Longhurst, B., Taylor, M., Williams, I. 2018. Long-term maize grain growing in Waikato – Factors affecting sustainability. In: *Farm environmental planning – Science, policy and practice*. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12 pages.

LONG-TERM MAIZE GRAIN GROWING IN WAIKATO - FACTORS AFFECTING SUSTAINABILITY

Bob Longhurst[1], Matthew Taylor[2] and Ian Williams[3]

[1] agKnowledge Ltd; [2] Waikato Regional Council; [3] Genetic Technologies Ltd

Abstract

Maize grain is a common high-energy crop grown in the Waikato. Typically, maize crops are sown in September/October but as the maize grain harvest is not until mid-April/early June growers typically leave the soil fallow over the winter period. This results in certain paddocks being dedicated to continuous maize growing year after year. The effect of these monoculture crops on soil quality and its sustainability is of great interest.

The Waikato Regional Council (WRC) soil quality indicator programme covers chemical, physical and biological attributes from long-term monitoring sites that includes arable land use. WRC findings for their monitored arable sites after 20 years showed, on average, decreased Total Carbon and Total Nitrogen, and increases in bulk density and the number of sites with excessive Olsen Phosphorus levels.

With the aim of identifying land management practices that maintain soil quality, three Waikato arable sites with good soil records of decades of continuous maize growing were studied. Data from soil analysis has been collated and compared against the trends of some of the key soil quality indicators found from the WRC monitoring.

Background

Maize (*Zea mays*) is a common high energy crop grown in the Waikato for either silage or grain production. Although the plant establishment and management practices are very similar for both crops, the timing of harvests and its implications (such as bare soil and its potential environmental effects) provides the biggest difference between the silage or grain crops. Typically, maize crops are sown in September/October, however maize silage is harvested earlier (late February/early April) compared to maize grain (mid April/early June). Growers harvesting maize silage have time in the autumn to get pasture established before winter. In contrast, maize grain growers, because of the later harvest, typically leave the soil fallow over the winter period. Thus, bare soil is exposed to direct rainfall that may cause degradation of surface aggregates, reduced infiltration, and increased overland flow of runoff that may carry contaminants and contribute to erosion (Duley 1940, Palis et al. 1997, Assouline 2004). This practice also results in certain paddocks being dedicated to solely growing maize year after year, thus, the effect of this monoculture system on soil quality and its sustainability is of great interest.

The Waikato Regional Council (WRC) soil quality monitoring programme gathers information on the regions soils from 150 long-term monitoring sites (Taylor et al., 2017). Arable land use sites comprise 11% of these monitor sites and are predominantly from either market garden (potatoes, onions, asparagus) or maize crops. The WRC soil quality monitoring programme covers chemical, physical and biological attributes with seven key measurements, termed indicators, that form the recommended minimum data set: soil pH, Olsen P (phosphorus), total carbon (C), total nitrogen (N), mineralisable N, bulk density (BD) and macroporosity (Hill et al. 2003).

The main soil quality indicator concerns on arable land from the WRC monitoring (Taylor et al., 2017) were loss of soil organic matter (SOM), indicated by declining trends in Total C and Total N (Figures 1 & 2), soil compaction (increased BD and lower macroporosity) and excessive nutrients (high Olsen P levels).

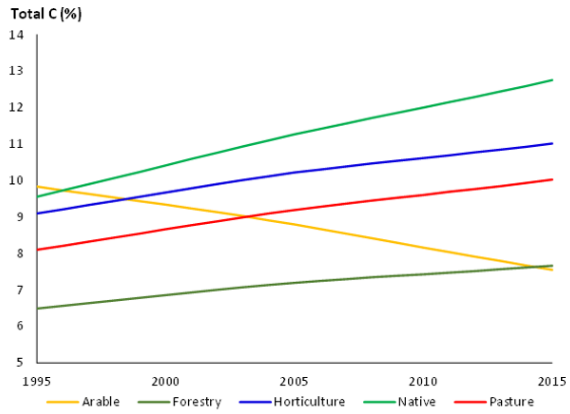

Figure 1: Total carbon in soil by land use.

