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DEVELOPING A SUCCESSFUL NITROGEN MITIGATION STRATEGY IN A MAIZE GRAIN - CATCH CROP PRODUCTION SYSTEM

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Abstract

Two small-plot replicated trials were initially established on two Waikato soils (clay and ash) in 2019 to evaluate the success of 11 catch crop cultivar species and establishment timing options after maize grain harvest. Maize plots were planted in spring and catch crop treatments were applied either between V5 maize development stage or after maize harvest. The catch crop options were selected on their ability to grow in winter, “mop” rather than add to soil nitrogen (N), and for their use as forage. The species included perennial ryegrass, Italian ryegrass and oats, and were either direct drilled, disc-and-drilled or broadcasted as a monoculture, or in a mix with plantain.

The five best-performing catch crop species and timing treatments were then selected for further trialling in 2020 and 2021. These consisted of Italian ryegrass and oats that were either interseeded at V5 maize development stage, broadcast at the maize brown husk stage, or either direct drilled or disc-and-drilled after maize grain harvest. The most consistent catch crop treatments were further tested via 15 on-farm sites across four North Island regions of New Zealand to demonstrate commercial feasibility.

The most successful catch crop treatments from the replicated trials were the broadcast Italian ryegrass at brown husk maize stage, direct drilled oats, and disc-and-drilled Italian ryegrass options. The V5 treatment was the most inconsistent, resulting in either the greatest or least amount of soil N removal, depending on soil type and season.

Over both years, catch crop N removal rates from the various treatments tested were greater on ash than clay soil (by 0.2–3.1 and 2.2–7.5 fold in 2021 and 2022, respectively). In 2022, catch crop cultivar had a greater impact on success than establishment method on the ash site. Oats significantly outperformed Italian ryegrass options in terms of N removal, by up to 81%. However, under the same establishment method in 2021 the amounts of N removal were similar between species. On the clay soil site in 2022, establishment method had the greatest impact on success, whereby direct drilled oats and ryegrass broadcasted at the brown husk stage outperformed the disc-and-drill options by almost 50%.

Across the on-farm trials, conditions were particularly wet making post-harvest establishment of catch crops difficult. Consequently, the brown husk stage treatment

removed more N than direct drilled oats. The lower amounts of N removed by the oats was attributed to their lower N content, rather than a reduced biomass yield.

These results show that catch crops can successfully be adopted into maize grain rotations to reduce the risk of N leaching. Importantly, the methodology and choice of catch crop should be selected on a case-by-case base by considering the soil type and climatic conditions. Both broadcast Italian ryegrass at the brown husk stage (particularly on clay soils) and drilled (direct drilled or following discing) oats or Italian ryegrass (or a combination of both) post-maize harvest can improve the success, sustainability and environmental impact of these systems.

Introduction

Maize is grown on approximately 80,000 ha nationally, of which 40% is grown in the Waikato region (Arable Industry Marketing Initiative 2022). About 80% of maize is grown for silage which is used as supplementary feed for dairy cows. The remaining 20% is grown for grain for stock or compound feed, food corn, industrial use and export. The area of maize grown is predicted to rise in the next 5 years by as much as 20,000 ha as the dairy industry looks to transition from existing supplemental feed sources (e.g. palm kernel extract) to other more sustainable, locally-grown feed sources. However, as maize often requires large amounts of nitrogen (N), there is a risk of it contributing to environmental degradation if fertilizer applied exceeds crop needs. Addressing this issue is therefore a high priority to support the industry and ensure future growth is sustainable.

As a general rule, about 12 kg N is removed per tonne (t) of maize grain dry matter (DM) produced (Bender et al. 2013). In the last 20 years average maize yields have ranged between 12 and 15 t/ha (grain, 14% moisture) and 20 and 25 t DM/ha (silage). Very high performing crops can yield in excess of 17 t/ha (grain) and 28 t DM/ha (silage), whereas very poor performing crops can yield as low as 5 t/ha (grain) and 12 t DM/ha (silage). Crop yield differences are largely due to variation in management or in seasonal weather variation, especially in rainfall, radiation and temperature (Teixeira et al. 2016). Clearly, yield potential has a big effect on N use efficiency and therefore the risk of environmental losses. For example, in the event a grain crop has been fertilised to achieve 16 t/ha and only achieves 10 t/ha, about 80 kg N/ha left over in the soil after harvest could potentially be lost during winter months.

The majority of the annual rainfall in New Zealand falls in winter when evapotranspiration losses are at their lowest, resulting in water draining from the soil profile, and with it, N. For instance, in most North Island areas on the East Coast and north of Taupo, only 40% of the annual rainfall (approx. 1,200 mm) occurs during spring and summer (NIWA 2021). Through intensification of primary production systems, N leaching losses attributed to N fertilisers are estimated to have almost doubled between 1990 and 2012 (Ministry for the Environment 2014).

While maize silage paddocks are typically planted into annual ryegrass in early autumn, maize grain and late-harvested silage paddocks are normally left fallow over winter, exposing the soil to a greater risk of N and sediment losses. They are fallow because conditions after harvest are often too wet and/or cold for permanent pasture establishment, and the often large amounts of surface stover remaining after maize grain make establishing subsequent crops in winter difficult. Therefore, new and novel ways of reducing the risk of environmental contamination are necessary to explore.

Catch crops, sometimes referred to as cover crops, can be effective in ‘mopping up’ excess soil N before it is lost, either to the atmosphere or to surface and ground water (Carey et al. 2016; Thapa et al. 2018; Carey et al. 2019; Malcolm et al. 2022). While annual ryegrass has been widely adopted in maize silage rotations as a winter feed, there are other winter options to consider that not only provide productivity and feed quality gains, but more efficient uptake of surplus N during cooler winter months (Carey et al. 2017). Research has shown that winter active catch crops are very effective at reducing potential N leaching losses during the winter period (Malcolm et al. 2018). In the case of excess soil N after maize harvest, a suitable winter catch crop has the potential to be used as a mitigation tool and a form of insurance against N leaching. Among other factors, successful establishment of a winter catch crop is largely influenced by timing of sowing, the species used, and the soil and weather conditions.

