Changes in soil chemical properties under contrasting farming systems for a long-term experiment in the dry cropping zone

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Information

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Executive Summary

A long-term farming systems trial at Condobolin, (commenced 1998), consisting of four farming systems, traditional tillage (CT), reduced tillage (RT), zero-till continuous cropping (CC) and perennial pasture (PP) was investigated to determine the influence of the farming systems on soil properties. Soil samples collected in 1999, 2004, 2008 and 2012 and were used to determine the change in chemical properties over that time.

Key findings from the analysis include:

- Farming system influenced soil organic carbon (SOC, Walkley Black), although differences were not consistent throughout the experiment. There were similar levels between systems at the beginning of the experiment. SOC increased across all farming system until 2008, when the RT (2.03%) was higher than the CT (1.65%) and PP (1.55%), with the CC intermediate (1.73%). Between 2008 and 2012, SOC decreased in all of the cropping systems. Under PP SOC increased at a rate of 0.037% per year over the experiment (Adj R^2 = 0.35).
- Colwell P levels at 0-10 cm were closely related to the number of years of cropping and P addition in fertiliser. From 2008 there were higher P levels in the CC (2012 = 36.5 mg/kg) than the RT (2012 = 16.4 mg/kg) and CT (2012 = 16.1 mg/kg), which were higher than the PP (2012 = 6.6 mg/kg). In the CC treatment, P increased linearly at a rate of 1.8 mg/kg per year of crop (Adj R^2 = 0.66). Furthermore in the PP, where P was not applied, it decreased at a rate of -0.3 mg/kg per year in pasture (Adj R^2 = 0.11), although this trend was weak it was still significant.
- There was a decrease in pH ($CaCl_2$) at the soil surface (0-10 cm) under higher levels of cropping. By 2012 the CC had the lowest pH (4.96) and the PP (5.40) had the highest. Under CC pH decreased at -0.23 units per year of crop (Adj R^2 = 0.09).
- Sulphur showed consistently lower levels in the PP than the cropped farming systems.
- Exchangeable Al is closely linked to changes in pH. It did not show differences between farming systems until 2012 when the CC was highest (0.118 meq/100g), PP lowest (0.044 meq/100g) and the RT and CT were intermediate (average 0.075 meq/100g).

Overall, changes in soil chemical properties reflected the frequency of cropping that occurred in the farming system and subsequent fertiliser inputs that increased soil P levels and cation removal or nitrate leaching that reduced pH. Although there were tillage differences between the CC, RT and CT, tillage does not appear to have as large an influence as cropping frequency. The PP had less degradation from reduced pH, and increased exchangeable Al. Changes made to the phases in the RT and CT between 2010 and 2011 made it difficult to determine whether there were consistent differences between phases and may also have contributed to the reduction in SOC in these systems between 2008 and 2012. The changes in chemical properties should be assessed in conjunction with physical attributes which were not available when this report was prepared.

Introduction

There are a number of competing processes that can determine the nutrient levels in different farming systems. The input of fertilisers can increase nutrients that are often limiting for production, but the relative level and response of each nutrient will depend on the amount of nutrient exported in products or that is tied up through short-term nutrient cycling or long-term fixation in the soil. The mineralisation of nutrients and accessibility to plants is also in part determined by soil moisture. Changes in properties can be slow and therefore need to be assessed over long periods.

The Central West Farming Systems (CWFS) Systems Comparison Trial commenced in 1998 at the Condobolin Agricultural Research and Advisory Station. The aim of the trial was to compare the profitability and sustainability of four contrasting farming systems. This report examines the results of the soil chemical analysis that was undertaken as part of the trial.

The Site and Treatments

The CWFS Systems Comparison Trial site covers 160ha at the Condobolin Agricultural Research and Advisory Station consisting of four 40ha replicate blocks. Each replicate has the four different farming systems on trial (10ha per farming system), with 5 separate phases in 2ha plots. Each of the farming systems were cropped and grazed differently depending on the farming practices associated with each system.

Traditional farming system (CT)

The CT represents a mixed farming system that uses conventional tillage with a pasture phase and grazing by livestock. This system was set up to reflect what many growers in the region were using on their own properties. The crops in rotation on the system included long fallow wheat (LFW), short fallow wheat undersown with a pasture combination (SFWu/s) and a grazed pasture. The sown pasture contained annual medics and lucerne.

Reduced tillage with livestock (RT)

The RT represented another mixed farming system using a rotation of LFW, long fallow wheat undersown with a pasture combination (LFWu/s), grazed pasture and a period of rest between wheat crops. During the rest period stubble was maintained and weeds were controlled by grazing and herbicide application (in August). The sown pasture contained annual medics and lucerne.

Zero-till with no livestock (CC)

The CC represented a continuous cropping rotation that was dependent on herbicide application for weed control. This system was chosen to represent the intensified cropping systems in the Central West (NSW). The crops in rotation were wheat, barley, a pulse crop, SFWaP (aP – after pulse) and a green manure crop (Pulse). Initially the pulse crop was sown as canola and then converted to a pulse. After a number of years the pulse crop was not harvested and the pulse and green manure crops were essentially the same treatment.

Perennial Pasture (PP)
This farming system was divided in 12 equal segments and was rotationally grazed. Decisions regarding stocking rates and grazing pressure were made based on seasonal climatic conditions. The pasture established in the PP system was a combination of lucerne, clover and medics. After an initial period of grazing, these treatments were only stocked periodically and the rotational treatments were not kept in place.

There were five phases in each of the three cropping farming systems, while the PP was all permanent pasture and did not differ between phases (Table 1). The phases were managed in the order shown in Table 1 until 2010 when they became out of sequence. The pasture phases in the CT and RT were not bought back into crop in 2010 and they were not sown again in 2011. There was a higher proportion of cropping than normal in 2012 with four crops in RT and three in CT.

Table 1 The farming systems and cropping phases implemented at the Condobolin comparison trial

Farming System	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
CT	LFW	SFWu/s	Pasture	Pasture	Pasture
RT	LFW	No crop	LFWu/s	Pasture	Pasture
CC	Wheat	Barley	Pulse	SFWaP	Green Manure
PP	Pasture	Pasture	Pasture	Pasture	Pasture

u/s: undersown with pasture, aP: after pulse

Methods

Paddock Management
Each of the farming systems were managed differently depending on the requirements for that system. For example, variations existed in timing and number of pesticide applications, cultivation time and the detail methods are described in appendix 1.

Soil Chemical Analysis
Soil cores were collected from different depths over the experimental period. Table 1Table 2 describes the number soil samples collected, and the depths these were collected from, where available. Sampling methodology was unavailable for 2008.

The deep core and hand cored samples were bulked separately into five depths (0-10cm, 10-30cm, 30-50cm and 70-90cm [70-100cm in 2012]). Soil samples were collected in April 1999, March/April or November 2004 (all plots were sampled in April 2004 with the exception of CT Pasture2 plot, CT Pasture3 plot and all PP plots which were all sampled in November 2004), pre sowing 2008 and in August/September 2012.

Soil cores were subsampled in the plot and then dried (40°C) before storage. The soil samples were sent to CSBP Soil and Plant Analysis Laboratory for analysis. The analysis included soil pH (4A1 and 4B2), electrical conductivity (EC; 3A1), Soil organic carbon (SOC; 6A1); nitrate and ammonium N (7C1); Colwell P and K (9B); Sulphur (10B); Exchangeable cations (Al^{3+}, Ca^{2+}, Mg^{2+}, K^+ and Na^+); DTPA Cu, Fe, Mn and Zn; and Boron (hot CCl_2 extraction) (Rayment *et al.* 2011). A complete list of the properties analysed and measurement units can be found in appendix 2.

Table 2 Soil samples collected at the Condobolin comparison trial

	1999	**2004**	**2008**	**2012**
Deep Corer				
- cores per plot	10	10	n/a	11
- depths	0-10cm	0-10cm	n/a	0-5cm
	10-30cm	10-30cm		5-10cm
	30-50cm	30-50cm		10-20cm
	70-90cm	70-90cm		20-30cm
				30-50cm
				50-70cm
				70-100cm

Statistical Analysis

The analysis examined the differences in soil properties (a) between farming systems (across all phases), (b) between phases within farming systems and (c) were compared to key management actions to determine what was influencing the differences in soil chemical properties. The analysis for farming systems (a) and phase (b) was done using ANOVA. The management interaction (c) was done using regression analysis and examined the number of years under crop and the change in soil properties to determine the rate of change in soil chemical properties. This was generally done for the CC or PP treatments, due to the complexity introduced by the phases.