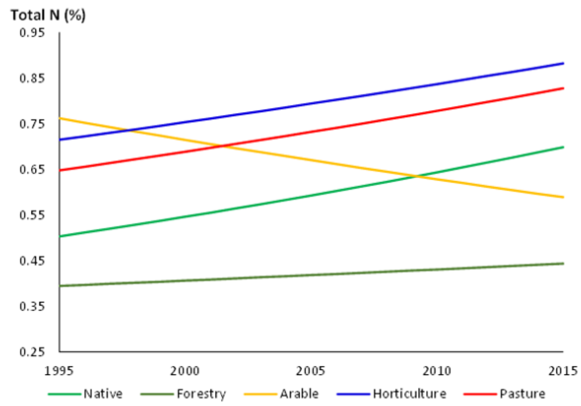

Figure 2: Total N in soil by land use.

(Figures 1 & 2 from Taylor et al., 2017).

It is widely recognised that organic matter has a prime role in influencing soil physical conditions (Russell 1971). This led Cotching et al. (1979) to investigate the effect of maize cropping on a Horotiu (Allophanic) soil in the Waikato. After nine years of continuous maize cropping Organic carbon was found to have decreased by 40% from 9.1% at the 0-5 cm depth and decreased by 15% from 6.6% at the 6-16 cm depth however it was observed the rate of decrease declined the longer the cropping continued.

Loss of SOM leads to a consequent decrease in biological contribution to fertility and soil resilience. SOM is considered a key soil attribute as it affects many physical, chemical and biological properties that control soil services such as productivity, the adsorption of water and nutrients, and resistance to degradation (Dick & Gregorich, 2004).

Approach

In this paper, the soil test data (where available) from three sites with a history of growing maize grain for decades was investigated and their soil quality indicators compared to the findings of a WRC monitoring maize grain site on the same Allophanic soil series.

Maize Sites

Site A

This property in the Morrinsville area is primarily a poultry growing operation with the broiler litter providing a major source of nutrients for the continuous maize cropping over 31 years. The soil type is a Waihou sandy loam and annual rainfall is 1100mm. Maize stubble is incorporated back into the soil by discing in early winter. Broiler litter is surface applied (average 4.7 t/ha/year). The paddocks are left fallow until around mid-August, before spraying out in spring.

Site B

This property is near Pirongia is a high producing dairy farming operation (1480 kg MS/ha). Maize silage grown on-farm to supplement the 800 Friesian cow herd with 1t DM/cow/year. The soil type is Horotiu sandy loam and annual rainfall is 1450mm. Maize grain has also been continuously grown on some paddocks and in one particular paddock since 1962. Great emphasis is placed on returning organic matter and this is accomplished through the application of poultry manures, dairy solids and a cover crop.

Site C

This was the Genetic Technologies Ltd site at Rukuhia where since 1995 new Pioneer maize varieties have been evaluated in test strips. The soil type is Horotiu sandy loam and annual rainfall is 1190mm. Following the mid April maize harvest the residues are incorporated into the soil within two weeks (usually by end of April) allowing greater time for microbial breakdown of the stubble prior to the next planting.

WRC site

This property at Te Kawa in the South Waikato. Maize for grain production has been continuously grown on some paddocks for 41 years. The soil type is Otorohanga silt loam and annual rainfall is 1355mm. The soil is left fallow over winter and the stubble is cultivated in during early spring.

The main soil characteristics of each site are summarized in Table 1. All the sites were on Allophanic soils (ASC 85-95%). The soil sampling depth at Sites A, B & C was 0-15 cm; but for the WRC site it was 0-10 cm, however, as the soils are cultivated each year to at least 15 cm the soil attributes should be uniform throughout that profile (Dr Peter Singleton, pers. comm.).

Table 1: Soil characteristics of the individual sites.

Site	pH	Olsen P	Ca	Mg	K	Na	CEC	Sulphate S
		(mg/L)	(m.e./100g soil)					(mg/kg)
A	6.4	40	12.5	1.10	0.90	0.10	18	62
B	6.6	41	11.2	1.17	0.87	0.08	17	31
C	6.6	21	14.7	0.95	0.49	0.07	22	25
WRC	6.4	47	14.0	1.10	0.90	0.10	30	58

Soil Quality Indicators

A summary of the key soil quality indicators for the WRC maize grain site (0-10 cm) is presented in Figure 3 using the SINDI (soil indicators) web-based Landcare Research tool. Results for the WRC maize grain site shows adequate status for all indicators except mineralizable N.