After an initial field screening of suitable catch crop species and sowing methodologies in the year prior to the present study, the objective here was to identify the most effective catch crop option (including species and sowing timing) after maize grain on both clay and ash soils. The anticipated outcome from this research was identifying which of the selected catch crop/s can establish well and have high winter growth (reducing the risk of N leaching losses) while fitting within the farming system and having sufficient feed/economic value to offset associated costs. Even though the current study focuses on catch crop establishment after maize for grain, the results are also considered relevant for late harvested maize silage crops.

Methodology

Field plot experiments were set up on two commercial properties in the Waikato region, representing two of the key soil types used for growing maize: ash (Typic Orthic Allophanic Soils; 37°57'S 175°14'E, 37 m above sea level) and a clay (Mottled Orthic Brown Soils; 38°03'S 175°19'E, 37 m above sea level) (Manaaki Whenua 2019). In the spring of 2019, 2020 and 2021 maize (cv. P0640) plots were planted at both properties in 76 cm wide rows at a target plant population of 100,000 plants/ha.

Base and starter fertiliser and pre-emergence herbicide applications for the maize growing phase were consistent with the pre-planting soil test result at each site. Sidedressing urea fertiliser and post emergence herbicide were applied at approximately the V5 maize growth stage (3–4 weeks after emergence) at 200–230 and 138–209 kg N/ha, in 2020-21 and 2021-22, respectively and 200 ml/ha product of Arietta® (active ingredient: Topramezone).

At both sites, the catch crop plots were established during or after maize grain crops in both 2020 and 2021. The treatments were arranged as a randomised block design, with plots approximately 3 m wide by 15 m long). The treatments imposed in both years are detailed in Tables 1 and 2.

Immediately after N side dressing at the V5 development stage, an Italian ryegrass catch crop was drilled between maize rows of randomly designated maize plots using a modified inter-seeder. The remaining plots were either 1) broadcast by hand with Italian ryegrass at the brown husk development stage to simulate aerial broadcasting by helicopter, 2) direct drilled oats following maize harvest, or 3) disc-and-drilled oats or Italian ryegrass following maize harvest. Italian ryegrass (cv. Tabu) and greenfeed oats (cv. Hattrick) were drilled using a commercial drill at seeding rates of 25 kg seed/ha and 100 kg seed/ha, respectively. The brown husk treatment of Italian ryegrass was broadcast at 30 kg seed/ha to allow for potential establishment issues associated with broadcasting seed. Other than the fallow treatment, all plots received 25 kg N/ha and slug bait at the time of drilling or broadcasting the catch crop to ensure successful establishment.

Table 1. Details of the catch crop treatments imposed during maize growth or after maize harvest during the 2020-21 and 2021-22 growing seasons at both experimental sites (Ash and Clay).

Treatment no.	Catch crop sowing timing	Catch crop species	Method of catch crop establishment	Number of replicates
1.	Nil (fallow)	-	-	4
2.*	V5	Italian ryegrass	Inter-seed	4
3.	Brown husk	Italian ryegrass	Broadcast	4
4.	Post-harvest	Italian ryegrass	Disc-and-drill	4
5.	Post-harvest	Oats	Disc-and-drill	4
6.	Post-harvest	Oats	Direct drill	4

*included in the 2020-21 growing season only

Catch crop biomass and N uptake patterns were determined on various occasions throughout the catch crop growth cycle, with final harvests occuring on 6 October and 4 October in 2020 and 2021, respectively. On each sampling occasion, above-ground biomass was measured in each plot from two 0.5 x 5 m mechanical mower passes. Cuts were made to residuals of 5 cm (Italian ryegrass) and 8–10 cm (oats) and then weighed fresh. A subsample (approximately 1 kg) was oven dried at 65°C to determine percent DM. A separate subsample was also sent to Hills Laboratories for total N content analysis. Biomass and N concentration in this tissue was used to determine crop N uptake on each sampling occasion.

Nitrogen leaching loss measurements were also obtained from maize grain plots at the clay soil site using ceramic suction cups (25 mm wide by 55 mm long) (Francis et al. 1992). This consisted of an array of four automated suction cup samplers placed at 120 cm below the soil surface in each plot, spaced 2.5 m apart. Each cup was connected to two 4 mm tubes leading to a central collection point. One tube was used to initiate a vacuum to allow soil water around the cup to be sampled (drawn into the cup), and the second a pressure, enabling the sampled water within the cup to be pushed through into small collection vessels. Adjacent to the trial were a total of six 50 cm diameter by 120 cm deep monolith lysimeters, used for determining drainage volume. Three lysimeters remained fallow, while the other half were sown in Italian ryegrass (as in the trial). Samples from the suction cups were obtained whenever drainage from the lysimeters was recorded. Suction cup samples were analysed for nitrate and ammonium concentration by flow injection analysis (FIA) (Gal et al., 2004; Tecator Inc., Sweden). Nitrogen leaching losses were then calculated for each plot (average of all four suction cups) on the basis of N concentration from the suction cups and drainage volume from the lysimeters.

In addition to replicated trials, the best three catch crop treatment options were extended to 15 on-farm extension trial sites across the Bay of Plenty, Waikato, Rangitikei and Manawatu regions. These were designed to evaluate the feasibility of commercial establishment under farmer conditions using commercial equipment. The treatments tested were as follows:

i. Direct drilled oats after maize grain harvest;
ii. Disc-and-drilled oats or ryegrass after maize grain harvest;
iii. Italian ryegrass broadcasted at maize brown husk stage;
iv. Winter fallow (control).

