Winter cover crop mixtures for increasing nitrate uptake and improving soil aggregation

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Abstract
The objective of this field trial was to observe eight cover crop blends made up of cereals, legumes, and brassica species, compare them with monoculture controls and assess which maximised dry matter production and potentially enhanced feed nutritional content, while improving nitrate uptake and soil structure through the winter months. The trial was conducted in 2019 from 18 April to 30 October in Irwell, Canterbury. The field trial examined soil aggregate stability and the soil mineral nitrogen from pre-sowing to termination of the trial. Aggregate stability improved in all treatments except the bare fallow control. D1/B Smart mix had the largest increase of 0.40mm mean weight diameter and a 24% increase in aggregates above 1 mm. Smart Radish® had the highest herbage nitrogen uptake of all treatments with 114.21 kg N DM/ha (LSD $P<0.05$). There were no significant differences observed between the Wintermax T100, T/B Smart mix, and D1/B Smart mix treatments, but all drilled treatments had significantly more nitrogen uptake than the bare fallow treatment which was 28 kg N DM/ha. Dry matter yields were highest for Smart Radish® treatments at 3938.52 kg DM/ha. Smart Radish® also had the highest crude protein (18.1% DM) and metabolizable energy (ME) (13 MJ kg DM). Further investigation is required to determine the significance of mixing species, and analysis of below-ground biomass and movement of nitrates through the soil profiles is recommended to gain a better understanding of the potential benefits to soil health and subsequent crop yields.

Additional keywords: *Avena sativa* L., *Eruca sativa* L., *Pisum sativum* L., *Raphanus sativus* L., soil compaction, soil structure, *Trifolium alexandrium* L., *Triticosecale* Wittmack, *Zea mays* L.

Introduction

Managing soil quality is becoming more important, as the requirement for agricultural production increases as the result of growing populations and the urbanisation of fertile land (Satterthwaite *et al.*, 2010). Intensive mono-cropping systems, with the use of conventional cultivation techniques, degrade soil quality causing losses in organic matter and aggregate stability, leading to soil compaction and a reduction in crop yields (Sithole *et al.,* 2016).The degradation of soil structure and the depletion of organic matter also promotes leaching of nutrients such as nitrates and phosphates through the soil profile during periods of wet weather, and leads to soil erosion (Perera & Weerasinghe, 2014). In New Zealand, soils left bare fallow following a maize (*Zea mays* L.) rotation are at greater risk of nitrate leaching over the winter period (May-August), with rainfall being substantially higher than evapotranspiration in many regions (Trolove *et al.*, 2019). The use of autumn-sown cover crops between intensive cropping systems, such as maize, has been shown to reduce soil compaction and leaching of nutrients through the winter period (Chen & Weil, 2011). However, Fraser *et al.* (2013) reports that there is a lack of quantitative data on the nutrient loss mitigation effects of cover crops in various climatic conditions, which are very variable from year to year. The objective of this work was to assess the agronomic performance and compatibility of eight blends of cereals with legume and brassica species as winter cover crop mixes for use in New Zealand maize cropping systems, with a focus on identifying a blend that may potentially maximise dry matter production and enhance feed nutritional content, compared to monoculture cover crops. This trial also assessed the nitrate uptake of these cover crop mixes, and measured soil aggregate stability.