Results and discussion

Over the following two sections the differences between farming systems are compared for the initial year (1999) and subsequent years (2004, 2008 and 2012). For the cropping farming systems (CT, RT and CC) analysis was pooled across the five phases, while for the perennial pasture that contained only one form of management, there were 4 separate bulked samples for each depth. This analysis enabled the average change in soil chemical properties across the systems to be determined. Analysis was done to a depth of 90 to 100 cm, but significant differences were generally only found at the soil surface (0-10 cm) and only the differences at the soil surface are presented, except where there were significant differences at depth for the major chemical properties. Appendix 3 compares the full analysis of all properties measured at each of the soil depths sampled for the four farming systems.

Initial chemical soil properties

The soil chemical properties were consistent across the three rotational farming systems at the beginning of the trial though the perennial pasture system showed significantly lower levels of Phosphorus, Sulphur and Electrical Conductivity ($P<0.05$; Table 3), possibly due to addition of fertilisers with P and S, or cycling of S in the farming systems that were cropped in the first year of the experiment. Nevertheless, these initial differences were not large enough to result in differences in productivity between systems initially.

Table 3 The average Colwell phosphorus, pH, sulphur, organic carbon, exchangeable aluminium, cation exchange capacity and conductivity at 0-10cm for each farming system at the beginning of the experiment

Farming System	Col P (mg/Kg)	pH (CaCl2)	S (mg/Kg)	Carbon (%)	Exc. Al (meq/100g)	CEC (meq/100g)	Conductivity (dS/m)
CC	12.60	5.30	7.99	1.27	0.06	10.35	0.08
CT	12.60	5.26	7.57	1.30	0.05	10.00	0.07
RT	12.00	5.33	7.84	1.29	0.06	10.25	0.08
PP	10.25	5.35	5.84	1.28	0.06	10.39	0.05

Organic Carbon

Organic carbon was monitored during the experiment and the changes over the experimental period (0-10cm profile) shown in Figure 1. No significant differences ($P=0.967$) were found in organic carbon levels between any of the four farming systems at the beginning of the experiment in 1999. Organic carbon levels increased in all treatments until 2008 when differences between farming systems developed ($P=0.009$) and at this time RT was higher than CT and PP. By 2012, organic carbon levels decreased in all of the systems with cropping (CC, CT and RT) and continued to increase in the PP farming system and there were no significant differences between farming systems at this time. The decrease in SOC found in the systems with cropping in 2012 was possibly due to increased cropping frequency in the rotations in the previous year due to changes made to reinstate the phases after some phases were not sown in 2010 and 2011. The monitoring of systems in spring in 2012 rather than autumn (pre sowing) may also shown seasonal difference in SOC between treatments.

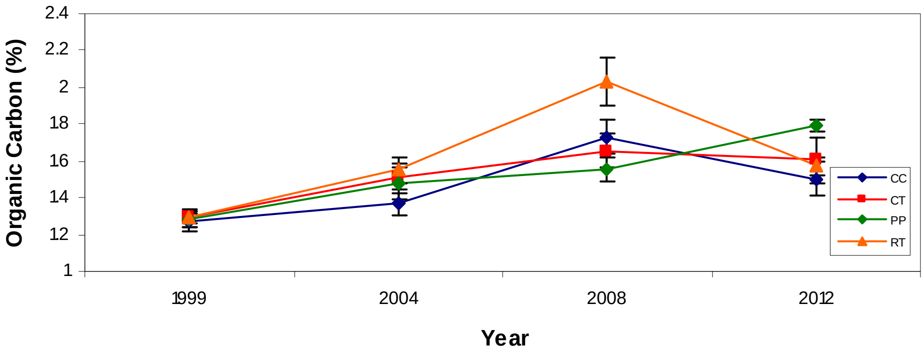

Figure 1 Organic carbon (%) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

Phosphorus

Changes in P over the duration of the experiment are shown in Figure 2 for the 0-10cm soil profile. At the beginning of the experiment there were no significant differences between the farming systems in the amount of P in the 0-10cm soil profile (P=0.149), however differences were found between the farming systems from 2004 onwards (P<0.001 in 2004, 2008 and 2012). In 2004 the CC was higher than the other farming systems and in 2008 and 2012 there were higher P levels in the CC than the RT and CT, which were higher than the PP. The P levels at 0-10 cm appear to be closely related to the level of cropping and P addition in fertiliser (e.g. MAP).

When examining the deeper soil profiles, it was also found that there were no significant differences at the beginning of the experiment, although differences did develop over the duration of the experiment (appendix 3). By 2008, the Colwell P level at 10-30 cm was higher in the CC (6.8 mg/kg) than the PP (3.3 mg/kg) (P=0.032; CT and RT average = 4.8 mg/kg). By 2012, the Colwell P level at 10-30 cm was higher in the CC (7.3 mg/kg) than the RT (5.1 mg/kg) and PP (4.1 mg/kg), the CT (6.1 mg/kg) and RT were not significantly different, but the CT was higher than PP (P=0.003).

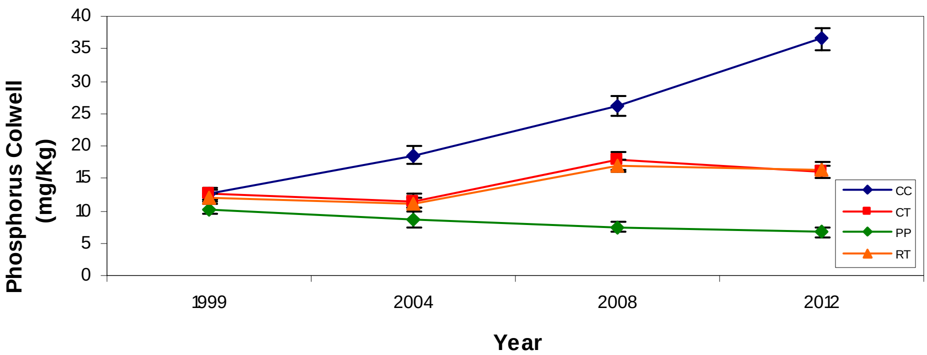

Figure 2 Colwell phosphorus (mg/kg) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

pH

pH was measured during the experimental period and changes over time (0-10cm profile) are presented in Figure 3. There was no significant difference between treatments measured in 1999, but changes between the farming systems occurred later in the experiment. There were significant differences in 2004 (P = 0.003), where PP was higher than the other farming systems, and in 2012 (P<0.001) where the CC was lower than CT and PP was highest. Clearly PP maintained a higher soil pH than the treatments with cropping, particularly with the higher cropping frequency in the CC.

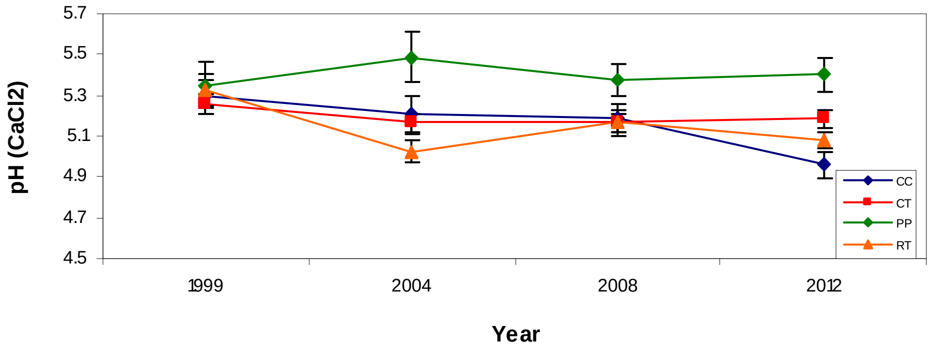

Figure 3 pH ($CaCl_2$) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

Sulphur

Changes in sulphur were monitored during the experimental period and the measurements recorded (0-10cm) are presented in Figure 4. After an initial build up in the first five years of the trial, levels remained stable until 2012 when they decreased again. Significant differences were found between the treatments for each of the years measurements were collected (P < 0.001 in 1999, 2004 and 2012, P = 0.006 in 2008). It was also found that throughout the trial, the PP system consistently had lower sulphur levels that the other treatments. In 2004 the CC was also higher than RT and in 2008 the CT was not significantly higher than PP.

