.7	9.8
10	Poncho fb. Diazinon	**11.5**	12.5	12.0	11.7	12.0	11.5	9.3
	Mean	**10.85**						
	P value	**<0.001**						
	SEM	**0.25**						
	LSD (p=0.05)	**0.76**						

[a] Figures in yellow indicate treatments which are among those producing the greatest grain yield.

Beneficial biodiversity for greater good

Project Code X20-08-00

Duration Year 1 of 5 (2021-2022)

Author Abie Horrocks (FAR)

Location Canterbury

Funding Ministry for Primary Industries, Sustainable Food and Fibre Futures programme.

Acknowledgements Stephen Brailsford (Brailsfords Ltd), Brad Howlett, Melanie Walker and Melanie Davidson (New Zealand Institute for Plant & Food Research), all the farmers and growers with old and new biodiversity plantings involved in the project.

Key Points

- Many native plants can support a diversity of beneficial insects capable of improving pollination and suppressing pest populations on arable farms.
- FAR's Chertsey Arable site is part of a research programme aiming to improve understanding of how to maximise the flow on benefits insects provide to farms.
- Preliminary results show that insect pollinators were more abundant and diverse near old mixed native plantings compared with new plantings or bare fence sites. For the natural enemies of aphids, the trend was more dependent on the sampling method used than location.
- The small orange hoverfly adult was the most common insect pollinator species caught in sweep net samples. The orange hoverfly larvae are predators of small soft-bodied insects such as aphids.
- Percentage parasitism of white butterfly larvae by parasitic wasps was highest on kale plants near new mixed native plantings (58%), followed by old mixed native plantings (47%) and lowest on plants beside bare fences on control farms (36%).
- Harnessing the benefit of beneficial insects in the crop depends on the selectivity of insecticides used as the choice of insecticides can have a big impact on the micro and macro invertebrates present.

Background

Plant & Food Research received funding from the Ministry for Primary Industries Sustainable Food and Fibre Futures (SFFF) in 2021 for a project called 'Beneficial Biodiversity for Greater Good - designing native plantings for beneficial insects'. Previous Sustainable Farming Fund research had found many native plants could support a diversity of beneficial insects without also creating a reservoir for pests (Davidson et al. 2015). For insect pollinated crops, biodiversity plantings can improve crop yields by supporting a range of efficient crop pollinating species such as native bees and flies. Enhancing pollinator diversity allows different pollinators to work in tandem providing better and more resilient pollination. For example, if weather conditions are too cold, honey bees won't visit flowers, but some fly pollinators prefer these conditions. There is also significant potential for native plantings to reduce on-farm pesticide use by providing a habitat for predatory insect species such as bristle flies (tachinids) and hover flies (Figure 1).