Materials and Methods

The trial was in Irwell, Canterbury (43° 43’31.8” S, 172° 21’20.1” E) and ran from 18 April 2019 to 30 October 2019. The 2018-19 crop was maize, and the crop surrounding the trial in 2019 was Milton oats (*Avena sativa* L.*)*. The soil type at the trial site is a Wakanui silt loam, which is classified as a Mottled Immature Pallic soil (Landcare Research, 2020). This soil is deep, stoneless, imperfectly drained with a high-water holding capacity, and has a plant rooting depth that extends further than 1 m. Plot size was 1.05 m wide x 9 m, consisting of eight rows 0.15 m apart, with a 0.50 m gap between plots. Soil sampling was completed in the middle of the plot area, to simulate actual field conditions. Sowing was conducted with an Ojyord cone seeder drill with a targeted plant population of 150 plants/m^2. The experimental design was a randomised complete block design with fifteen treatments, replicated two times, giving a total of thirty plots. All treatments are described in Table 1. Species for this trial were selected carefully for soil quality-improving and forage quality characteristics based on observation plots planted in 2018. Entries were comprised of triticale (*x Triticosecale* Wittmack cv. Wintermax T100), oats (cv. D1), radish (*Raphanus sativus* L. cv. Smart Radish®), rocket (or arugula *Eruca sativa* L. cv. Extender), berseem clover (*Trifolium alexandrium* L.), and winter pea (*Pisum sativum* L. cv NAP94.4). These were sown both as monoculture plots and in mixes, which included cereal and legume species. The cereal, legume, Extender rocket and Smart Radish® treatments were compared with a bare fallow treatment as a control. The trial seedbed was prepared by power harrowing on 17 April and was sown on 18 April. Seedbeds were Cambridge rolled immediately afterwards. No fertilisers or agrichemicals were applied over the duration of the trial. Dry matter yield and soil mineral nitrogen data were analysed using ANOVA with Agrobase Generation II (SQL 2012, Express Edition, Agronomic Software, INC, Canada). Treatment differences were compared using 5% Fisher’s Least Significant Difference (LSD).

Measurements

Air temperature and soil surface temperature

Soil surface temperature was recorded in the monoculture berseem clover treatment and the T/B Smart mix treatment, after cold stress observations were made in the monoculture treatment but not the mixed species plot. Tinytag Plus data loggers (Model Tgp-1500, Gemini Data Loggers (UK) Ltd, Chichester, West Sussex PO19 8UJ England) were placed on the soil surface in the middle of the plot canopy to compare the temperature from 12 July to 24 July 2019 to observe any differences between the canopy temperatures between the two treatments over a 13-day period in mid-winter. Data loggers were checked after 13 days and the data demonstrated there was a difference in canopy temperature, so no further measurements were required. Soil surface temperature data were supplemented with hourly average air temperature data collected from the Lincoln, Broadfields NIWA weather station (43°37’34” S, 172°28’13” E) located roughly 12 km north of the trial site.

Table 1: The species composition of each treatment including controls sown in Irwell, Canterbury on 18 April 2019.

Treatment name	Treatment composition	Percentage of Plot
T100/NAP94.4 pea	T100 triticale	60
	NAP94.4 pea	40
T100/Berseem	T100 triticale	60
	Berseem clover	40
T/NP Smart mix	T100 triticale	50
	NAP94.4 pea	35
	Arugula Rocket	10
	Smart Radish®	5
T/B Smart mix	T100 triticale	50
	Arugula Rocket	10
	Smart Radish®	5
	Berseem clover	35
D1/NAP94.4 Pea	D1 Oat	60
	NAP94.4 pea	40
D1/Berseem	D1 Oat	60
	Berseem clover	40
D1/ NP Smart mix	D1 Oat	50
	NAP94.4 pea	35
	Arugula Rocket	10
	Smart Radish®	5
D1/B Smart mix	D1 Oat	50
	Arugula Rocket	10
	Smart Radish®	5
	Berseem clover	35
D1	D1 Oat	100
T100	T100 triticale	100
NAP94.4	NAP94.4 pea	100
Smart Radish	Smart Radish®	100
Arugula Rocket	Extender Rocket	100
Berseem clover	Berseem clover	100
Bare fallow	Bare fallow	100

Soil aggregate stability

Soil aggregate stability was measured by taking an undisturbed block sample using a small spade, producing a 0.18 x 0.18 m block at 0.15 m depth. Samples were taken prior to sowing, on 9 April, as a baseline over 12 randomised locations. From these, four randomly selected samples were analysed at Plant and Food Research (Canterbury Agriculture & Science Centre, Lincoln, Christchurch). Aggregates 2-4 mm diameter were separated from the whole soil sample by gentle sieving and then air drying at 25°C before aggregate stability determination using a wet-sieving method (Kemper & Rosenau, 1986). The air-dried 2-4 mm aggregates were sieved underwater for 20 minutes on a nest of sieves (2.0, 1.0 and 0.5-mm diameter). The soil remaining on each sieve was weighed after oven drying at 105°C. The weight of material remaining on the 2 mm sieve was corrected for stone content. The aggregate stability was expressed as a mean weight diameter (MWD):