Plots with established catch crops were harvested between July and October. When the catch crop had reached a 30–40 cm height, two 0.5 m x 5 m strips were cut using a push lawn mower and weighed fresh. Two 1 kg sub samples were collected for DM and N determination. In addition to measuring catch crop biomass yield, N content was also determined to estimate N removal from the soil.

Statistical analysis

To compare yield and N removed between treatments for 2021 and 2022 at the last sampling point, generalized linear models (GLMs) were performed in R (R Core Team 2022) using the brms package (Bürkner 2017). The fixed effect was treatment for all models. A log normal likelihood was specified as response variables had continuous and positive values. Since there was high variability between trial sites, sigma was allowed to vary between trials (Bürkner 2017).

Results and Discussion

Catch crop yield

Year 1 (2020) was considered a screening study and results are not shown or discussed in this manuscript. The Year 2 (2021) catch crop DM yields and associated modelled contrasts for the various catch treatments are given in Figures 1 and 2, respectively. Final catch crop yields across both soil types ranged from a mean of 1.35–7.30 t DM/ha. Retrospective results for Year 3 (2022) are shown in Figures 3 and 4, and yields were shown to generally be lower in Year 3 compared to Year 2, ranging from 0.92–4.65 t DM/ha.

Catch crop establishment success was variable between sites, treatments and years. In general, V5 interseeded ryegrass plots established well initially, but by autumn plant survival was patchy and variable, particularly on the ash site. This result could have been due to drought during summer 2020 as well as shading and smothering effects from the maize crop and residues. The V5 interseeded ryegrass option appeared better suited to the clay site. The opposite was observed for Italian ryegrass catch crops broadcast at the brown husk stage during the screening study in Year 1, and this was also attributed to drought. The clay soil had formed large cracks as it dried and a “crusted” surface, making it difficult for the seed to penetrate the surface and for the seed-to-soil contact required for successful establishment.

When comparing species/method on Ash soil, the disc-and-drill oats and brown husk stage Italian ryegrass options were significantly higher-yielding than all other options. However, in Year 3 (2022), oats direct drilled and disc-and-drilled yielded significantly more than drilled and broadcast Italian ryegrass.

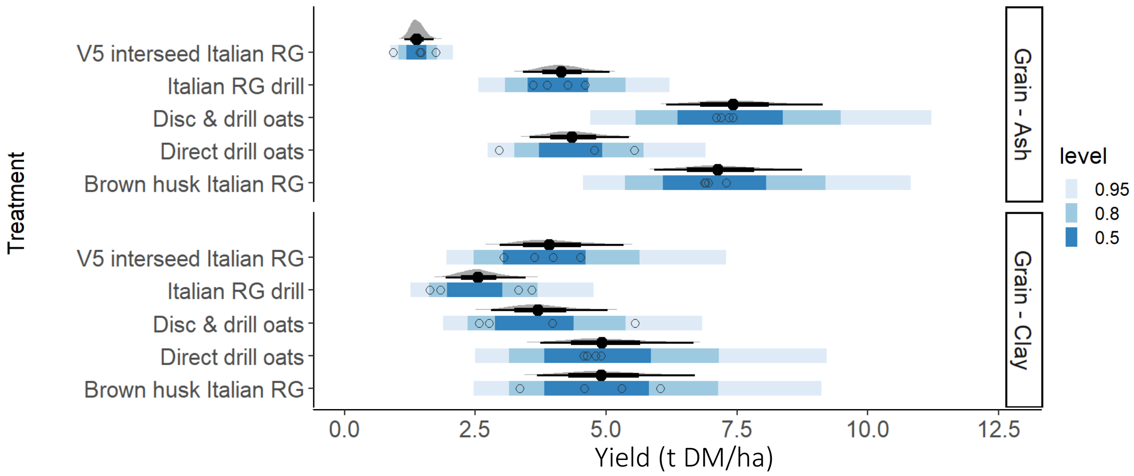

Figure 1. Final dry matter (DM) yield (t DM/ha) in Year 2 (2021) from catch crops incorporated into maize grain rotations, on both Ash and Clay soil. For each response variable open circles represent observed values for individual replicates. Model estimates [mean (black dots) and 95% credible interval (thin black horizontal line)] are displayed as half eyes, with predictive intervals shaded in blue: 50% dark; 80% medium; and 95% light. Credible intervals are intervals within which an unobserved parameter value falls with a particular probability (e.g. 95%). Predictive intervals represent the range of possible outcomes of a future event predicted by the model. RG=ryegrass.

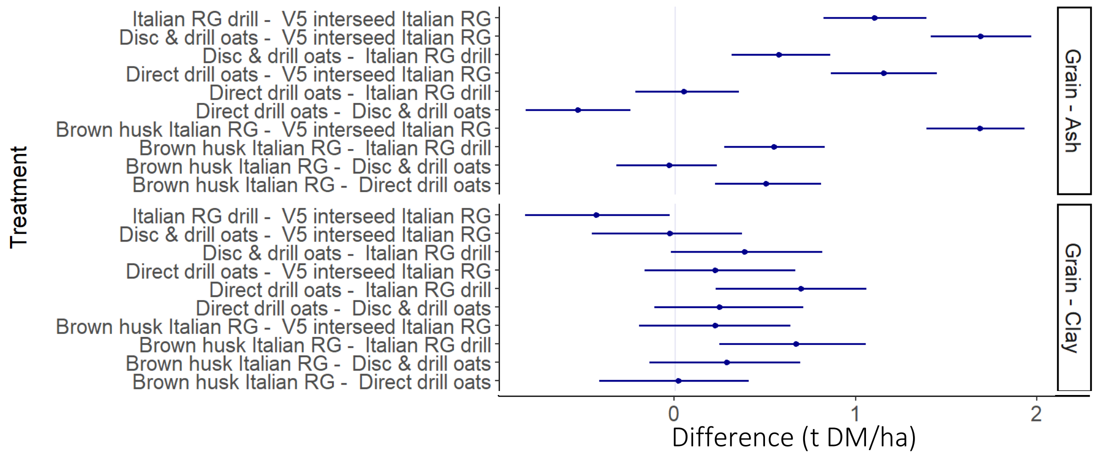

Figure 2. Modelled contrasts for final DM yield in Year 2 (2021) from catch crops incorporated into maize silage and maize grain rotations, on both Ash and Clay soil. If the contrast estimate (horizontal line) does intercept the vertical zero line, then treatments are considered to be statistically different. For each contrast where the contrast estimate does not intercept zero, the left-hand species is considered statistically lower or higher than the right-hand species if the contrast estimate is less than or greater than zero, respectively. RG=ryegrass.