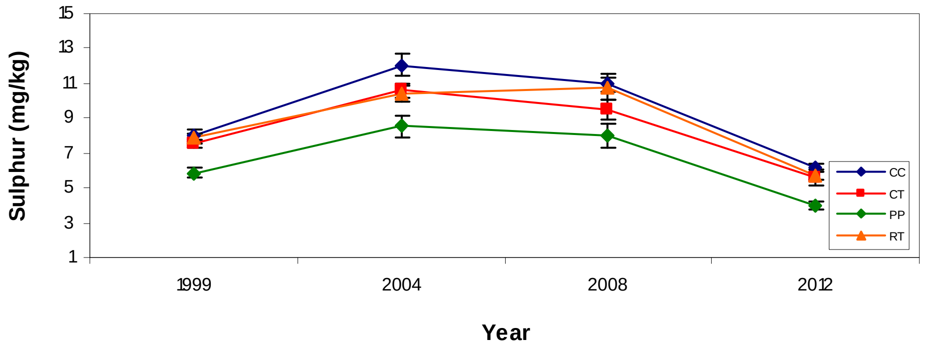

Figure 4 Sulphur (mg/Kg) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

Electrical Conductivity (EC)

When examining the 0-10cm soil profile, significant differences were found in 1999 and 2004 (FP < 0.001) and are presented in Figure 5. In 1999, the PP was lower than the other treatments and in 2004 CC was higher than the other treatments. No significant differences were found at any other soil profile depths throughout the trial period. Overall the levels were low and would not have influenced production.

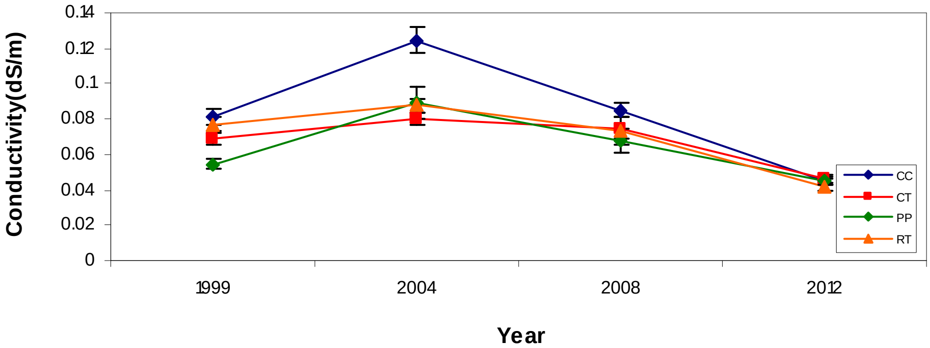

Figure 5 Electrical conductivity (dS/m) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

Exchangeable cations

Exchangeable cations capacity (CEC) were measured as the sum of the Al^{3+}, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} cations. There were differences in CEC between treatments by 2012 (Figure 6). At this time the CC was lower than the PP, which was highest. The changes in CEC, follow a similar pattern to those for pH.

Exchangeable Al^{3+} at 0-10cm is presented in Figure 7. There were no significant differences found between any of the treatment throughout the experiment until the final measurements that were taken in 2012 ($P < 0.001$). The CC had the highest exchangeable Al^{3+} levels, PP the lowest and the RT and CT were intermediate. When examining the deeper soil profiles, no significant differences were found during the experimental period.

In 2012, there were also differences in exchangeable Mg^{2+} ($P = 0.005$) and K^{+} ($P=0.002$) at 0-10 cm. There was higher Mg^{2+} in the PP (1.97 meq/100g) than the other treatments (average = 1.68 meq/100g) and lower K^{+} in the CC (1.63 meq/100g) than the other treatments (average = 1.86 meq/100g). There was no difference in exchangeable Ca^{2+} at any time throughout the experiment.

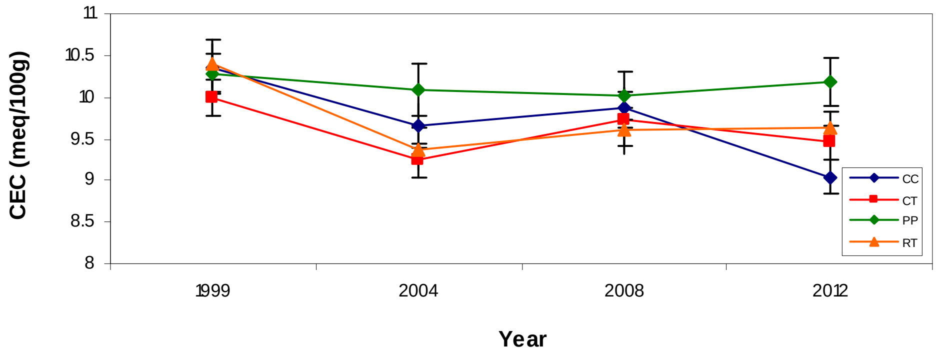

Figure 6 Exchangeable cations (meq/100g) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

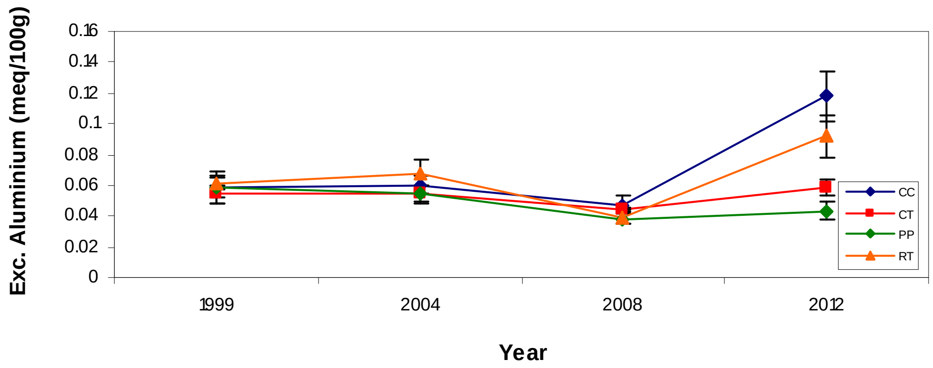

Figure 7 Exchangeable aluminium (meq/100g) levels in the 0-10cm soil profile measured during the experimental period. Standard error (mean) bars presented.

Mineral N 2012

Nitrate N (NO_3) and ammonium (NH_4) were measured on the archived samples from 1999, 2004 and 2008 and from fresh samples collected in 2012. The mineral N levels are only reported for the newly collected samples from 2012, due to possible changes in mineral N over the archived period. NO_3 varied between treatments when measured in August/September 2012 (Figure 8). There were lower nitrate levels in the PP compared to other treatments at 0-10 cm (P=0.006), 10-30 cm (P=0.049) and 30-50 cm (P=0.006), although CC was higher than RT at 30-50 cm. At 50-70 cm, PP was lowest, but not significantly different from CT and CC was highest (P=0.002). At 70-100cm, the CC was higher than the other treatments (P=0.014). There were no differences in NH_4 between treatments in 2012.

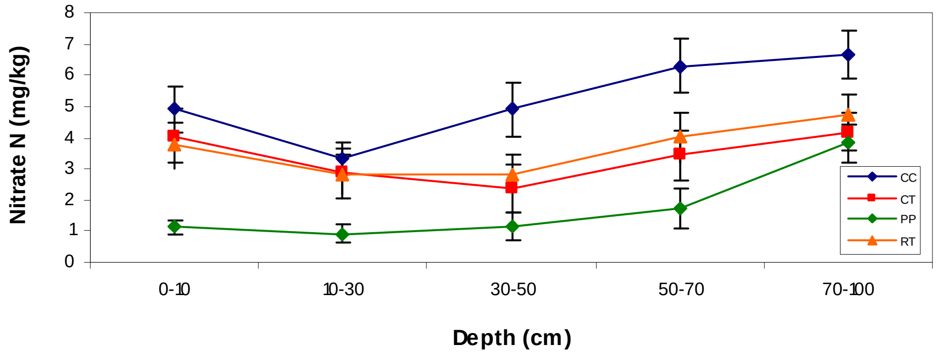

Figure 8 Nitrate N (mg/kg) levels throughout the soil profile measured in August and September 2012. Standard error (mean) bars presented.

Understanding the influence of cropping phases

Statistical analysis (ANOVA) was conducted to determine the difference in chemical properties between phases for each farming system. The perennial pasture farming system was excluded from the analysis as this system did not contain differences in phases. Appendix 4 describes where significant differences were found between phases for each different farming system for the 0-10cm soil profile for all of the elements measured during the experiment.