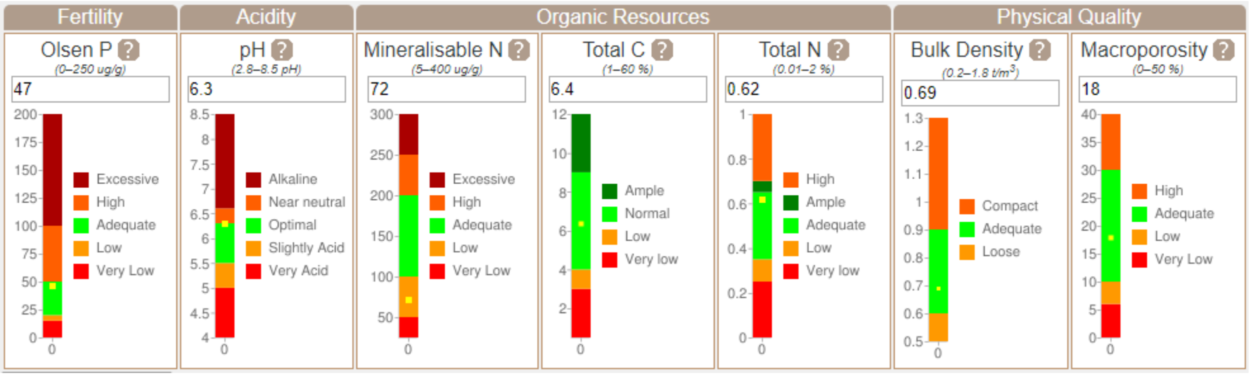

Figure 3: Key soil quality indicators for the WRC maize grain site (shown as yellow dots) using SINDI layout (Landcare Research).

Olsen P

Olsen P is the recognized agronomic test that tries to mimic the ability of a plant to remove solution and absorbed phosphates from soil, and hence get a measure of the P status for plant nutrition. Response curves for cropping have been developed through arable research and are used, like in pastoral agriculture, to calculate the required rate of fertilizer P.

Soil test results from the maize grain cropping sites show Olsen P values between 40-50 for all sites except Site C (Figure 4). These Olsen P values appear to be in excess of the economic optimum. Morton et al (2000) stated that for continuous maize grain crops the economic yield responses to P fertilizer only occurs when the soil Olsen P is <10 and for levels >10 only 20 kg P/ha (equivalent of 100 kg DAP fertiliser/ha) need be applied as a starter to help in plant establishment.

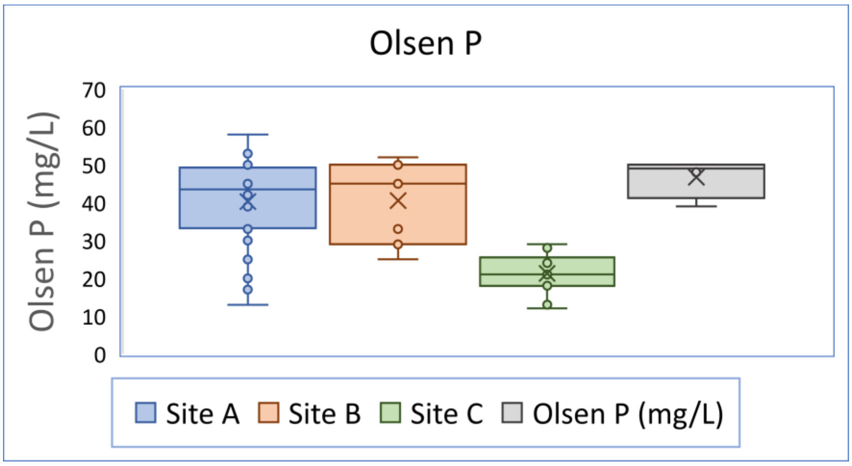

Figure 4: Boxplots of soil Olsen P of sites.

Soil pH

The pH, a measure of soils' acidity or alkalinity, is a common test and is important as each crop has differing pH needs. Although maize can tolerate a reasonably wide pH range, the optimum is 5.7-6.2 (Morton et al., 2000). The most critical factor to getting good yields is to avoid aluminum (Al) toxicity. Results from the case study sites (Figure 5) show that the mean soil pH were in excess of this optimum range and that, in fact, three of the sites had reached pH 7.0 or above over time. The major concern from having very high pH levels is that maize can be prone to zinc, manganese, and occasionally boron, deficiency when pH exceeds 6.5 (Morton et al, 2000).