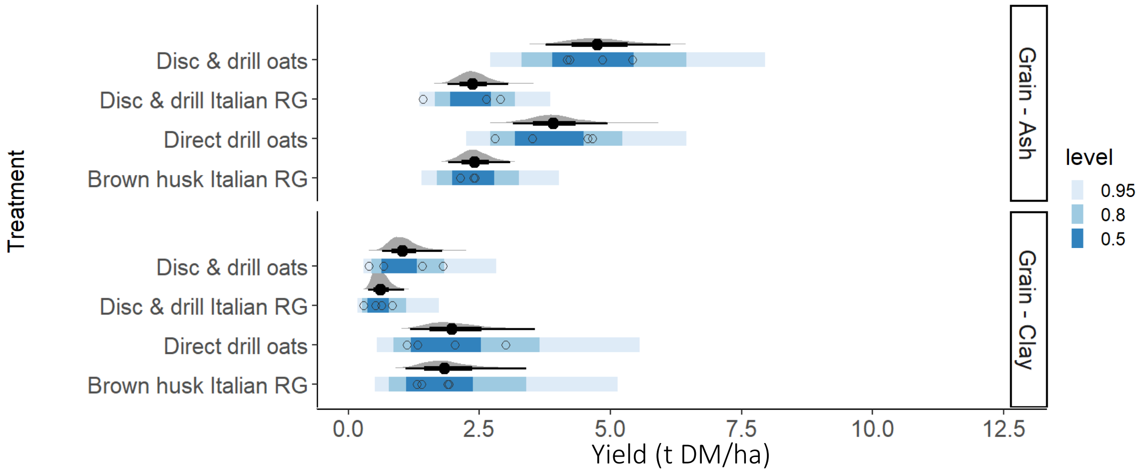

Figure 3. Final DM yield (t DM/ha) in Year 3 (2022) from catch crops incorporated into maize grain rotations, on both Ash and Clay soil. For each response variable open circles represent observed values for individual replicates. Model estimates [mean (black dots) and 95% credible interval (thin black horizontal line)] are displayed as half eyes, with predictive intervals shaded in blue: 50% dark; 80% medium; and 95% light. Credible intervals are intervals within which an unobserved parameter value falls with a particular probability (e.g. 95%). Predictive intervals represent the range of possible outcomes of a future event predicted by the model. RG=ryegrass.

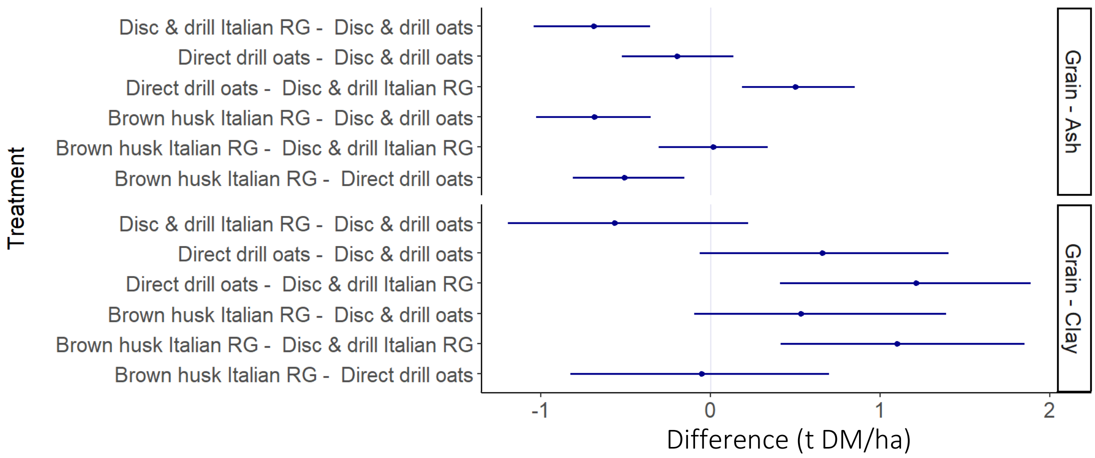

Figure 4. Modelled contrasts for final DM yield in Year 3 (2022) from catch crops incorporated into maize grain rotations, on both Ash and Clay soil. If the contrast estimate (horizontal line) does intercept the vertical zero line, then treatments are considered to be statistically different. For each contrast where the contrast estimate does not intercept zero, the left-hand species is considered statistically lower or higher than the right-hand species if the contrast estimate is less than or greater than zero, respectively.

Catch crop nitrogen removed

Nitrogen removal and associated modelled contrasts results for Year 2 are given in Figures 5 and 6, respectively. Final cumulative amounts of N removed across both soil types ranged from a mean of 34.9–223.6 kg N/ha. Retrospective results for Year 3 are given in Figures 7 and 8, and as was the case with DM yields, N removals were shown to generally be lower in Year 3 compared to Year 2, ranging from 9.3–111.6 kg N/ha overall.