Traditional farming system (CT)

Figure presents the differences found between the rotational phases for P, conductivity, exchangeable Al, pH, S and organic carbon over the duration of the trial (0-10cm soil profile). The differences found between phases for exchangeable Al, pH or organic carbon were not significantly different. Significant differences were found for P in 2008, electrical conductivity in 1999 and 2004, and S in 1999 and 2012. The Colwell P in 2008, was lowest in year 1 of wheat (before sowing and fertiliser addition) and highest in year 2 and then steadily decreased over the pasture phase. The conductivity, showed highest levels in the 2nd year of wheat (1999 and 2004) and levels decreased over the pasture phase, before increasing with year 1 of cropping. As the increases were found in soil samples taken before fertiliser addition, it indicates the higher conductivity in cropping is due to soil preparation methods more so than fertiliser addition. There were no clear trends for S.

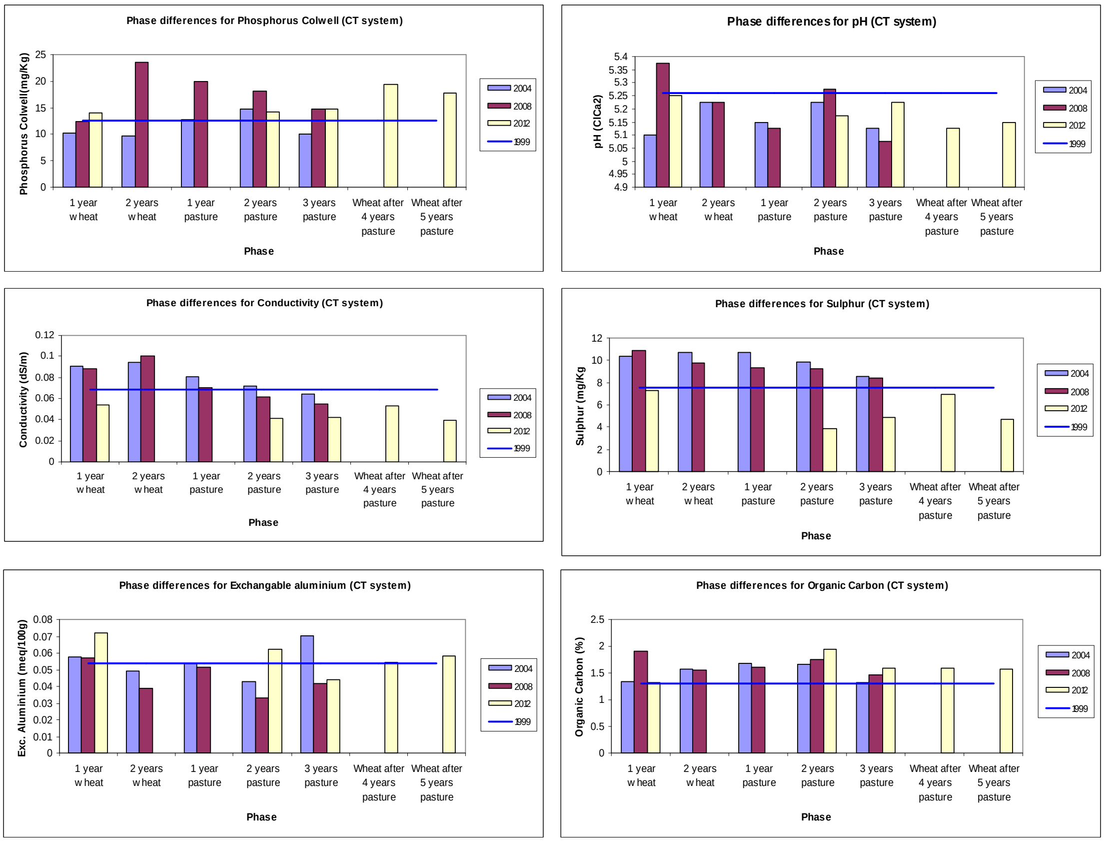

Figure 9 Difference in soil chemical properties between the rotational phases for the CT farming system

Reduced tillage with livestock (RT)

Figure 10 presents the differences found between the rotational phases for P, conductivity, exchangeable Al, pH, S and organic carbon over the duration of the trial (0-10cm soil profile). In the RT treatment organic carbon did not significantly change. Of the remaining elements, all show significant differences between rotational phases in 2012. P levels were lowest after 2 years of pasture and highest in wheat after rest and under sown wheat. Al was highest in the wheat after pasture and rest. pH was highest in the skip compared to the other treatments. Sulphur was lowest after 2 years of pasture and highest after 3 years in 2012, which indicates that there may not be cumulative effects of pasture or cropping explaining the differences in S between phases. In 2008 and 1999 the S was higher in under sown wheat. Electrical conductivity was lowest in under sown wheat in 2012, but highest in 2008.

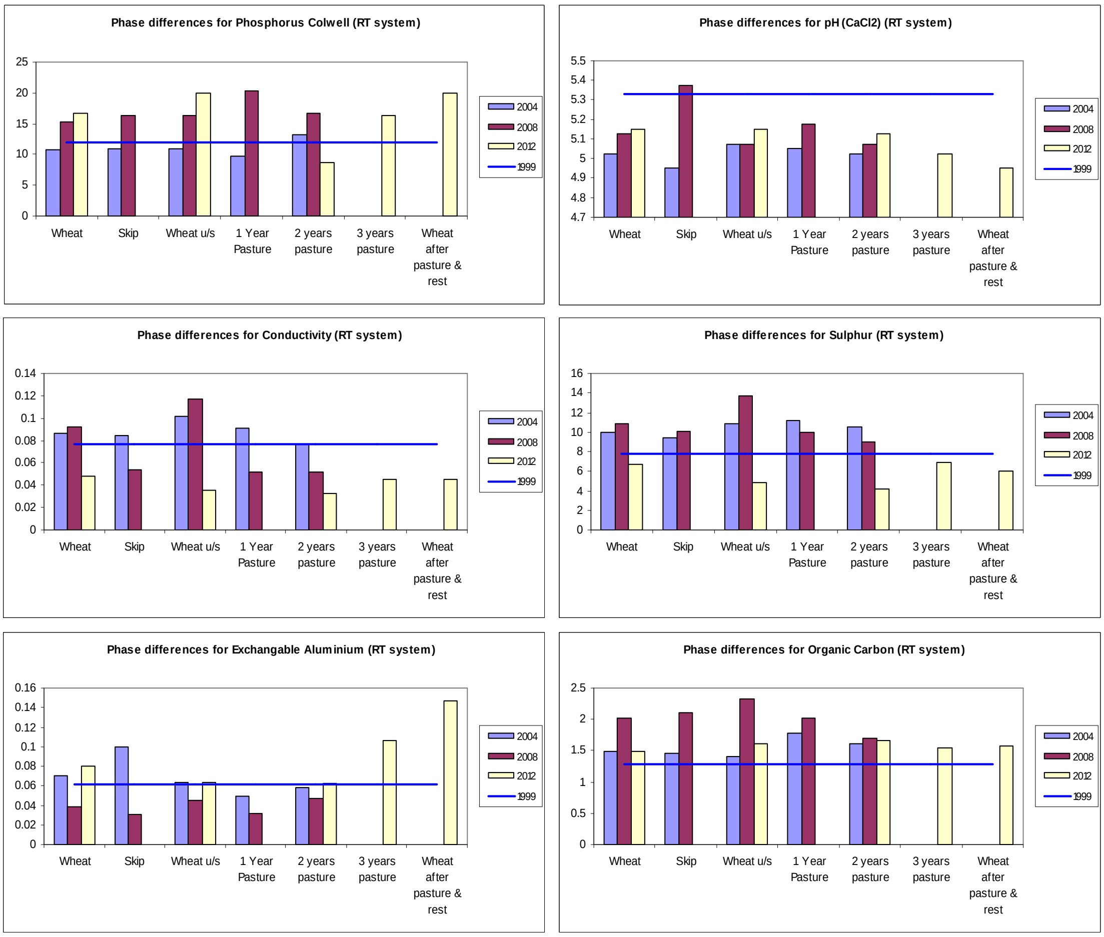

Figure 10 Difference in soil chemical properties between the rotational phases for the RT farming system

Zero-till with no livestock (CC)

The analysis of phases for the CC cropping systems found there was no difference for P, conductivity, exchangeable Al, pH, and organic carbon over the duration of the trial (0-10cm soil profile; Appendix 3). Only S was found to show any significant differences occurring between the phases, in 1999 (P = 0.002) so is unlikely to be the cumulative effects of the treatments. Because there were only differences in crop types and there was no pasture, the cumulative affects of cropping were also investigated (Figure 11). P increased linearly at a rate of 1.83 mg/kg or 2.56 kg/ha (assuming a bulk density = 1.4 g/cm^3[*]) per year of crop (Adj R^2 = 0.66). The pH also decreased at -0.23 units per year of crop (Adj R^2 = 0.09). There were no other clear trends with the other soil properties.