$$MWD = \sum_{i=1}^{n} w_i \bar{X}_i$$

Where $\bar{X}_i$ is the mean diameter of the adjacent sieves and w_i is the proportion of the total sample retained on a sieve (Kemper & Rosenau, 1986). Soil aggregate stability was also assessed after the completion of the trial on 30 October. Sample cores were taken from the four treatments that visually displayed the greatest commercial potential and from the bare fallow control treatment. Selection for commercial potential was based on a visual assessment of above-ground biomass as this is a potential indication of the amount of nitrogen taken up by the plant.

Soil mineral nitrogen and potential mineralizable nitrogen

A pre-season soil mineral inorganic level was assessed over the whole trial area for the top 0-0.45m of soil. Baseline measurements for soil inorganic nitrogen were sampled over 12 different random locations in the trial area at three different depths on 9 April at the following soil depths; 0-0.15 m, 0.15-0.30 m, and 0.30-0.45 m. Soil samples were taken using a 0.45 m corer, with a 25 mm diameter. Samples were put through a 4 mm sieve and air dried at 25°C, and laboratory analysis was completed at Plant and Food Research (Canterbury Agriculture & Science Centre, Lincoln, Christchurch) on composite core samples from the trial area. Inorganic nitrogen concentrations were determined using a 1-hour extraction of 5 g soil with 25 ml of 2 M KCI and subsequent analysis of the filtered extract for NH_4-N and NO_3-N on a Lachat QuikChem 8500 Series 2 Flow Injection Analysis System (Lachat Instruments, Loveland, Colorado, USA) (Keeney & Nelson, 1982). A composite sample was used for a hot water extractable organic nitrogen (HWEON) test to predict the amount of potential mineralisable nitrogen (PMN) that could be mineralised by the soil during optimum growing conditions. The PMN was assessed in a 14-week aerobic laboratory incubation. The air dried samples (equivalent to 25 g of oven-dry soil) were weighed into plastic vials (50 ml) and deionized water was added drop-wise (using an electronic pipette in titrate mode) to adjust soil water content to 90% of field capacity (field capacity defined as soil water content at -10 kPa: measured using a tension table). The soils were incubated at 25°C. To minimise moisture loss during incubation, the vials were covered with film (holes were punctured in the film to facilitate aeration). Water was added, if required, at weekly intervals to compensate for any evaporative losses. Mineral nitrogen was extracted (using 2 mol/ L KCI) after 2, 4, 7, 10, and 14 weeks of incubation and determined using an automated colorimeter (QuickChem 8000 FIA+, Lachat Instruments, Loveland, CO). Mineralized nitrogen was estimated by subtracting mineral nitrogen at the start of incubation from the amount determined at each incubation interval (Curtin *et al.*, 2017). Final soil inorganic nitrogen was also measured at the same three depths when the treatments were at approximately green chop silage maturity, 137 days after planting (DAP) on the four most visually commercially viable blends and the bare fallow control, to estimate the amount of mineral nitrogen removed from the soil from pre-sowing to green chop silage maturity when the cereals were at approximately GS40-49. A bulk density measurement was taken to convert mineral nitrogen µg/g to kg N/ha. The fine-earth bulk density (<4 mm) was calculated from the weight of the oven-dried soil taken from the known volume of collected soil and corrected for its stone content.