On the Ash site, broadcasting Italian ryegrass at the brown husk stage was the best performing treatment in terms of N removal in Year 2; however, all treatments were similar in Year 3. The success of broadcasting of seed is particularly dependent on soil and environmental conditions around the time of broadcasting, and therefore it is expected that results will be seasonally dependent (Malcolm et al. 2017). In both years, establishing a catch crop by disc-and-drill was shown to be more succesful than direct drilling. For instance, in Year 2, N removed by disc-and-drilled oats was significantly higher (by 59%) than direct drilled oats. Similarly, in Year 3, there was a trend for higher N uptake by disc and drill methods, although not statistically significant. Large amounts of surface stover can restrict the ability of subsequent crops to establish quickly, and therefore incorporating this by discing encourages establishment and consequently, greater N removal.

On the clay site, broadcasting Italian ryegrass at brown husk was also a top performer and was shown to recover significantly more N (by 80–156%) compared to disc & drill or direct drilled oats or Italian ryegrass. As per the Ash site, differences between treatments were less conclusive, although there was still a significant increase in N recovered by broadcast Italian ryegrass at brown husk compared to direct drilled Italian ryegrass and disc and drilled oats.

Overall, our data suggests that if conditions are conducive and it is predicted that there is enough moisture for germination, broadcasting Italian ryegrass catch crops at the brown husk stage is likely to be a very suitable option for maize grain growers (or in late maize silage harvesting situations). In seasons where this may not be suitable prior to maize harvesting, establishing an oat or Italian ryegrass catch crop by way of disc-and-drill, after maize grain has been harvested, is also likely to result in favorable environmental benefits.

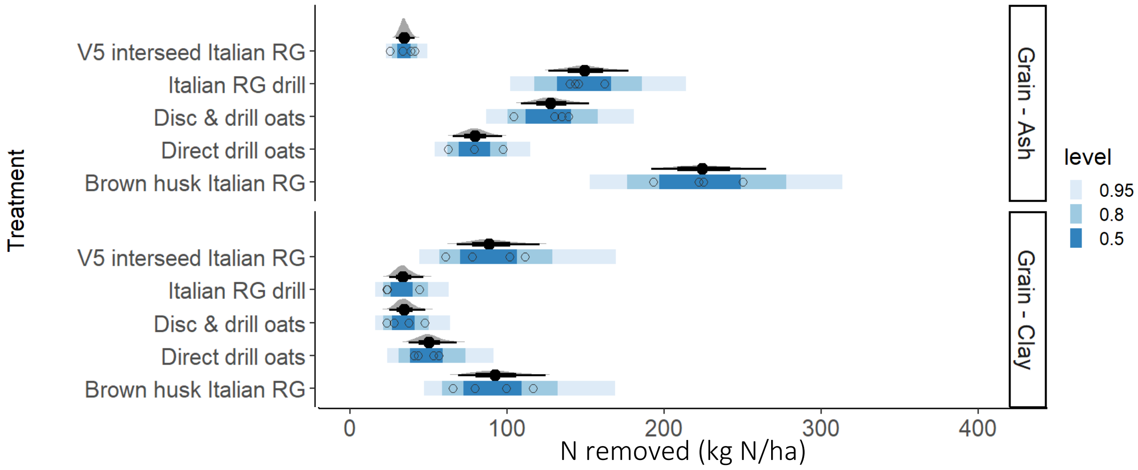

Figure 5. Final N removed (kg N/ha) in Year 2 (2021) from catch crops incorporated into maize silage and maize grain rotations, on both Ash and Clay soil. For each response variable open circles represent observed values for individual replicates. Model estimates [mean (black dots) and 95% credible interval (thin black horizontal line)] are displayed as half eyes, with predictive intervals shaded in blue: 50% dark; 80% medium; and 95% light. Credible intervals are intervals within which an unobserved parameter value falls with a particular probability (e.g. 95%). Predictive intervals represent the range of possible

outcomes of a future event predicted by the model. RG=ryegrass.

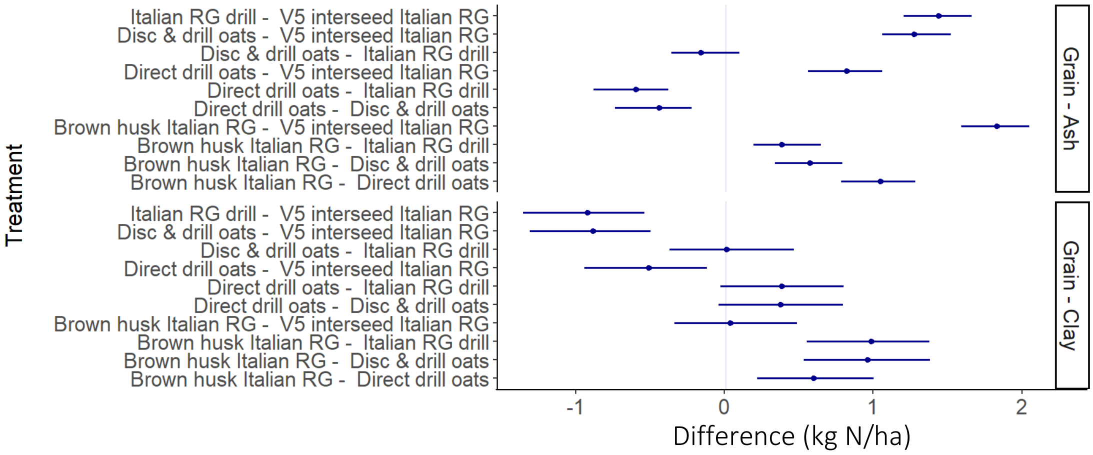

Figure 6. Modelled contrasts for N removed in Year 2 (2021) from catch crops incorporated into maize grain rotations, on both Ash and Clay soil. If the contrast estimate (horizontal line) does intercept the vertical zero line, then treatments are considered to be statistically different. For each contrast where the contrast estimate does not intercept zero, the left-hand species is considered statistically lower or higher than the right-hand species if the contrast estimate is less than or greater than zero, respectively.