[*] This was the average bulk density measured at the site in 2011 for the SCaRP project, which sampled parts of the RT, CC and PP treatments. There was no significant difference in bulk density between these systems.

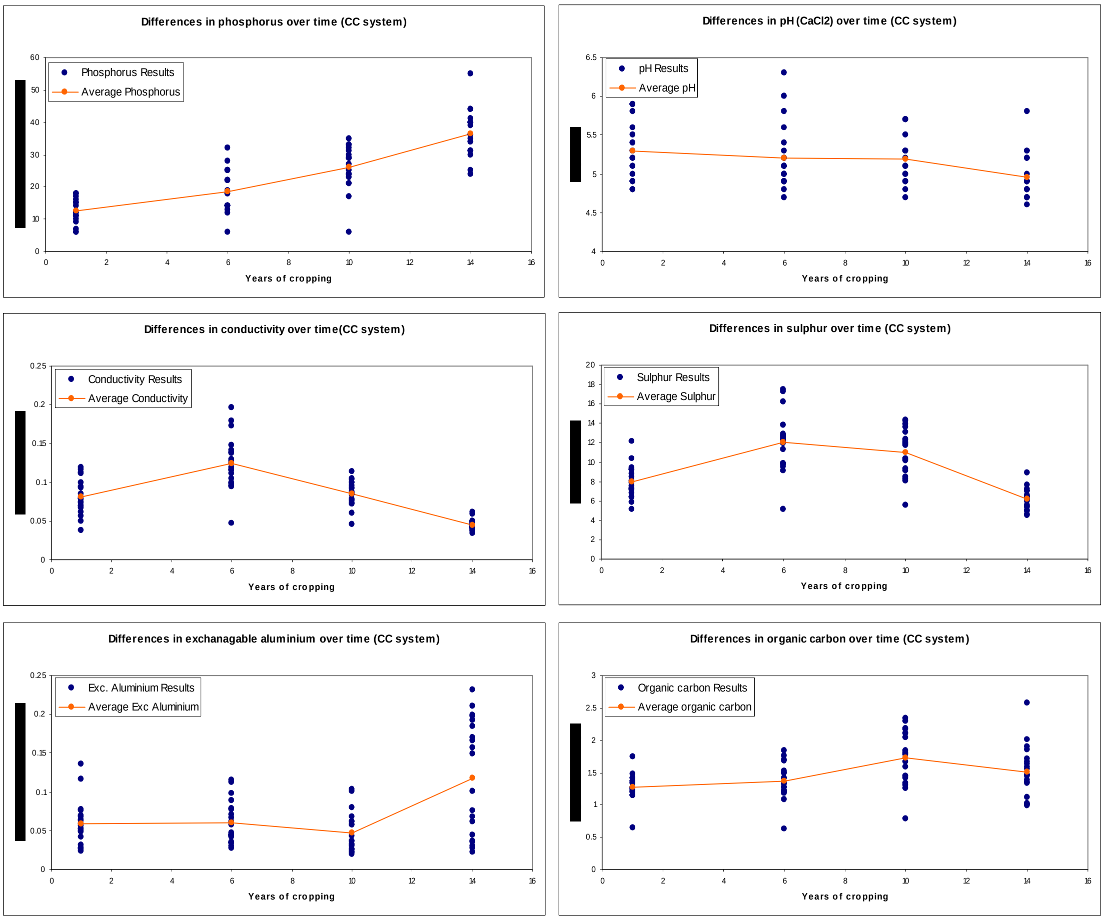

Figure 11 Difference in soil chemical properties over time for the CC farming system

Perennial pastures (PP) farming system

There were no phases for the PP system, and the cumulative difference in soil properties were compared over time (Figure 12). The differences in P, electrical conductivity, exchangeable Al, pH, S and organic carbon were examined over the duration of the trial (0-10cm soil profile). In PP, P was not applied and it decreased at a rate of -0.28 mg/kg or 0.39 kg/ha (assuming a bulk density = 1.4 g/cm^3) per year of pasture (Adj R^2 = 0.11). Organic carbon also increased at a rate of 0.037% or 0.52 t C/ha (assuming a bulk density = 1.4 g/cm^3) per year of pasture (Adj R^2 = 0.35). There were no clear trends for the other soil properties.

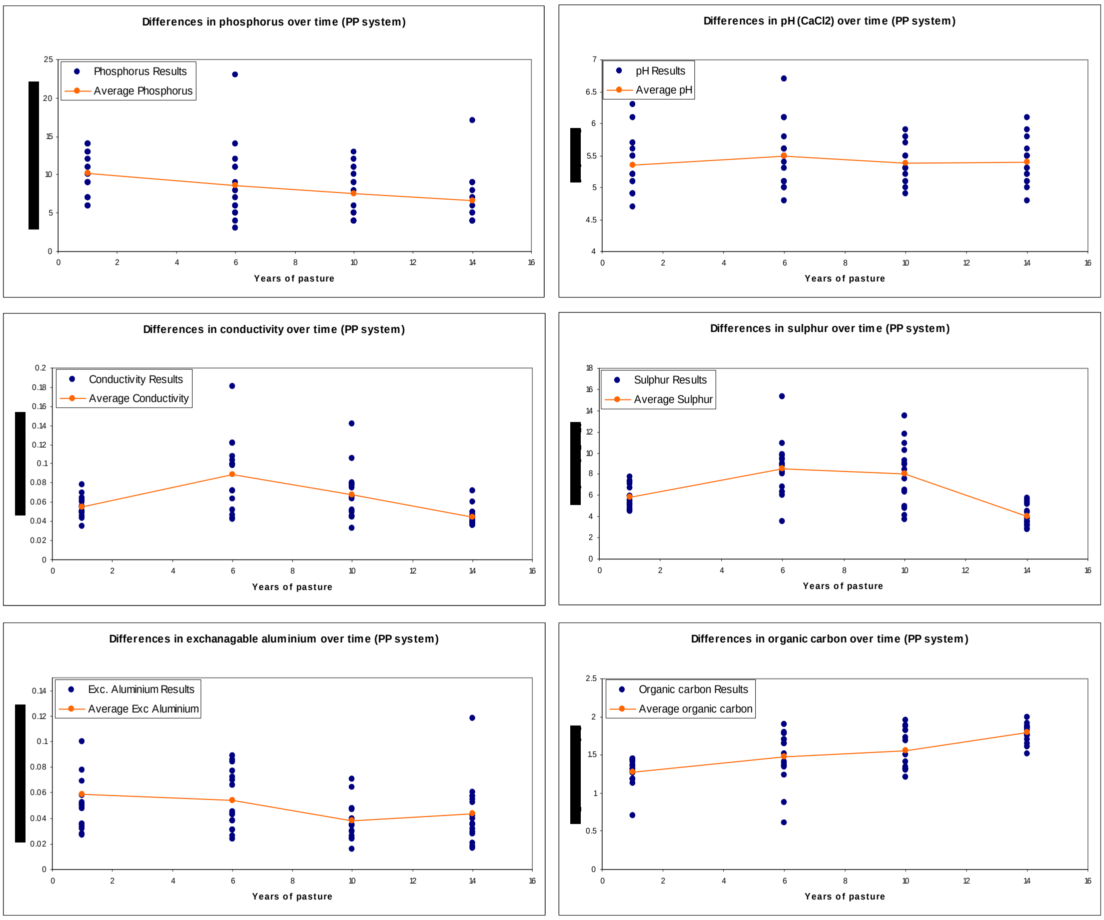

Figure 12 Difference in soil chemical properties over time for the PP farming system

Mineral N between phases

For the CC treatment there were differences in NO_3 between phases ($P<0.001$) and soil depths ($P<0.001$), but there was no interaction between them (Figure 13). Phase 5, which was a pulse crop after wheat, had highest NO_3 levels. Phase 2, which was barley after wheat, had the next highest levels. There were no differences between the remaining phases. This indicates there was higher NO_3 level in the crops that occurred in the year after wheat. This was shown by the pulse crop that had higher levels after wheat than after barley. Phase 1 and 4 were both wheat crops following a pulse and they had the lowest NO_3 levels.

For the CT treatment there was no significant difference with depth ($P=0.058$), but there were difference due to phases ($P<0.001$; Figure 14). Phase 1, which had wheat after three years of pasture, had the highest NO_3 levels. Phase 7, which was out of phase (should have been phase 2) and had wheat under sown following four years of pasture, had the next highest levels of NO_3. There were no differences between the remaining treatments. This shows that NO_3 levels were lower in pasture than cropped treatments, although wheat following five years of pasture also had low levels. It appears the longer the pasture phase before wheat the lower the NO_3 levels measured at this time.