Dry matter

Dry matter yield (kg DM/ha) was measured by cutting sample quadrants of 1 m^2 of the four most commercially viable treatments at approximately green chop silage maturity 137 (DAP) and any above-ground biomass present in the bare fallow treatment, using a Briggs & Stratton Toro 650 Series GTS multicycler push mower. Composite samples of 0.2 kg were taken from each quadrant to assess percent dry matter (% DM) in each of the treatments. Fresh samples were weighed to determine the fresh yield and then a composite sample was dried at 65°C for five days until the material was evenly dry and had reached a constant weight to determine dry matter yield (kg DM/ha). Composite 0.5 kg plant samples of both replications were sent to Hill Laboratories (Christchurch) for feed nutrient analysis including crude protein (% DM), metabolisable energy (MJ/kg DM) and nitrogen (% DM). For feed sampling, plant tissue samples were oven dried at 62°C and ground to pass through a 1 mm sieve. Feed test parameters are reported on a dry weight basis. Nitrogen (% DM) was determined by the Dumas method of combustion, in which 200 mg of dried and ground plant material was combusted with oxygen at 900°C and the resultant gas determined using a thermal conductivity detector. Crude protein was calculated from the plant nitrogen using industry standard conversion factor of 6.25 (Undersander *et al.*, 1993; AOAC International, 1990). Metabolisable Energy (ME) was derived from dry organic matter digestibility (DOMD) by calculation ME= 0.16DOMD (AFRC, 1993).

Results and Discussion

Soil surface temperature

The monoculture berseem treatment started exhibiting purpling of the leaves in early June, indicative of the presence of anthocyanins in plant tissue from exposure to cold temperatures (Rasmussen *et al.*, 2006). In contrast, the berseem clover polyculture treatments did not exhibit anthocyanin build-up in the leaf tissues. Data recorded from 12 July to 24 July 2019, as shown in Figure 1, show the temperature was much more stable in the T/B Smart mix treatment in comparison to the monoculture berseem clover treatment. Temperature variations of 26°C were recorded in the berseem clover, with the lowest temperature being -1.9°C and the warmest being 24.1°C. In comparison to the T/B Smart mix treatment, with a variation of 11.6°C, the lowest temperature was recorded at 1.1°C and the warmest temperature at 11.7°C. This data was supplemented by hourly average air temperatures recorded at the Lincoln, Broadfields NIWA weather station, with the lowest air temperature being recorded at 0.6°C and the highest at 17.4°C. This data suggests that during the winter period, the cool season vigour of Wintermax T100, Smart Radish® and Extender rocket appeared to provide shelter for the berseem clover from exposure to temperature variations. Despite these compatibility traits being a potential advantage to using a polyculture instead of a monoculture cover crop, research is limited and additional investigations are required to explore what influence the reduction in temperature fluctuation may have in increasing dry matter production and soil health.

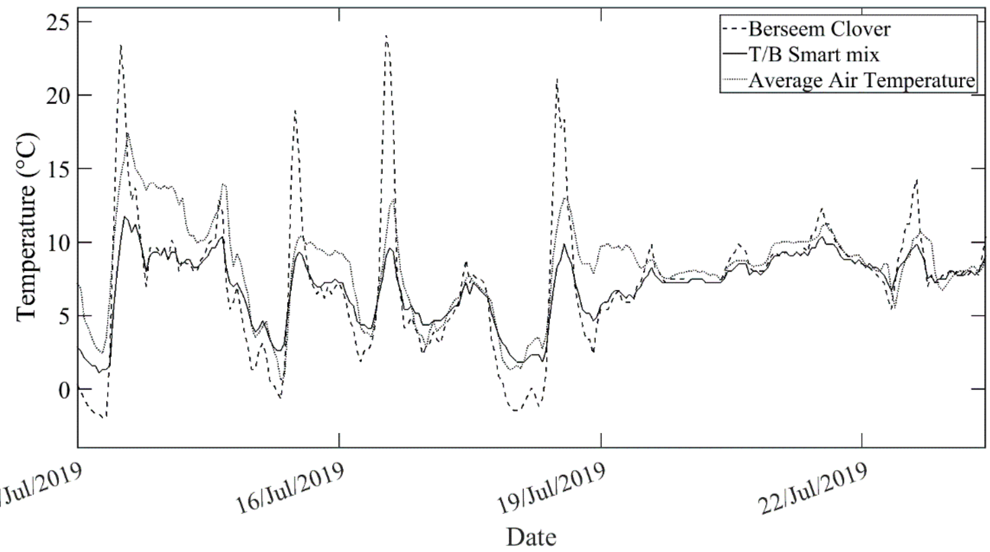

Figure 1: Soil surface hourly temperature's (°C) in monoculture Berseem clover treatment compared to soil surface in the T/B Smart mix treatment with average hourly air temperature (°C) from Broadfield, Lincoln NIWA Cliflo database.