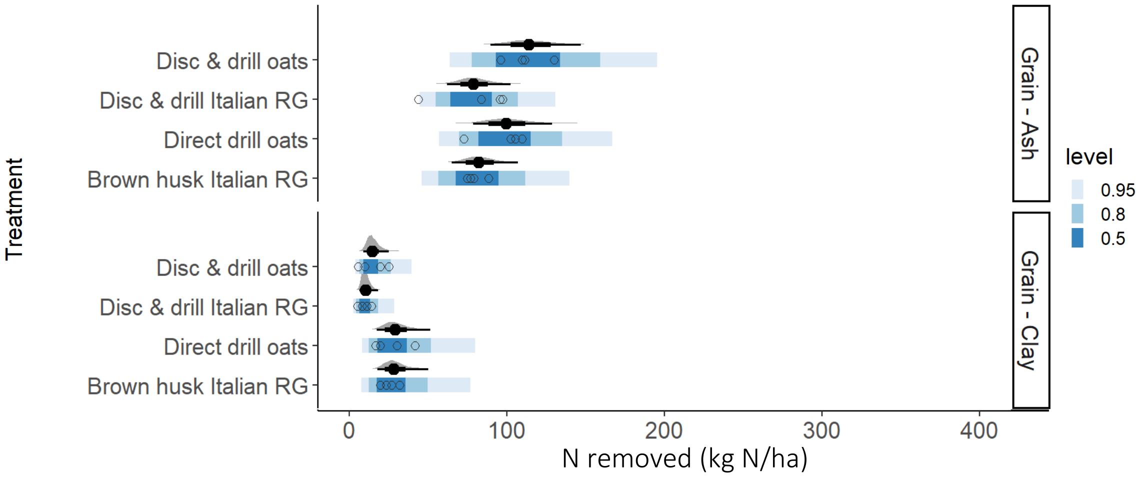

Figure 7. Final N removed (kg N/ha) in Year 3 (2022) from catch crops incorporated into maize silage and maize grain rotations, on both Ash and Clay soil. For each response variable open circles represent observed values for individual replicates. Model estimates [mean (black dots) and 95% credible interval (thin black horizontal line)] are displayed as half eyes, with predictive intervals shaded in blue: 50% dark; 80% medium; and 95% light. Credible intervals are intervals within which an unobserved parameter value falls with a particular probability (e.g. 95%). Predictive intervals represent the range of possible outcomes of a future event predicted by the model. RG=ryegrass.

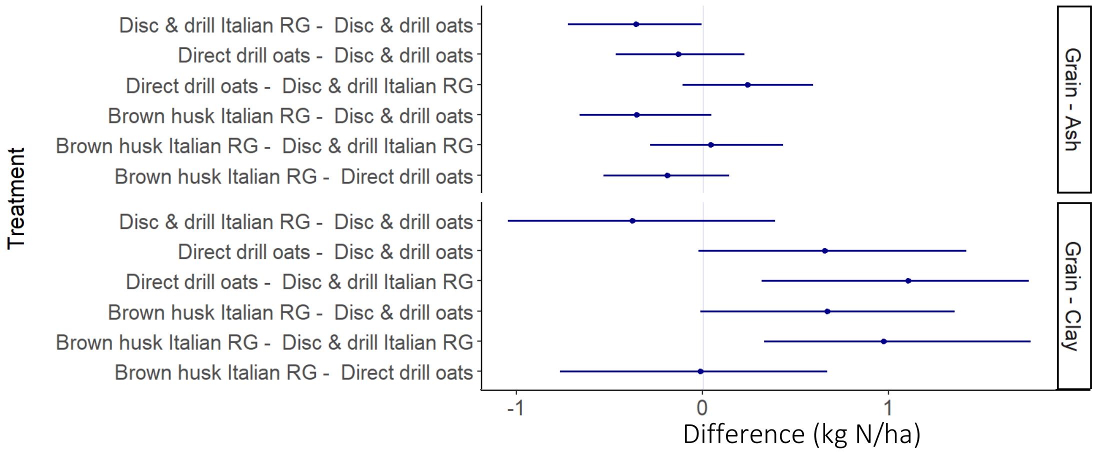

Figure 8. Modelled contrasts for N removed in Year 3 (2022) from catch crops incorporated into maize grain rotations, on both Ash and Clay soil. If the contrast estimate (horizontal line) does intercept the vertical zero line, then treatments are considered to be statistically different. For each contrast where the contrast estimate does not intercept zero, the left-hand species is considered statistically lower or higher than the right-hand species if the contrast estimate is less than or greater than zero, respectively.

There did not appear to be any consistent soil N removal benefit of oats over Italian ryegrass. This result was particularly interesting as oats are generally more winter active than Italian ryegrass (Carey et al. 2017; Malcolm et al. 2020). This result could be attributed to the frequent cuts (simulated harvests) that were initiated when all crops reached 30–40 cm height, as cereal crops are less suited to this practice and regrowth was therefore likely to have been compromised compared to Italian ryegrass. The greater N content for Italian ryegrass relative to feed oats could also attribute to this observation.

Mineral nitrogen leaching losses

Soil mineral N measurements prior to maize planting and after maize harvest indicated that in general, after accounting for removed N, there was significantly more N after maize harvest compared to starting N levels, indicating an increased leaching risk. The majority of mineral N after maize harvest was largely concentrated in the top 30 cm (data not shown). If catch crops are established early enough, they should remove a significant amount of N before it moves further down the soil profile.

Mineral N leaching losses measured between October 2020 and October 2022 were very low (<3 kg N/ha/year) (data not shown). This could be attributed to the good N fertiliser management which involved split applications of N between planting and V6 maize growth stage, as well as applying N according soil test recommendations and paddock yield potential. While the Year 3 summer was 20% drier than average (531 mm), the winter was 30% wetter than the 20-year average of 682 mm. Year 2 annual precipitation was consistent with the 20-year average. Precipitation variability was hence not considered to have had a greater influence on the observed leaching values. That said, it must also be noted that drainage volumes (data not given) collected from the lysimeters were highly variable and therefore could have a significant effect on the calculated result. It is also plausible that, being a clay soil, a texture boundary at the base of the lysimeter may restrict natural drainage from occurring. Further modelling work could be completed to give greater confidence in the drainage amounts expected at this depth.