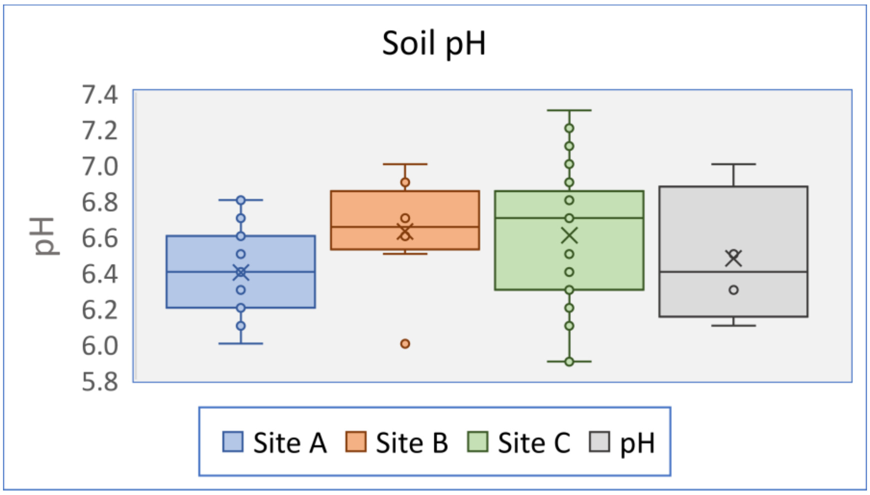

Figure 5: Boxplots of soil pH from sites.

Total carbon

Total C measures the carbon stored in soil organic matter and is one of the most important attributes influencing nutrient turnover and soil stability. Soil quality target ranges for carbon in Allophanic soils are between 4-9% C (Hill et al., 2003). Mean soil C of the sites studied fell within this target range (Figure 6). Sites A & B had similar carbon content (4.5-4.7% C), Site C was considerably higher at 7.1% C, the WRC site had the largest variability and mean of 6.4% C.

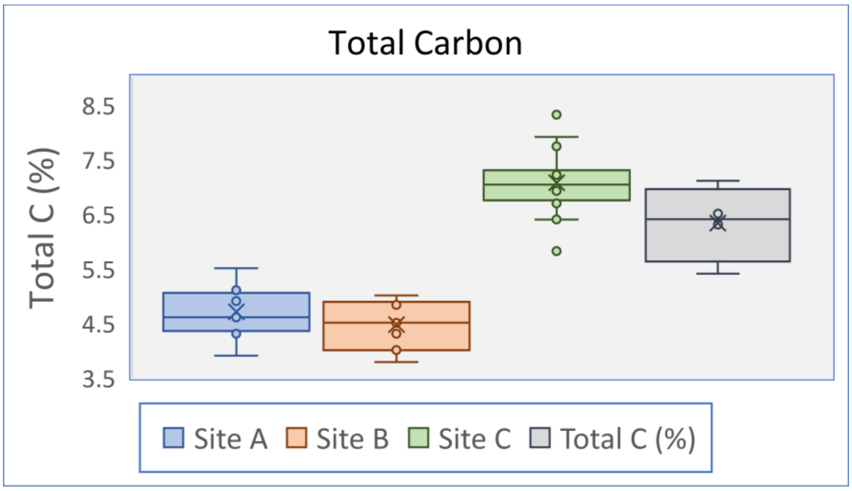

Figure 6: Boxplots of soil carbon from sites.

However, when the soil carbon content is viewed over time the results show (Figure 7) that there is a slight upward trend for Sites A, B & C but a downward trend for the WRC monitored site.