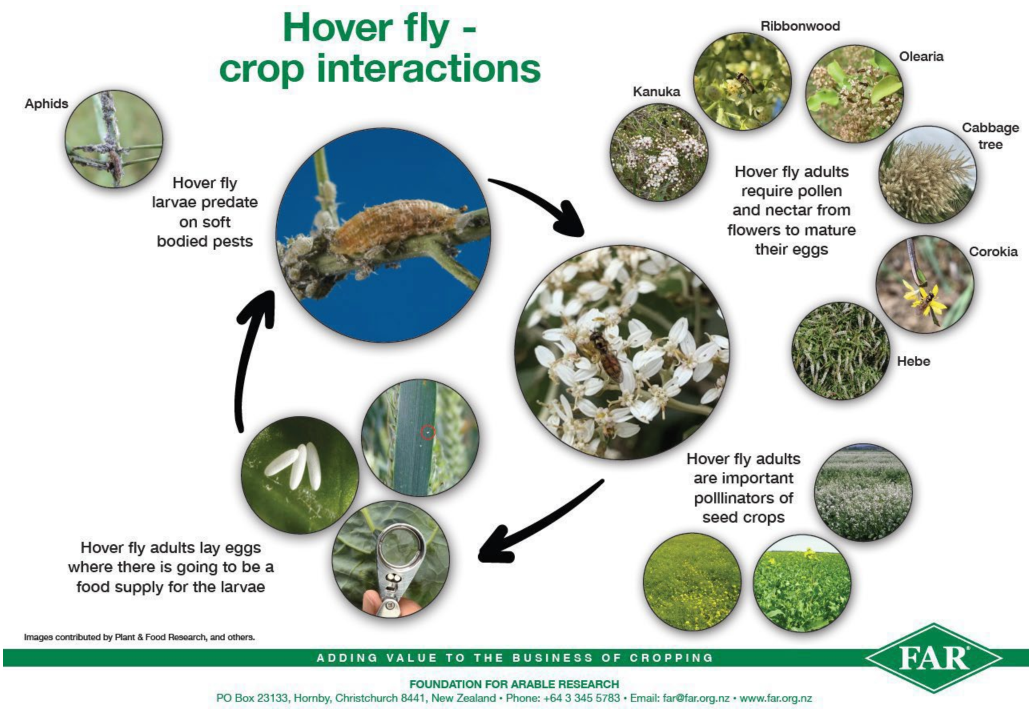

Figure 1. Hover fly crop interactions for the different stages of its life cycle.

An important next step is to find out what insect species are supported by native planting across different farm types and then how to maximise the flow on benefits they provide to these farms. FAR's Chertsey Arable site is one of the sites included in the programme where the research will primarily focus on pollination and pest suppression.

Methods

The project was established to compare insect diversity and abundance associated with old mixed native plantings that were planted between 2013 and 2018 (nine sites), to sites with new mixed native plantings (19 sites established on cropping, dairy and other livestock farms) and sites without any native vegetation (23 bare wire fence sites). All project sites are in Canterbury (Selwyn, Ashburton and Waimakariri districts).

The FAR Chertsey Research site is one of the 19 new mixed native plantings sites where plantings were carried out in 2020 and 2021 (Table 1, Figure 1). The primary function for the plantings was to support alternative pollinators and beneficial insects. Priority plant species (those associated with beneficial herbivorous insect species) comprised a minimum of 80% of the total number of plants established. The peripheral plant species were included to fill gaps in canopy and/or help suppress weeds, or provide a sub canopy layer. The priority plant species included Tī kōuka/cabbage tree (*Cordyline australis*) and Koromiko/shore hebe (*Veronica salicifolia*). These plants support more than 30 different species of pollinating insect. Other plant species known to support many beneficial insects include Kānuka (*Kunzea ericoides*, *K. robusta* and *K. serotine*), Harakeke (flax, *Phormium tenax*) and Tauhinu (cottonwood, *Ozothamnus leptophyllus*) that support at least 20 insect pollinators. Plant species that are expected to support beneficial insects, but have not been well studied because of their scarcity in agricultural environments, were also planted. These include several *Olearia* species, Wharariki/mountain flax (*Phormium cookianum*), Tororaro (*Muehlenbeckia astonii*) and Teucridium (*Teucrium parvifolium*). These species were included to improve our understanding of the role they can play to support beneficial insects on farm. A range of *Coprosma* species were included in low numbers as they are an important understory component of an ecological mix providing good ground cover and shade tolerant understory screening. Low stature shelterbelt options were chosen for underneath power lines. Where power poles were not present a double row combination of small trees and shrub understory were planted. Where space was limited a single line of small trees and shrubs was planted.

Table 1. The plant species established at the FAR Chertsey Site (2020-2021), the number of insect species known to visit the flowers and flowering time of the plants. An '*' indicates there is no information currently available. Flowering time depends on location and can vary between years.