Soil aggregate stability

Samples were each given an index score for structural stability, which was expressed as mean weight of diameter (MWD) of aggregates in millimetres (mm) and the percentage of aggregates in the sample that were above 1 mm. Index scores below 1.5 mm MWD were considered to have poor structural stability (Haynes & Stephen, 1990). The results presented in the Table 2 show the D1/B Smart mix had the largest increase of 0.40 mm MWD and a 24% increase in aggregates above 1 mm from the initial baseline measurement. T/B Smart mix and Smart Radish® both had an 18% increase in aggregates above 1 mm, and the Wintermax T100 had a 17% increase in aggregates above 1 mm. The bare fallow treatment was the only treatment with a decrease of 0.27 mm MWD and a loss of 5% of aggregates above 1mm from the initial baseline measurement. A possible reason for the decrease may have been breakdown in aggregates over the winter period caused by rainfall erosion without a substantial root system to hold aggregates together. Aggregate stability is a direct measure of the soil structure. Soils with lower aggregate stability are prone to soil erosion, soil compaction and reduced crop yield from reduced plant root depth (Huang *et al.*, 2017). This data is supported by previous research illustrating that cover crops improve soil aggregate stability by increasing the amount of soil organic matter (SOM), which acts as a binding agent for soil particles and thus increases soil aggregates (Osbourne *et al.*, 2014). However, further work is needed to determine whether a particular species mix is more beneficial for improving soil aggregation.

Table 2: Soil aggregate stability scores expressed as mean weight of diameter (MWD) of aggregates in millimetres (mm) and a percentage of aggregates in the sample that are above 1 mm. Baseline measurements taken on the 9 April and final measurement of the 30 October 2019.

Treatment	Aggregate stability (mm, MWD)	Aggregate stability (% >1mm)	(mm, MWD) Difference from Baseline	(% >1mm) Difference from Baseline
Baseline	1.08	28		
D1/B Smart Mix	1.48	52	0.4	24
Bare fallow	0.81	23	-0.27	-5
Wintermax T100	1.30	45	0.22	17
T/B Smart Mix	1.35	47	0.27	18
Smart Radish®	1.34	47	0.26	18

Initial and final soil inorganic nitrogen and herbage nitrogen uptake

At green chop silage maturity on 2 September (137 DAP), dry matter and soil inorganic nitrogen samples were taken from the four most commercially viable treatments based on a visual assessment of biomass accumulation. The treatments selected were Smart Radish®, Wintermax T100, T/B Smart mix, and D1/B Smart mix and the bare fallow treatment acted as a control. Soil inorganic nitrogen to a depth of 0.45 m was sampled to estimate the amount of soil mineral nitrogen removed from pre-sowing on 9 April to green chop silage cut on 2 September (Table 3). Pre-sowing soil nitrogen levels were 196.38 kg N/ha, with the supplementation of HWEON results, which were 41 kg N/ha. This was to estimate the amount of potential mineralisable nitrogen (PMN) that could be mineralised by the soil over the duration of the season (Table 3). The nitrogen content of dry matter samples was analysed and used to determine the plant nitrogen uptake of the above-ground biomass. Soil inorganic nitrogen at harvest nitrogen showed no significant differences between the treatments apart from the bare fallow treatment, which was the highest at 62.14 kg N/ha, most probably due to having the lowest dry matter and nitrate uptake of all the treatments. Smart Radish® had the highest above-ground herbage nitrogen uptake of all treatments with 114.21 kg N DM/ha (LSD $P<0.05$).

Table 3: Final soil inorganic nitrogen levels at 0-0.45 m at harvest on 2September, Above ground herbage dry matter (DM) yield (kg DM/ha), herbage nitrogen (N) content (%), Above ground herbage N uptake (kg DM/ha), sampled at approximately green chop silage maturity (137 DAP) on 2 September 2019.