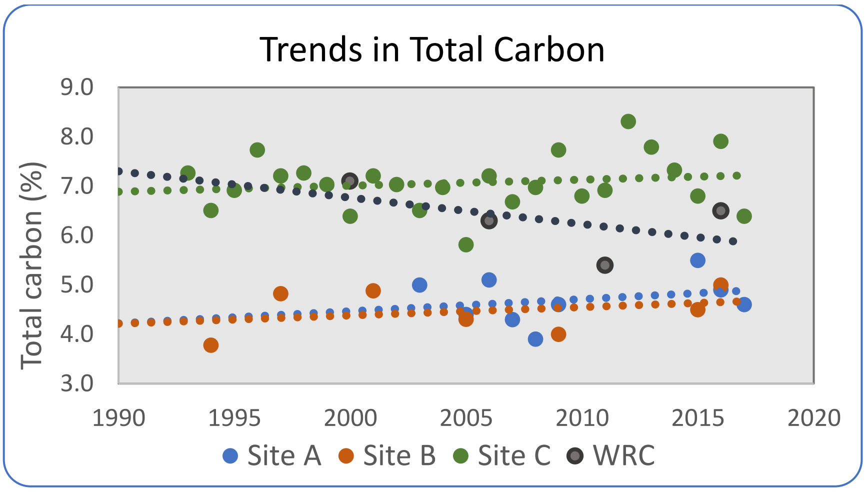

Figure 7: Trends in soil carbon over time.

The reason for the downward trend at the WRC site is unclear. All sites returned maize stubble, Sites A & B also applied organic manures (discussed later) but Sites C did not, yet had the highest carbon content. The only difference at the WRC site was that the stubble was incorporated into the soil during the spring cultivation and would not be as decomposed as the autumn incorporated stubble from Site C. In fact, with the spring soil sampling of the WRC site the undecomposed stubble is likely to have been screened out in the laboratories soil preparation procedures prior to chemical analysis (Brent Millar, Eurofins, pers. comm.). Sites A & B are also consistent with the results of Densley et al (2002) who reported the soil carbon content increased from 3.8 to 4.0% C over a six-year period when 5 t/ha chicken manure was incorporated into an Allophanic soil in the Waikato under continuous maize growing.

In a Land Management Index study in the Waikato (FAR, 2007) reported that in the top 15 cm of soil the carbon content was 65 t C/ha from continuous maize grain grown on Allophanic soils compared to 80 t C/ha from pastoral sheep farming. Using the WRC database and extrapolating from Longhurst (2017) the comparative values for the WRC maize grain site would be 66 t C/ha compared to 100 t C/ha from sheep farms on Allophanic soils (n=5). Clearly there is a loss of carbon from cultivated soils compared to permanent sheep farmed pastures. However, with good management practices and return of OM the decline in soil C can be halted and even reversed.

Total nitrogen

Total nitrogen (N) measurement of soil organic matter and nitrogen stocks. An adequate Total N target range for cropping soils, although poorly defined, is considered to be between 0.25-0.70 % (Taylor et al., 2017). Soil test results for Total N from the study sites were not as consistent as for pH and Olsen P and tended to be concentrated in the last decade. No Total N soil data was available from Site C. Results of Total N content in soil, where available, are summarized in Table 2.

Table 2: % Total N in soil (mean ± 95% Confidence Interval) of the individual sites.

Site	Mean	95% C.I.
A	0.45	0.02
B	0.42	0.03
WRC	0.63	0.07

Total N soil results show that these long-term maize grain sites fall within the adequate range mentioned above. Quinto & Catto (2016) reported a mean of 0.67% Total N (±0.01% 95% C.I.) in nearly 3,000 non-pastoral Waikato soils at 0-15 cm depth, these samples included a range of soil series and land uses (market garden and horticulture as well as maize).

Anaerobically mineralised N

Anaerobically mineralised N (AMN), sometimes referred to as available mineral-N is the method commonly used to assess soil microbial health and how much organic N is available by mineralization to the plants. An adequate level for cropping soils is between 100-200 kg/ha (Hill et al, 2003).

AMN, like the Total N soil test, has also not been measured as intently as pH and Olsen P. Soil AMN data from Site C was only available from one season but had been measured three times during the maize growing period at 16, 41 and 11 kg/ha during November, December and January, respectively. Soil AMN data from the other sites are summarized in Table 3.

Table 3: Soil Anaerobically mineralised N (Mean ± 95% Confidence Interval) of the individual sites. Data reported in kg/ha.

Site	Mean	95% C.I.
A	59	2
B	83	14
WRC	75	12

From the same dataset used for Total N, Quinto & Catto (2016) found that the mean AMN value for ~3000 Waikato soils was 148 mg/kg (± 2 95% C.I.). These units are different to those in the above table but if a mean BD of 0.70 t/m^3 was assumed then AMN would translate to 155 kg/ha.

Bulk density

Bulk density (BD) measures (weight/volume) of soil physical condition indicating whether a soil is firm and compacted, or loose and friable. The adequate BD range for cropping soils is between 0.60-0.90 t/m^3 (Hill et al, 2003). The mean BD values for these Allophanic soil sites were found to be within a very narrow band 0.69-0.72 t/m^3 (Figure 8).