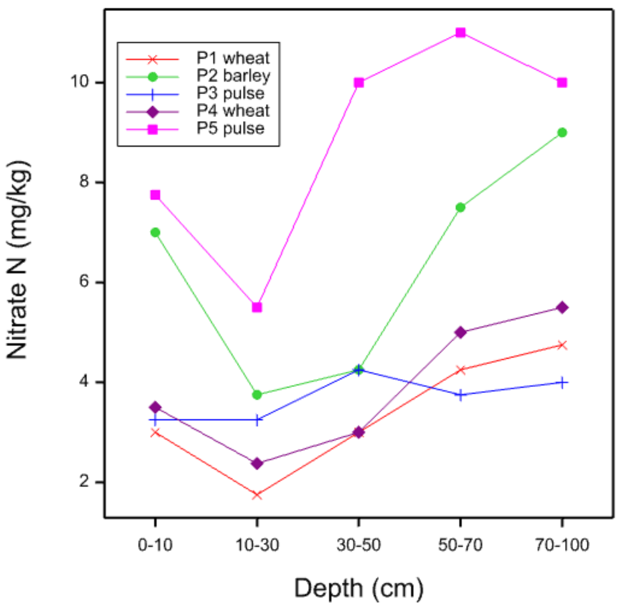

Figure 13 Soil nitrate (NO_3) levels between different phase and soil depths for the CC treatment.

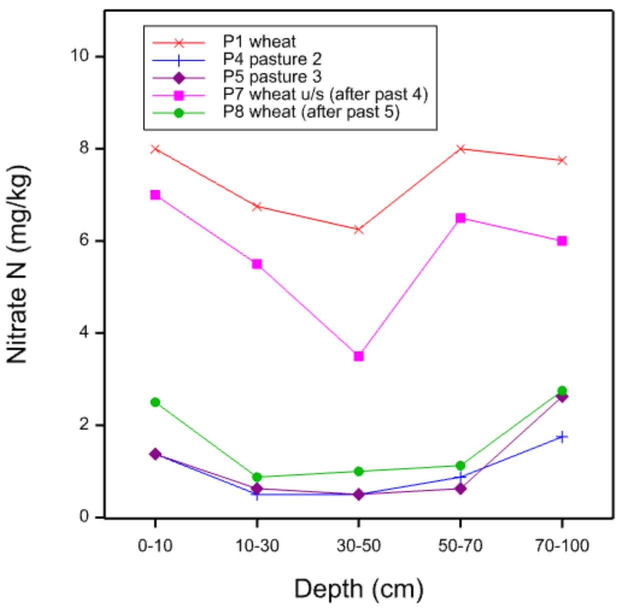

Figure 14 Soil nitrate (NO_3) levels between different phase and soil depths for the CT treatment.

For RT there were significant differences with depth (P=0.016) and with phase (P<0.001) but not for the interaction between the two (Figure 15). The highest NO_3 levels were found in phase 7, which was out of phase (should have been phase 2) and had wheat following three years of pasture and phase 8, which was also out of sequence and had wheat under sown following volunteer pasture in the previous year (should have been phase 4). The next highest was phase 1, which had wheat after three years of pasture. The lowest levels were found in phase 3, which had wheat following a skip, and phase 5, which had two years of pasture. Pasture again had the lowest NO_3, but there were no clear trends from the history of the cropped treatments to indicate why there were relatively large differences in NO_3 between phases.

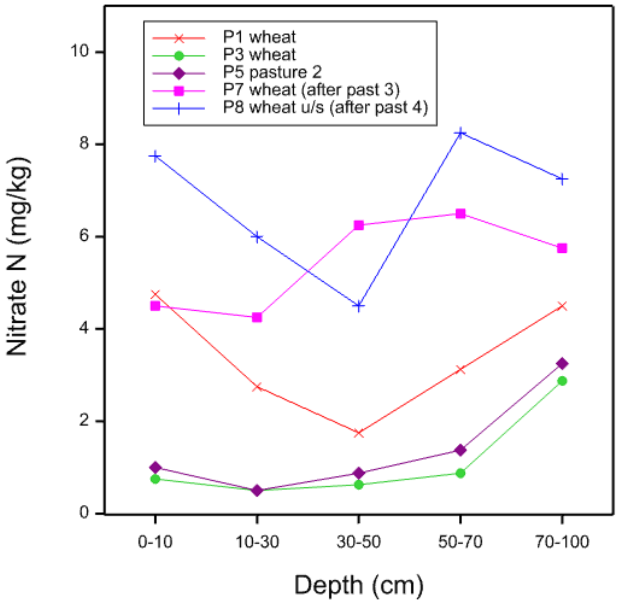

Figure 15 Soil nitrate (NO_3) levels between different phase and soil depths for the RT treatment.

Relationships between pH and exchangeable cations

The relationships between pH and exchangeable cations at 0-10cm are presented in Figures 16, 17 and 18. CEC increased with increasing pH. Exchangeable Al increased exponentially below a pH of 4.8. While exchangeable Ca also increased with increasing pH. When treatments were compared, there were no treatment differences in the response of cations to pH. This indicates that treatment did not influence the availability of Al, Ca and CEC, beyond differences caused due to changes in pH.

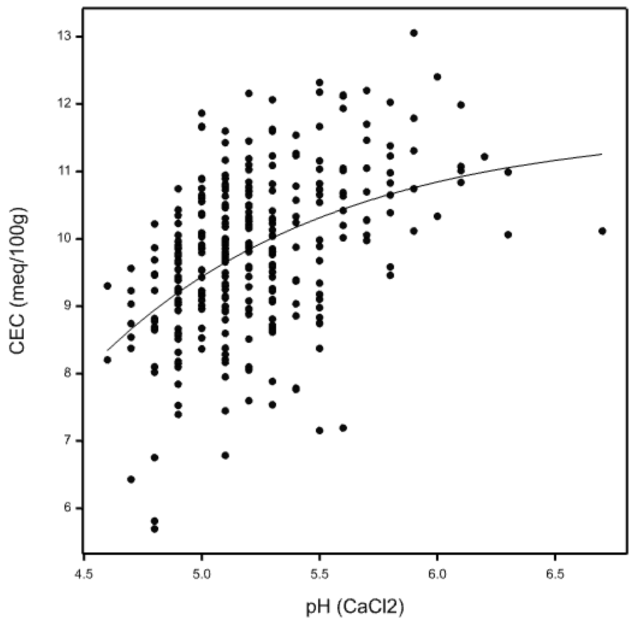

Figure 16 Cation exchange capacity (CEC) compared to pH($CaCl_2$) at 0-10 cm across systems, phases and years. Y = 11.661 - 330(0.368X); Adj R2 = 0.212

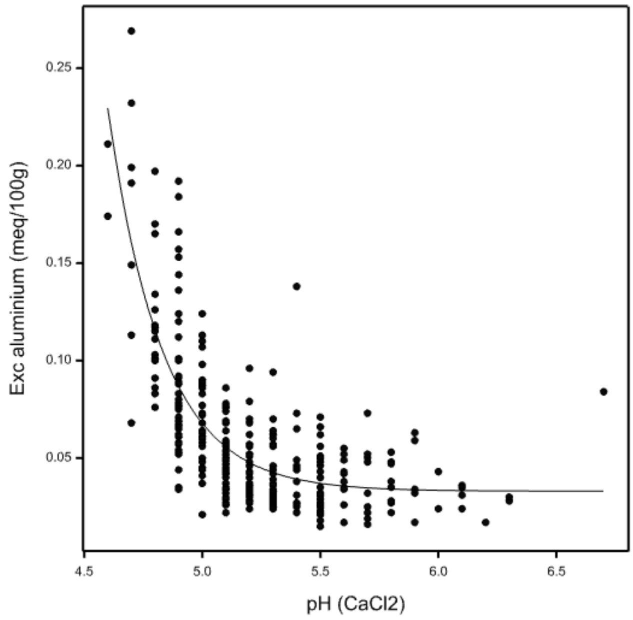

Figure 17 Exchangeable aluminium compared to pH($CaCl_2$) at 0-10 cm across systems, phases and years. Y = 0.03299 + 85680440(0.01323X); Adj R2 = 0.579