Plant species	Māori name	Common name	No. pollinator species[1]	Flowering time
Carpodetus serratus	Putaputawētā	Marble leaf	8	Nov. - March
Cordyline australis	Tī kōuka	Cabbage tree	31	Sept. - Jan.
Griselinia littoralis	*	Broadleaf	1	Sept. – Dec.
Hoheria angustifolia	Houhi	Narrow-leafed lacebark	17	Dec. - Feb.
Kunzea ericoides	Kānuka	Kanuka	21	Oct. - Feb.
Kunzea serotina	Makahikatoa	Kanuka	26	Nov. – May
Lophomyrtus obcordata	Rōhutu	NZ myrtle	6	Nov. - March
Olearia paniculata	*	Golden akeake	5	March – Aug.
Pittosporum eugenioides	Tarata	Lemonwood	13	Oct. - Dec.
Pittosporum tenuifolium	Kōhūhū	Black matipo	5	Oct. - Dec..
Plagianthus regius	Manatu* check	Ribbonwood	18	Sept. – Nov.
Pseudopanax arboreus	*	Five finger	2	June – Aug.
Pseudopanax crassifolius	Horoeka	Lancewood	2	Jan. - April
Pseudopanax ferox	*	Toothed lancewood	1	Nov. - April
Sophora microphylla	Kōwhai	Weeping kowhai	6	May - Oct.
Sophora prostrata	Kōwhai	Prostrate kowhai	1	Sept. – Oct.
Teucrium parvifolium	*	NZ shrub verbena	*	Oct. – Jan.
Carmichaelia australis	Mākaka	NZ broom	12	Oct - Feb.
Corokia cotoneaster	Korokio	Wire-netting brush	16	Oct. - Jan.
Coprosma sp.	Mikimiki		*	*
Melicytus alpinus	*	*	*	Nov. – Jan.
Muehlenbeckia astonii	*	*	13	Aug. – Jan.
Muehlenbeckia complexa	*	*	*	Dec. – Feb.
Myrsine divaricata	*	Weeping matipo	1	*
Olearia avicenniifolia	*	Mountain akeake	12	Feb. - March
Olearia adenocarpa	*	Canterbury Plains tree daisy	*	Jan. - Feb.
Olearia cheesemanii	*	Streamside tree daisy	*	Aug. - June
Olearia solandri	*	Coastal tree daisy	*	*
Ozothamnus leptophyllus	Tauhinu	Cottonwood	26	Nov. - Feb.
Phormium cookianum	Wharariki	Mountain flax	14	Oct. – Nov.
Phormium tenax	Harakeke	Flax	20	Sept. - Jan.
Veronica salicifolia	Koromiko	Willow-leaf hebe	32	Oct. - July

[1] Published research, grey literature (reports and unpublished data). Information was also obtained from the databases PlantSynz™ for insect pollinators and New Zealand Plant Conservation Network (NZPCN) for flowering time.

Figure 1. Before and after photos as the FAR Chertsey Research, one of 19 new mixed native plantings sites that are part of an MPI, Sustainable Food and Fibre Futures project 'Beneficial Biodiversity for Greater Good - designing native plantings for beneficial insects'. Plantings were carried out in 2020 and 2021.

Key insect taxa (species, genera, family, order, etc.) were identified to the lowest taxonomic level possible in each case, then counted and recorded at each site using three collection methods (intercept traps, pitfall traps and sweep netting). The relative diversity and abundance of insects was measured at each site for 7-15 days in November 2021 by two window intercept traps (insects moving through the air) and five pitfall traps (insects moving along the ground). Sweep net sampling to monitor diversity and abundance of beneficial insects was carried out at selected sites.

An ecosystem services evaluation of potential insect pollinators was carried out using flowering pak choi plants (15 pots per site) that were placed near the field boundary of a new or old mixed native planting or beside a bare wire fence. Bare wire fence sites were located on farms with native plantings (treatment farms) or without any known native plantings (control farms). The day after potted plants were placed in the field the number and species of insects that visited the pak choi flowers was observed for 5 minutes at each site, at 6 time points between 9.30 am and 4 pm. Assessments were carried out in December 2021, January 2022, February 2022, and March 2022. A natural pest suppression evaluation was carried out using potted kale plants (24 plants per site) that were placed in similar fashion to the pak choi plants. Crop plants or potted plants were surveyed weekly from the first week of February to the end of March 2022. At the end of the survey period, 10-12 of the potted kale plants per site were collected and the number of pests, predators, parasitoids, and parasitised insects were recorded. The older lepidoptera larvae (body length ≥1.5 cm) were dissected to determine if parasitic wasp larvae were present.

Results and Discussion

Preliminary results from site comparisons show that insect pollinators were more abundant and diverse near old mixed native plantings than near new plantings or bare fence sites. For natural enemies, sampling method had more of an effect than location. For the window intercept and pitfall traps there were more natural enemies at the new planting sites whereas with the sweep net sampling there were more natural enemies at the old mixed native plantings sites (Table 2).