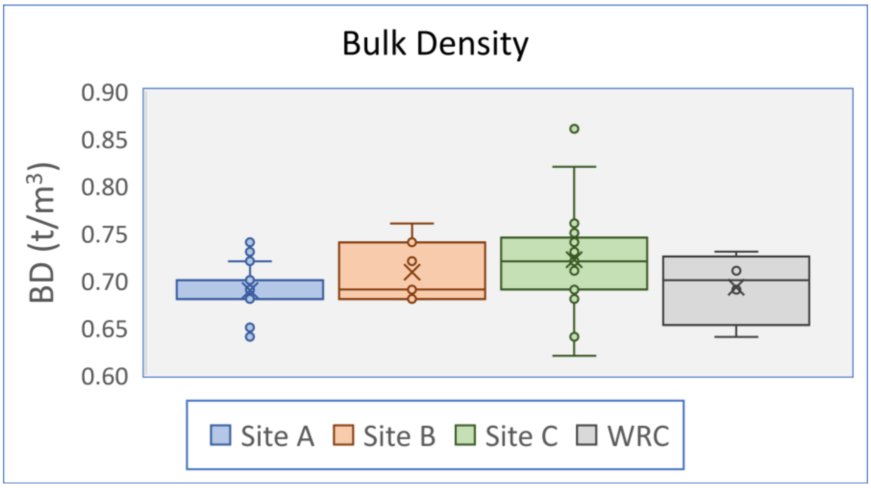

Figure 8: Boxplots of bulk density from sites.

However, what is more telling is how BD changes with length of time in maize cropping. Although there is considerable scatter of individual results, Figure 9 shows the trends from three of the four sites increasing slightly in BD over time. Only one site (Site B) indicates a downward trend. What is most interesting is that this was the site that has been growing maize the longest!

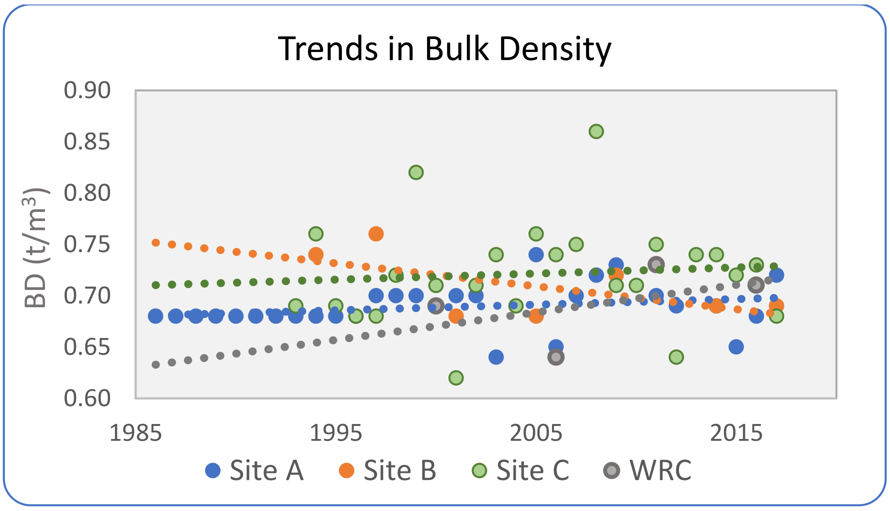

Figure 9: Changes in bulk density at sites over time.

Cotching et al. (1979) reported that BD increased from 0.72 t/m^3 to 0.79 t/m^3 after nine years of maize cropping on an Allophanic soil in the Waikato. Densley (2002) compared BD on two Waikato farms with 10-15 years history of continuous maize growing on Allophanic soils. While both Sites (1 and 2) followed similar cropping programs, Site 2 also applied 5 t/ha of poultry manure. Soil test results (6 years' data) showed that on Site 1 there was a slight increase in BD from 0.65 to 0.69 t/m^3. In comparison, Site 2, which was also receiving poultry manure (8 years' data), BD decreased from 0.80 to 0.65 t/m^3.