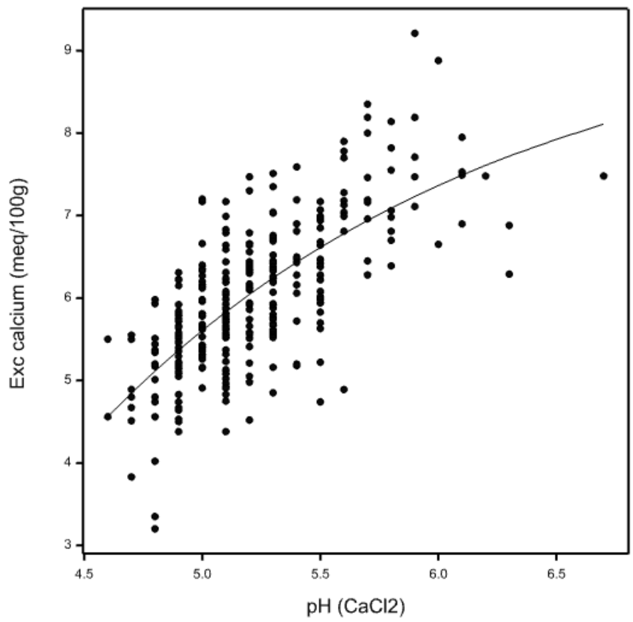

Figure 18 Exchangeable calcium compared to pH($CaCl_2$) at 0-10 cm across systems, phases and years. Y = 9.59 – 73.3(0.558X); Adj R2 = 0.494

Conclusion

The aim of this project was to assess the chemical fertility of the soil and to investigate differences between systems. The chemical properties of soil showed substantial differences and changes between systems and phases by 2012.

Soil P increased with soil fertility as a result of P fertiliser application with cropping. Soil organic carbon is an indicator of soil fertility and it increased across all systems during the experiment, further indicating that soil fertility was being built across all systems, although there was a decline in the cropping systems between 2008 and 2012. There was no clear indication to which system is the most beneficial for building organic carbon. While PP consistently built carbon, there were differences in the response of the other systems. In PP the increase in organic carbon occurred at a higher rate than the decrease in available P, which is largely inorganic (1333 kg/ha increase in SOC, for every kg/ha decrease in available inorganic P). There is a C:OP ratio of 187:1 for Australian soils (Kirkby *et al.* 2011). This indicates that either P was supplied from other sources (e.g. mineralisation of organic matter) or that SOC and available P were relatively independent. While RT had the highest SOC in 2008, there was a change in the implementation of phases, the timing of sampling and wetter than average seasonal conditions (possibly causing higher mineralisation) between 2008 and 2012, which all may have contributed to the decrease in organic carbon in the cropping treatments. There was no data on crop and pasture productivity available to determine whether changes to these fertility indicators has resulted in increased productivity and profitability.

There were also signs of soil degradation over time in the systems. This was shown by a decrease in pH in the higher cropping frequency treatments by 2012, which caused exchangeable Al^{3+} to increase and other exchangeable cations (largely Ca^{2+}) to decrease. The decrease in pH was related to cropping frequency and did not appear to be related to differences in tillage. This was demonstrated by similar pH (and related soil properties) found in the RT and CT treatments, which had a similar cropping frequency but differences in tillage and other management activities. There may be other physical constraints that have resulted from the differences in management that have not been assessed in this analysis. Particularly, the impact of higher levels of tillage on soil aggregates which might negatively impact on soil properties like water holding capacity and the mineralisation of nutrients.

There were significant differences in several soil properties between phases, but this mainly occurred in the RT and CT treatments that had combinations of crop and pasture. The differences largely reflected the differences in nutrient cycling between crop and pasture land uses (e.g. NO_3 and S) and fertiliser addition in the cropping phases (e.g. P), but increases in EC as a result of preparation for cropping indicate mobilisation of salts when converting from crops to pasture (levels were not expected to influences yields). In the CC, which was cropped in each phase, there were only differences in the labile nutrients (e.g. NO_3 and S).

Overall, the increase in fertility associated with intensive cropping is also accompanied by degradation in the form of reduced pH and the subsequent influence on exchangeable cations. Further work is need to determine the outcomes of the systems on soil physical attributes and how these changes influence the processes that influence nutrient availability and the productivity of the farming systems. This will give a more balanced indication of how these systems have influenced soil properties and enable clear comments to be made about the sustainability of the systems.

References

Kirkby CA, Kirkegaard JA, Richardson AE, Wade LJ, Blanchard C, Batten G (2011) Stable soil organic matter: a comparison of C:N:P:S ratios in Australian and other world soils. *Geoderma* **163**(3), 197-208. [In English]

Rayment GE, Lyons DJ (2011) 'Soil Chemical Methods - Australasia.' (CSIRO Publishing: Collingwood)

Appendices

Appendix 1: Description of the paddock management for the four farming systems

Traditional farming system (CT)

This system is a mixed farming system that uses conventional tillage with a livestock component. The crops in rotation on the system included long fallow wheat (LFW), short fallow wheat undersown with a pasture combination (SFWu/s) and a grazed pasture. After the final phase of the rotation (coming out of three years of pasture) the paddocks receive a fallow spray in August. Up to two sprays could be applied before cultivation, though this depended on seasonal conditions. The first cultivation would occur any time from October onwards, following a suitable rainfall event. Cultivation was usually carried out with a chisel plough with narrow points. Weed control was through subsequent cultivations using a chisel plough with sweeps. Up to four cultivations would be carried out though in exceptionally wet years an additional fifth cultivation was possible.

When the system came out of its cropping phase, and after the crop was harvested, weed control was performed by spraying and cultivation.

Reduced tillage with livestock (RT)

As with the traditional farming system, when coming out of the pasture phase the paddocks received a fallow spray in August, and possibly up to two sprays before Christmas. The first (of three) cultivations occurred just prior to Christmas and once suitable rainfall had been received. However if weather forecasts predicted a dry to average summer, the first cultivation would occur as early as possible (from October onwards), depending on rainfall. The initial cultivation was conducted with a chisel plough using narrow points and covering harrows. Depending on the regrowth of Lucerne and the amount of rainfall, up to a further three cultivations were carried out with a chisel plough and sweeps. Chemical weed control was used up until the time of sowing, though dependant on weather conditions.

When the system is in its cropping phase all weed control was performed by spray application. This included the skip year of the phase.

Zero-till with no livestock (CC)

The CC represented a continuous cropping rotation that was dependent on herbicide application for weed control. All weed control was conducted by spray application.

Fertiliser application

Fertiliser, in the form of MAP (Mono-Ammonium Phosphate), was applied at approximately 40-50 kg/ha to all plots when in the cropping phase of the farming system. Fertiliser was not applied to plots in the PP farming system.

Sowing Methods

All sowing since 2005 has been carried out by specialist no till tine planter. From 2005-2008 with shearer combine with Janke high breakout tines, knife points and press wheels. Since 2009 all sowing was carried out by DBS airseeder (7 inch deep tillage knife point, parallellogram closer plate for seed depth and press wheel). All pasture has been undersown with last crop.

Variations between 2010 and 2013

In 2009 a decision was made to change the crop rotations at the experimental site. It was decided that from 2009, no fallows would be prepared for paddocks that were scheduled to go into a wheat phase, and instead pasture was continued in the paddocks. This decision was maintained until 2012 when it was decided to reinstate the rotational phases for the reduced tillage with livestock (RT) farming system and the traditional (CT) farming system. Those 3 paddocks that went back into a wheat crop were immediately sprayed and slashed after 4 days. Cultivations were conducted using a chisel plough with sweeps and sowed using a DBS seeder.