Previous research in the same environment showed that more than 90% of the total season's N leaching losses occurred during the catch crop growing cycle (April – October; Tsimba et al. 2021). Even though overall N leaching losses were very low, there was evidence that catch crops were very effective at mitigating leaching losses especially during the earlier parts of the drainage season (Figure 9). This is promising from a leaching mitigation perspective provided a catch crop can be successfully established to allow effective soil N uptake to occur before the high leaching risk period.

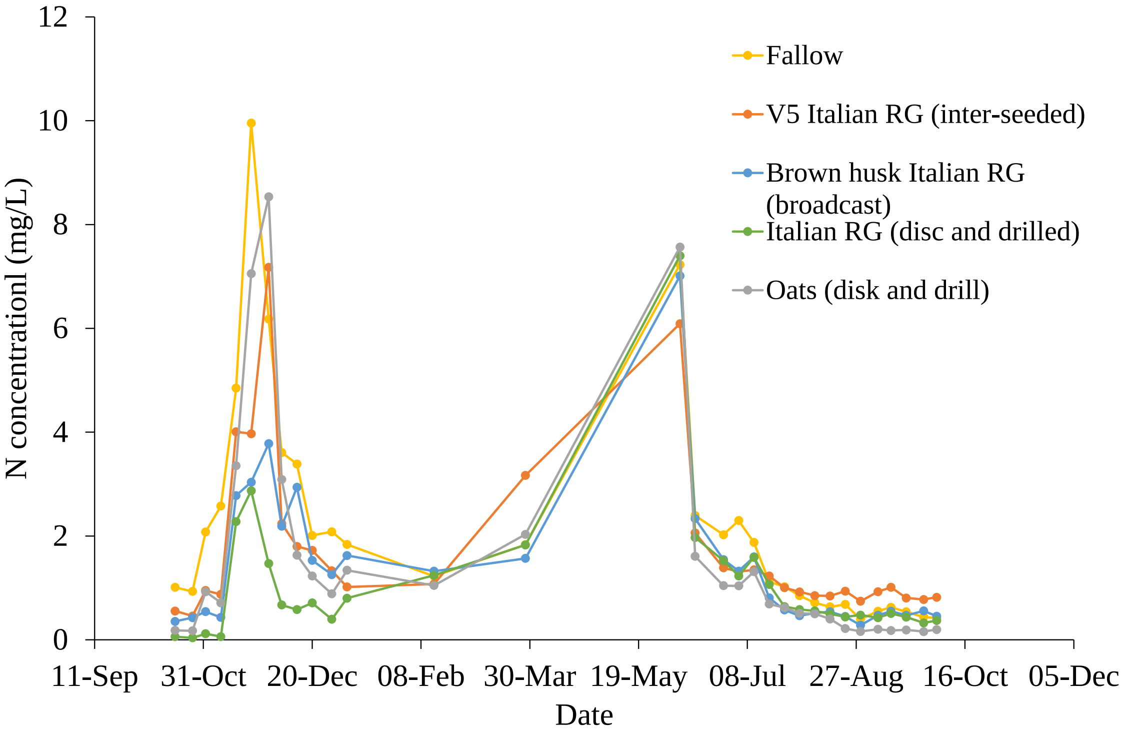

Figure 9. Changes in mineral N concentration at 120 cm depth across a range of catch crop treatments on a Waikato clay soil site during the 2021-22 maize-catch crop growing season.

On-farm demonstration plots

In 70% of the Manawatu and Rangitikei sites, the broadcast Italian ryegrass treatment at the brown husk stage was the only treatment that established successfully. The other options were unsuccessful due to particularly wet soil conditions.

Figures 10 and 11 illustrate the mean DM yields and catch crop soil N removal on sites with at least two catch crop treatments across the four regions, i.e., data from five Manawatu and Rangitikei sites are not in the figures because the brown husk broadcast Italian ryegrass treatment was the only option that successfully established.