Macroporosity

Macroporosity at -10 kPa (shortened to macroporosity for this paper) is a measure of soil pores that air and water can use to enter the soil. Although this test is considered a key soil quality indicator it is not commonly measured on cropping farms but is rather a soil compaction attribute used for research or monitoring purposes. So macroporosity was only measured at the WRC site and was found to average 17.5% which falls within the adequate status range of 12-24% (Hill et al, 2003).

Post-harvest management

Several land use options are available in the period between maize crops. Some growers choose to leave the area "fallow" over the winter period. Previously, farmers would run cattle on the fallow ground over winter to eat any residues, this practice would exacerbate the problem of soil damage. Ideally the stubble (stover /residues) should be shredded and incorporated into the soil through shallow cultivation (using either discs or power-harrows). This practice promotes the rapid break-down of the stubble which in turn reduces the likelihood of fungal disease carry over to the next crop. Some growers employ a reduced tillage management system, these operations leave more stubble on the surface which then requires more careful management at planting.

Cover crops such as annual ryegrass or oats that are planted before or after the maize can play an important role in protecting the soil, reducing nutrient loss from surface runoff and by suppressing weed growth. At Site B the grower found that in addition to returning maize stubble there was great value in direct drilling an annual ryegrass immediately following harvest in early June. The annual ryegrass could produce 3.5-4.0 t DM/ha but instead of harvesting the crop, it was sprayed out to save time, and when desiccated to the "brittle stage", ploughed in (around September 10). This grower attributed as much value to the organic matter returned in the root mass as to the above ground biomass. This observation is backed up by FAR (2007) that grass is good at restoring soil structure due to its extensive fine root system that provides an excellent source of carbon and assists in maintaining the organic matter content of the soil.

Organic manures

Poultry

Both Sites A and B applied some form of poultry waste each year. Site A was actually a broiler chicken producer and maize grain was a secondary income source. Copious amounts of broiler litter are generated from the rearing sheds (~3m^3/1000 birds) throughout the year. The broiler litter is used on the maize crops, applied at average of 4.7 t/ha, and the surplus is used by neighboring dairy farmers. At Site B either broiler litter (from chickens) or poultry manure (from egg-layers) has been applied to the maize paddocks.

Some nutrient analysis of the poultry wastes from the maize growers were available and are summarized in Table 4. Poultry wastes are N and P rich in comparison to potassium (K) and sulphur (S) therefore may not completely meet pasture or crop nutrient requirements. Poultry wastes contain ~50% organic matter and at an application rate of 5 t/ha for example would return around 1.4 t C/ha to the soil.

Table 4: Composition of Broiler Litter and Poultry Manure (on "as received" basis).

Source	% DM	%N	%P	%K	%S	%OM	pH
Broiler Litter	68	2.65	1.05	1.45	0.35	52	8.3
Poultry Manure	77	3.40	1.25	1.30	0.65	45	7.5

Dairy

At Site B pond solids from desludging the effluent pond every two years were also applied to maize grain paddocks. This farm also had a feed pad so the pond solids would be likely to contain a relatively high concentration of nutrients. As most maize growing properties are in close proximity to dairy farms it is highly beneficial to utilise the various dairy effluents, slurries or solids onto cropping land. Some of the chemical characteristics of dairy solids have previously been described by Longhurst et al., (2017) plus unpublished pond solids data.

Table 5: Composition of some Dairy Cow manures and solids (on "as received" basis).

Manure Source	% DM	%N	%P	%K	%S	%OM	% Min-N
Storage pond solids	2	0.07	0.01	0.04			0.02
Feed pad scrapings	21	0.52	0.12	0.71	0.07	13	0.05
Static screen	15	0.23	0.04	0.07	-	9	0.01
Weeping wall	17	0.29	0.05	0.08	0.05	9	0.03
Mechanical separation	23	0.33	0.05	0.08	0.06	17	0.01
HH shelter – slurry[1]	11	0.31	0.07	0.55	0.06	7	0.15
HH shelter – solids[1]	20	0.53	0.14	0.71	0.08	11	0.18

[1] HH= Herd Home

Soil quality and grain yields

No comparative long-term maize grain yield data was available from the sites studied. However, three of the sites featured in the Pioneer trial results of individual Waikato farmers conducted by Genetic Technologies Ltd (Pioneer 2017) and provides some indication for the 2016/17 season (Table 6). For comparison, AIMI reported that the average maize grain yield for 2016 was 11.8 T DM/ha (FAR, 2016).