Treatment	Soil inorganic nitrogen at harvest (kg N/ha)	Herbage (kg DM/ha)	Nitrogen (% DM)	Herbage nitrogen uptake (kg N DM/ha)
Wintermax T100	43.49	3346.50	2.4	80.32
DI/B Smart Mix	38.5	2668.97	2.5	66.73
T/B Smart Mix	36.99	3142.23	2	62.85
Smart Radish®	41.63	3938.52	2.9	114.21
Bare Fallow	62.14	1059.93	2.7	28.62
Mean	44.58	2831.22		70.54
C.V.	14.15%	14.61%		15.34%
LSD (5%)	13.45	881.61		23.07

There were no significant differences observed between the Wintermax T100, T/B Smart mix, and D1/B Smart mix treatments, but all drilled treatments had significantly more nitrate uptake than the bare fallow treatment, which was 28 kg N DM/ha. The nitrogen content of the above-ground biomass changes throughout the growth stage of the plant, so more frequent harvests prior to green chop would have given a more accurate indication of nitrate uptake over the season. This may also account for earlier nitrate uptake when the percentage of nitrogen in the dry matter was higher. Below-ground biomass was not sampled for nitrogen content and merits further investigation, especially in treatments that contain Smart Radish®, as the large tap root can reach over 2 m length with numerous lateral roots. More investigation is needed to examine the movement of nitrogen in the soil profile to understand the nitrate leaching mitigation potential of these cover crop mixes. Further research is also needed to determine the nitrate efficiency of each species in a monoculture compared with a polyculture under different cultivation and fertiliser management treatments, in order to better understand nitrate use and the potential of a polyculture as a mitigation tool for nitrate leaching. Fraser *et al.* (2013) indicated that cover crops were efficient at reducing nitrate leaching over the winter period, but the effectiveness was dependent on climatic conditions (high rainfall leads to a higher level of nitrate leaching). Careful nitrogen management and minimal tillage had the lowest rates of nitrate leaching.

Dry matter yield

At approximately green chop silage maturity on 2 September (137 DAP) dry matter yields (Table 4) were highest for Smart Radish® treatments at 3938.52 kg DM/ha. Smart Radish® also had the highest crude protein (18.1% DM) and metabolisable energy (ME) (13 MJ kg DM). However, there were no significant differences between the Smart Radish® treatments and the Wintermax T100 and T/B

Smart mix treatments. All drilled treatments yielded significantly more than the bare fallow treatment. The high CV (14.61%) is a result of some variability in the growth vigour of treatments between the replications. The variability may be an indication of some inconsistency in soil structure observed in the trial area: the paddock was an ex-maize silage area and soil compaction from heavy machinery was evident from water pooling in patches during heavy rainfall periods. The dry matter results suggest that Smart Radish® has the potential to be a good candidate for New Zealand winter cover crops but that mixes do not increase the dry matter yield or feed quality. More investigation is needed under grazing and silage treatments to assess the livestock response.

Table 4: Dry matter yield at (kg DM/ha), crude protein (% DM), and metabolizable energy (MJ/kg DM) sampled at approximately green chop silage maturity (137 DAP) on 2 September 2019 from a Cover crop blend experiment sown in Irwell, Canterbury on 18 April 2019.

Variety	Dry Matter Yield (kg DM/ha)	Crude Protin (%DM)	Metabolisable Energy (MJ/kg DM)
Smart Radish®	3938.52	18.1	13.0
Wintermax T100	3346.50	15.1	11.8
T/B Smart Mix	3142.23	12.3	12.2
D1/B Smart mix	2668.97	15.5	12.8
Bare fallow	1059.93	16.8	13.9
Mean	2831.227		
C.V.	14.61%		
LSD (5%)	881.6146		

Conclusions

Using winter cover crops after maize silage can improve soil aggregate stability and significantly improve plant nitrate uptake, thus reducing the risk of nitrate loss to leaching while providing a high-quality livestock green chop silage feed in spring. The main conclusions from this trial are that there are some compatibility characteristics of mixing legumes, cereals, and brassicas that require further investigation to understand the benefits to soil and plant health. More detailed research is needed to evaluate the significance of mixing species and sampling below-ground biomass is recommended to gain a better understanding of the potential benefits to soil health and subsequent crop yields.