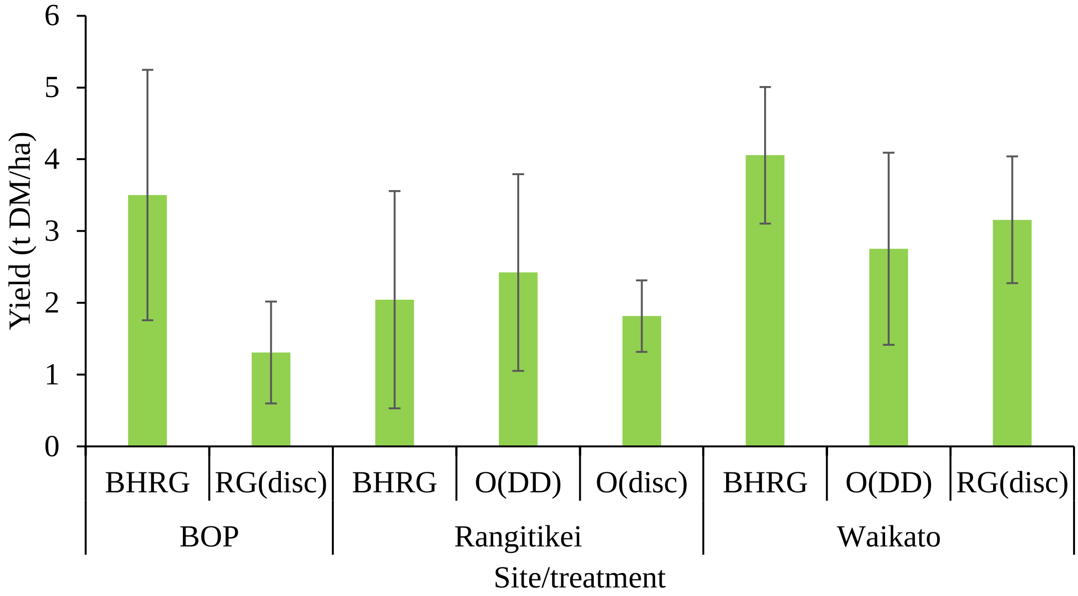

Figure 10. Catch crop dry matter (DM) yield (t DM/ha) after maize grain across three North Island sites in 2022. Treatments include Italian ryegrass broadcasted on a maize crop at brown husk stage (BHRG), disc-and-drilled Italian ryegrass [RG(disc)], direct drilled oats [O(DD)], and disc-and-drilled oats [O(disc)]. Vertical bars represent the standard error of the mean (SEM).

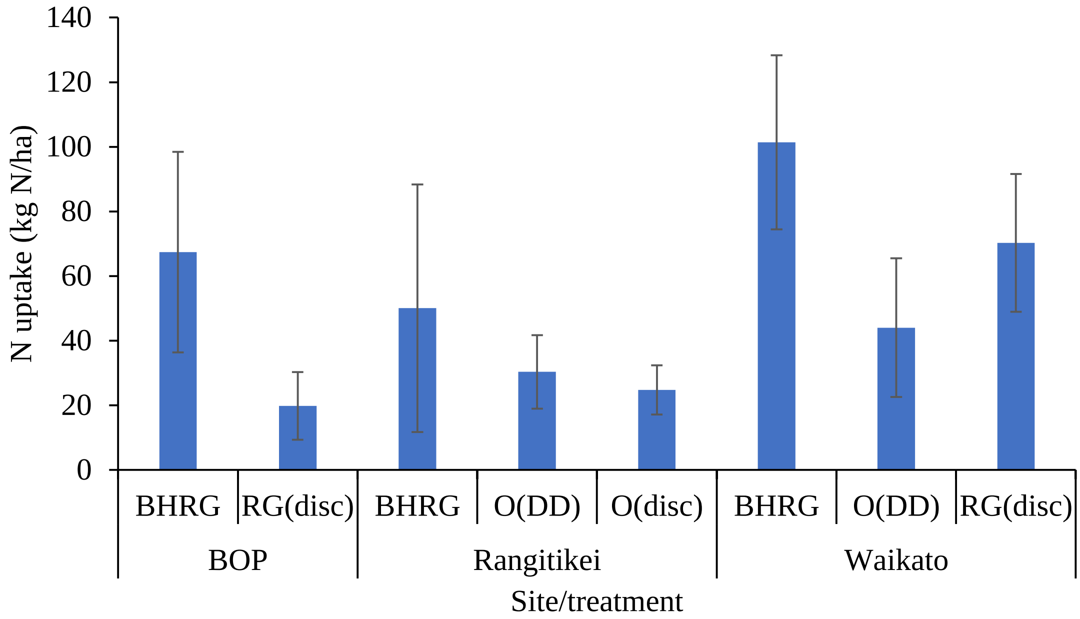

Figure 11. Catch crop nitrogen (N) removal (kg N/ha) after maize grain harvest across three North Island sites in 2022. Treatments include Italian ryegrass broadcasted on a maize crop at brown husk stage (BHRG), disc and drilled Italian ryegrass [RG(disc)], direct drilled oats [O(DD)], and disc-and-drilled oats [O(disc)]. Vertical bars represent the standard error of the mean (SEM).

Bay of Plenty
The BOP extension trials resulted in the brown husk broadcast Italian ryegrass treatment producing >1.5 times more biomass and 3-fold more N uptake than disc-and-drill Italian ryegrass during the winter period. The brown husk broadcast treatment was able to remove 44% of the soil N remaining after maize harvest, compared to only 6% for disc and drill Italian ryegrass (soil N data not shown).

Waikato
The main catch crop treatments tested in the Waikato were broadcast Italian ryegrass at brown husk, direct drilled oats and disc and drilled Italian ryegrass. The brown husk broadcast treatment significantly outyielded the other treatments by 28–46%.

Manawatu and Rangitikei
On average, the brown husk broadcast treatment yielded 1.74 t DM/ha, with an N removal of 45 kg N/ha. This amounted to 55% N removal relative to the starting soil N after maize grain harvest.

Considering the sites where brown husk broadcast Italian ryegrass, direct drilled oats and disc and drilled oats were successfully established, DM yields for the three treatments ranged from 2.0–2.4 t DM/ha. The brown husk broadcast treatment averaged 50 kg N/ha removal compared to 25 kg N/ha and 30 kg N/ha for disc and drill oats and direct drill oats, respectively.

Conclusions

The main conclusions drawn from this research work are:

- Both oats and Italian ryegrass represent suitable catch crop options following maize grain (both from a production and environmental perspective), capable of reducing the risk of N leaching losses.
- The choice of species and establishment methodology by growers will depend on their intended use for the catch crop, expected harvest timing, and soil and environmental conditions.
- Inter-seeding at V5 stage did not perform consistently enough to warrant further promotion for maize systems in New Zealand.
- Across all trial sites (replicated trials and demonstrations), broadcasting Italian ryegrass at brown husk stage was a consistent performing option, and one that performed well regardless of the environmental conditions, i.e. post-harvest sowing was problematic under wet conditions, and early establishment compromised.
- To improve success of the brown husk broadcast option maize residues should be finely chopped and uniformly spread at harvest to minimise smothering and broadcasting should coincide with a greater probability of a rain event for germination.
- Evidence from previous leaching trials has shown their potential to reduce losses. Catch crops are therefore considered a very viable option to reduce the risk of N leaching in maize production systems.

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