The small orange hoverfly adult was one of the most common insect pollinator species caught in sweep net samples in both the February and March samples. The orange hover fly larvae are predators of small soft-bodied insects such as aphids (Figure 1).

The most common pest species recorded depended on the sampling method; in window and pitfall traps it was grass grub adults, in sweep net samples it was wheat bug adults, and on potted kale it was white butterfly larvae. Grass grub and white butterfly were more abundant at old mixed native plantings, while wheat bugs were most abundant near new mixed native plantings (preliminary data do not factor in the timing or selectivity of insecticides used in the adjacent paddocks).

For the ecosystem services evaluation, the diversity of insects observed was greater visiting the pak choi flowers at the old mixed native plantings (n_{taxa} = 23), than potted pak choi flowers at the bare fence on treatment farms (bare fence lines near native plantings) (n_{taxa} = 19) followed by the diversity at the new native planting sites (n_{taxa} = 13) and control bare fence lines (bare fence lines not near native plantings) (n_{taxa} = 12).

For the natural pest suppression evaluation, the potted kale plants that had the greatest number of natural enemies recorded were from new mixed native planting sites (average per plant = 2.6), followed by old mixed native (average per plant = 1.5), with the lowest numbers from kale plants at bare fence lines on treatment and control farms (average per plant = 0.5) (Table 2).

Table 2. A summary of the main preliminary results. Abundance was measured as total number of insect pollinators, natural enemies, or pests. Diversity describes the number of taxa recorded. Old = old mixed native plantings, New = new mixed native plantings, Bare = bare wire fence lines. N.A. = the method was not applicable to the measure for that insect group.

Sampling method	Measure	Insect pollinators	Natural enemies	Pests
Window intercept traps	Abundance	Old > New or Bare	New > Old = Bare	**Old > Bare > New**
	Diversity	Similar	similar	**N.A.**
Pitfall traps	Abundance	N.A.	New > Old > Bare	**Old > Bare > New**
	Diversity	N.A.	similar	**N.A.**
Sweep net samples	Abundance	New > Bare > Old	Old > New > Bare	**New > Bare > Old**
	Diversity	Similar	Old > New > Bare	**N.A.**
Insect pollination	Abundance	Old > New or Bare	Old > New or Bare	**N.A.**
	Diversity	Old > New or Bare	Old > New or Bare	**N.A.**
Natural pest suppres sion	Abundance	N.A.	New > Old > Bare	**Old > New > Bare**
	Diversity	**N.A.**	**New > Old > Bare**	**N.A.**

The kale plants collected from the old mixed native plantings at the end of the potted kale experiment had more natural enemies and pests than from other boundary types. White butterfly neonate larvae were the most common pest recorded on kale plants collected from beside old mixed native plantings. Percentage parasitism of white butterfly larvae was highest on kale plants near new mixed native plantings (58%), followed by old mixed native plantings (47%) and lowest on plants beside bare fences on control farms (36%), Table 3.

Table 3. The percentage (%) of white butterfly larvae that were parasitised, and the percentage of white butterfly older larvae relative to number of neonate larvae recorded from the field collected potted kale plants (indicates survival of white butterfly larvae from neonate to older larval stages).

Boundary	% of parasitised white butterfly larvae	White butterfly larvae survival (%)
Old Mixed Native	47	**15**
New Mixed Native	58	**21**
Treatment farm, bare fence	43	**27**
Control farm bare fence	**36**	**58**

Summary

Although more data are required, to date insect pollinators appear to be more abundant and diverse near old mixed native plantings than new plantings or bare fence sites (for natural enemies the trend was more dependent on the sampling method used).

As is being demonstrated in this study, many paddocks can have high numbers of predators and parasitoids that can contribute to pest control, so smart plantings and rational insecticide use are important to enable beneficials to continue to work undisrupted alongside insecticides. Insecticides can have a big and varying impact on the micro and macro invertebrates present.

For more information on using an integrated approach to pest management (IPM) refer to the FAR Focus 12: Integrated Pest Management which is available on the FAR website.

References

Davidson, M, Howlett, B, and Walker, M (2015) Building better biodiversity on cropping farms. A Plant & Food Research report prepared for FAR. SPTS No. 11772.