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References

AFRC. 1993. Energy and Protein Requirements of Ruminants. An advisory manual prepared by the AFRC Technical Committee on responses to Nutrients. CAB International, Wallingford, UK.

AOAC International. 1990. Protein (Crude) in Animal Feed: Combustion Method. (990.03) Official Methods of Analysis. 15th Edition.

Chen, G.; Weil, R.R. 2011. Root growth and yield of maize as affected by soil compaction and cover crops. *Soil & Tillage Research 117*: 17-27.

Curtin, D.; Beare, M.H.; Lehto, K.; Tregurthua, C.; Weiwen, Q.; Tregurtha, R.; Peterson, M. 2017. Rapid assays to predict nitrogen mineralization capacity of agricultural soils. *Nutrient Management & Soil & Plant Analysis 81(4)*: 979-991.

Fraser, P.M.; Curtain, D.; Harrison-Kirk, T.; Meenken, E.D.; Beare, M.H.; Tabley, F.; Gillespie, R.N.; Francis, G.S. 2013. Winter nitrate leaching under different tillage and winter cover crop management practises. *Soil Science Society of America Journal 77*: 1391-1401.

Haynes, R.J.; Stephen, R.C., 1990. Changes in soil organic matter content and aggregate stability under Canterbury mixed cropping rotations. *Proceedings Agronomy Society of New Zealand 20*: 83-90.

Huang, R.; Gao, M.; Jiang, L. 2017. Effects of soil conditioners on aggregate stability in a clay loam soil: A comparison study of biomass ash with other four conditioners. *Communications in Soil Science and Plant Analysis 48(19)*: 2294-2313.

Keeney, D.R.; Nelson, D.W. 1982. Nitrogen-inorganic forms, In: Page, A.L, Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2 ed. American Society of Agronomy and Soil Science Society of America, Madison, USA. pp. 643-709.

Kemper, W.D.; Rosenau, R.C. 1986. Aggregate stability and size distribution. In: Klute A ed. Methods of Soil Analysis Part.1 Physical and mineralogical methods, 2nd edition. Madison, Wisconsin, Soil Science Society of America. pp. 425-442.

Landcare Research. 2020. Landcare Research, Environment Canterbury, Soil Report. Retrieved on the 7 Mar 2020 from http://smap.landcareresearch.co.nz/

Osbourne, S.L.; Johnson, J.M.F.; Virginia, J.L.; Hammerbeck, A.L.; Varvel, G.E.; Schumacher, T.E. 2014. The impact of corn residue removal on soil aggregates and particulate organic matter. *Bioenergy Research 7*: 559-567.

Perera, K.T.G.K.; Weerasinghr, T.K. 2014. A study on the impacts of corn cultivation (*Zea mays* (L.) family- Poaceae) on the properties of soil. *International Journal of Scientific and Research Publications 4(7)*: 2250-3153.

Rasmussen, S.; Cao, M.; Fraser, K.; Koulmam, A.; Park-Ng, Z.; Xue, H.; Lane. G. 2006. Cold stress in white clover- An integrated view of metabolome and transcriptome responses. '*Breeding for Success: Diversity in Action' C.F. Mercer (ed). Proceedings of the 13th Australasian Plant Breeding Conference*: 750-757.

Satterthwaite, D.; McGranahan, G.; Tacoli, C. 2010. Urbanization and its implications for food and farming. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences 365(1554)*: 2809-2820.

Sithole, N.J.; Magwaza, L.S.; Mafongoya, P.L. 2016. Conservation agriculture and its impact on soil quality and maize yield: a South African perspective. *Soil & Tillage Research 162*: 55-67.

Trolove, S.; Thomas, S.; van der Klei, G.; Beare, M.; Cichota, R.; Meenken, E. 2019. Nitrate leaching losses during pasture renewal - Effects of treading, urine, forages and tillage. *Science of The Total Environment 651*: 1819-1829.

Undersander, D.; Mertens, D.R.; Thiex, N. 1993. Forage Analysis Procedures, 3.3 Nitrogen Determination by Combustion Method.