Table 6: Individual site results of trial maize grain yields in Waikato (Pioneer 2017).

Site	Date		Grain yields from Pioneer maize hybrids (t DM/ha)				
	Plant	Harvest	P1253	P0891	P0640	P0725	Average
Site A	Oct 19	May 13	15.22	14.71	14.98	14.90	14.95
Site B	Oct 31	May 15	15.48	15.59	16.04	15.97	15.77
WRC	Oct 10	May 5	13.81	12.10	11.93	11.89	12.43

The results from Table 6 clearly indicate that although all these sites have been in continuous maize grain for over 30 years that the grain production is still above the Waikato average and particularly so for Sites A and B.

Conclusions

From this investigation of maize grain growing it appears that the addition of organic manures (and cover crops) are very important for retaining the SOM content of Allophanic soils enabling the sustainability of this land use. Returning stubble to soil is also an important factor in continuous maize growing but further investigations are required regarding the timing of incorporation and degree of stubble treatment (shredding) on nutrient availability (especially nitrogen) during the growing period.

Acknowledgements

We acknowledge the data supplied from Murray & Marg Hart and Alan & Joy Henderson.

REFERENCES

Assouline, S. (2004). Rainfall-induced soil surface sealing. Vadose Zone Journal 3(2): 570-591.

Cotching, WE., Allbrook, RF., & Gibbs, HS. (1979) Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand. New Zealand Journal of Agricultural Research 22(3): 431-438.

Densley, D. (2002) Sustainability of continual cropping of maize for silage in the Waikato. In: *Dairy farm soil management.* (Eds. LD Currie and P Loganathan). Occassional Report No. 15. Fertilizer and Lime Research Centre, Massey University, Palmerston North. Pp 111-118.

Dick, W.A., Gregorich, E.G. (2004) Developing and maintaining soil organic matter levels. In: *Managing soil quality: Challenges in modern agriculture.* (Eds. P Schjonning, S Elmholt, BT Christensen). CABI Publishing, Wallingford, UK. Pp 103-120.

Duley, F. L. (1940). Surface Factors Affecting the Rate of Intake of Water by Soils 1. Soil Science Society of America Journal, 4(C), 60-64.

FAR. (2007) Soil quality under different maize production systems. Maize: Arable Update No. 56. Foundation for Arable Research. 2 pages.

FAR. (2016) AIMI summary of maize areas and volumes. Arable Industry Marketing Initiative. Foundation for Arable Research. 6 pages.

Guinto, D. and Catto, W. (2016) Analysis of the relationship between total nitrogen and available nitrogen in non-pastoral topsoils of New Zealand from a large soil test database. In: Integrated nutrient and water management for sustainable farming. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 6 pages.

Hill, R.B, Sparling, G., Frampton, C., Cuff, J. (2003) National soil quality review and programme design. Technical paper. Ministry for the Environment, Wellington, NZ. 34 pages.

Longhurst, R. D., Rajendram, G., Miller, B. and Dexter, M. (2017) Nutrient content of liquid and solid effluents on NZ dairy cow farms. In: Science and policy: Nutrient management challenges for the next generation. (Eds L. D. Currie and M. J. Hedley).

http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

Longhurst, B. (2017) Analysis of the Waikato Regional Council Soil Quality Indicators Monitoring Database 1990-2016. WRC Technical Report 2017/29. Waikato Regional Council, Hamilton. 53 pages.

Morton, J., Craighead, M., Stevenson, K. (2000) Managing soil fertility on cropping farms. New Zealand Fertiliser Manufacturers Research Association (NZFMRA). 46 pages.

Palis, R. G., Ghandiri, H., Rose, C. W., & Saffigna, P. G. (1997). Soil erosion and nutrient loss. III.¤ Changes in the enrichment ratio of total nitrogen and organic carbon under rainfall detachment and entrainment. Soil Research, 35(4), 891-906.

Pioneer. (2017) Pioneer® Brand Maize for Grain 2016/2017. Genetic Technologies Ltd. 21 pages.

Russell, EW. (1971) Soil structure: Its maintenance and improvement. *Journal of Soil Science 22:*137-51.

Taylor, M., Cox, N., Littler, R., Drewry, J. (2017) Trends in soil quality monitoring data in the Waikato region 1995-2015. WRC Technical Report 2017/26. Waikato Regional Council, Hamilton, NZ. 74 pages.