Appendix 2: Listing of the soil properties analysed by CSBP Soil and Plant Analysis Laboratory

Table A2 Soil chemical properties analyses for the Condobolin comparison trial

Element	**Units**
Colour	
Gravel content	%
Texture	
Ammonium nitrogen	mg/Kg
Nitrate nitrogen	mg/Kg
Phosphorus colwell	mg/Kg
Potassium colwell	mg/Kg
Sulphur	mg/Kg
Organic carbon	%
Conductivity	dS/m
pH level ($CaCl_2$)	pH
pH level (H_2O)	pH
DTPA Copper	mg/Kg
DTPA Iron	mg/Kg
DTPA Manganese	mg/Kg
DTPA Zinc	mg/Kg
Exc. Aluminium	meq/100g
Exc. Calcium	meq/100g
Exc. Magnesium	meq/100g
Exc. Potassium	meq/100g
Exc. Sodium	meq/100g
Boron Hot $CaCl_2$	mg/Kg

Appendix 3: Interactions between farming systems

Table A3.1 Summary of the interactions between the farming systems in 1999 (0-10cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	10.55	9.40	7.50	9.20	<0.001	0.98
Nitrate Nitrogen[#]	mg/Kg	13.60	7.38	1.56	9.93	0.001	5.64
Phosphorus Colwell	mg/Kg	12.60	12.60	10.25	12.00	0.149	2.20
Potassium Colwell	mg/Kg	802.20	779.60	764.50	815.30	0.353	59.81
Sulphur	mg/Kg	7.99	7.57	5.84	7.84	<0.001	0.88
Organic Carbon	%	1.27	1.30	1.28	1.29	0.967	0.12
Conductivity	dS/m	0.08	0.07	0.05	0.08	<0.001	0.01
pH Level (CaCl2)	pH	5.30	5.26	5.35	5.33	0.874	0.23
pH Level (H2O)	pH	6.24	6.23	6.34	6.31	0.72	0.23
DTPA Copper	mg/Kg	1.31	1.48	1.47	1.34	0.041	0.15
DTPA Iron	mg/Kg	22.98	23.54	23.30	24.76	0.892	4.96
DTPA Manganese	mg/Kg	79.14	98.11	81.81	99.16	0.021	16.20
DTPA Zinc	mg/Kg	0.89	1.09	0.94	0.97	0.282	0.21
Exc. Aluminium	meq/100g	0.06	0.05	0.06	0.06	0.885	0.02
Exc. Calcium	meq/100g	6.45	6.15	6.23	6.43	0.741	0.63
Exc. Magnesium	meq/100g	1.82	1.79	2.01	1.87	0.166	0.20
Exc. Potassium	meq/100g	1.94	1.92	1.83	1.95	0.512	0.16
Exc. Sodium	meq/100g	0.09	0.08	0.11	0.08	0.15	0.03

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.2 Summary of the interactions between the farming systems in 1999 (10-30cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	5.40	5.00	3.75	4.85	0.003	0.85
Nitrate Nitrogen[#]	mg/Kg	8.65	5.03	1.47	5.53	<0.001	2.83
Phosphorus Colwell	mg/Kg	6.05	5.75	5.38	5.45	0.705	1.27
Potassium Colwell	mg/Kg	535.35	524.80	542.06	507.30	0.667	58.73
Sulphur	mg/Kg	6.37	6.31	5.06	6.77	0.005	0.92
Organic Carbon	%	0.71	0.68	0.71	0.71	0.884	0.09
Conductivity	dS/m	0.07	0.05	0.04	0.07	0.011	0.02
pH Level (CaCl2)	pH	5.47	5.15	5.28	5.42	0.378	0.41
pH Level (H2O)	pH	6.36	6.14	6.25	6.29	0.542	0.31
DTPA Copper	mg/Kg	1.32	1.51	1.47	1.39	0.094	0.16
DTPA Iron	mg/Kg	17.57	16.25	18.55	17.37	0.67	3.61
DTPA Manganese	mg/Kg	32.01	35.52	35.66	33.89	0.743	7.53
DTPA Zinc	mg/Kg	0.32	0.24	0.60	0.34	0.4	0.41
Exc. Aluminium	meq/100g	0.10	0.14	0.11	0.13	0.296	0.05
Exc. Calcium	meq/100g	6.35	5.71	6.00	6.35	0.449	0.95
Exc. Magnesium	meq/100g	1.96	2.05	2.43	2.07	0.109	0.39
Exc. Potassium	meq/100g	1.35	1.28	1.36	1.27	0.375	0.13
Exc. Sodium	meq/100g	0.18	0.17	0.25	0.15	0.17	0.08

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.3 Summary of the interactions between the farming systems in 1999 (30-50cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen#	mg/Kg	3.45	3.40	2.56	3.15	0.002	0.47
Nitrate Nitrogen#	mg/Kg	5.50	3.05	1.75	3.13	<0.001	1.61
Phosphorus Colwell	mg/Kg	3.20	3.30	3.06	3.05	0.511	0.38
Potassium Colwell	mg/Kg	567.40	557.00	573.81	553.80	0.979	101.10
Sulphur	mg/Kg	4.22	4.52	3.54	4.64	0.015	0.68
Organic Carbon	%	0.37	0.38	0.36	0.39	0.592	0.04
Conductivity	dS/m	0.07	0.07	0.08	0.08	0.723	0.03
pH Level (CaCl2)	pH	6.39	6.35	6.46	6.36	0.946	0.41
pH Level (H2O)	pH	7.37	7.32	7.46	7.29	0.839	0.38
DTPA Copper	mg/Kg	1.44	1.56	1.54	1.46	0.381	0.17
DTPA Iron	mg/Kg	11.64	10.73	12.51	12.25	0.507	2.52
DTPA Manganese	mg/Kg	16.46	18.65	19.25	18.31	0.478	3.72
DTPA Zinc	mg/Kg	0.21	0.18	0.21	0.18	0.719	0.07
Exc. Aluminium	meq/100g	0.11	0.13	0.12	0.12	0.282	0.02
Exc. Calcium	meq/100g	8.07	8.20	8.54	8.33	0.918	1.34
Exc. Magnesium	meq/100g	5.44	5.09	5.90	5.03	0.492	1.21
Exc. Potassium	meq/100g	1.39	1.38	1.46	1.36	0.869	0.24
Exc. Sodium	meq/100g	1.00	0.82	0.98	0.70	0.332	0.37

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.4 Summary of the interactions between the farming systems in 1999 (50-70cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen#	mg/Kg	2.25	2.35	1.91	2.08	0.315	0.49
Nitrate Nitrogen#	mg/Kg	6.15	4.60	4.63	4.10	0.185	2.00
Phosphorus Colwell	mg/Kg	1.85	2.40	1.75	1.65	0.019	0.51
Potassium Colwell	mg/Kg	675.50	661.15	695.75	713.55	0.716	98.49
Sulphur	mg/Kg	4.76	3.83	3.26	3.85	0.004	0.78
Organic Carbon	%	0.18	0.20	0.19	0.17	0.255	0.04
Conductivity	dS/m	0.13	0.11	0.11	0.11	0.736	0.03
pH Level (CaCl2)	pH	7.31	7.21	7.27	7.28	0.943	0.36
pH Level (H2O)	pH	8.32	8.16	8.30	8.25	0.834	0.38
DTPA Copper	mg/Kg	1.34	1.38	1.41	1.29	0.339	0.14
DTPA Iron	mg/Kg	6.72	6.55	8.13	7.89	0.372	2.18
DTPA Manganese	mg/Kg	7.86	8.58	9.52	9.05	0.353	1.88
DTPA Zinc	mg/Kg	0.23	0.19	0.18	0.22	0.72	0.10
Exc. Aluminium	meq/100g	0.14	0.13	0.13	0.12	0.589	0.02
Exc. Calcium	meq/100g	9.36	9.73	10.23	9.82	0.446	1.03
Exc. Magnesium	meq/100g	7.61	6.77	7.72	7.40	0.237	1.01
Exc. Potassium	meq/100g	1.64	1.60	1.71	1.70	0.769	0.22
Exc. Sodium	meq/100g	1.73	1.28	1.42	1.27	0.23	0.51

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.5 Summary of the interactions between the farming systems in 2004 (0-10cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System				F pr	lsd
		CC	CT	PP	RT		
Ammonium Nitrogen#	mg/Kg	7.55	6.95	9.06	5.95	0.045	2.12
Nitrate Nitrogen#	mg/Kg	38.65	19.20	18.19	23.25	<0.001	7.59
Phosphorus Colwell	mg/Kg	18.55	11.50	8.56	11.15	<0.001	3.16
Potassium Colwell	mg/Kg	788.65	787.25	718.44	805.10	0.403	103.60
Sulphur	mg/Kg	12.06	10.60	8.54	10.40	<0.001	1.51
Organic Carbon	%	1.36	1.51	1.48	1.55	0.262	0.20
Conductivity	dS/m	0.12	0.08	0.09	0.09	<0.001	0.02
pH Level (CaCl2)	pH	5.21	5.17	5.49	5.03	0.003	0.23
pH Level (H2O)	pH	6.02	6.08	6.32	5.96	0.009	0.21
DTPA Copper	mg/Kg	1.50	1.49	1.33	1.37	0.003	0.11
DTPA Iron	mg/Kg	21.45	21.77	17.42	21.13	0.044	3.22
DTPA Manganese	mg/Kg	84.90	87.25	58.77	80.81	<0.001	12.58
DTPA Zinc	mg/Kg	1.98	3.89	3.52	3.34	0.056	1.48
Exc. Aluminium	meq/100g	0.06	0.05	0.05	0.07	0.429	0.02
Exc. Calcium	meq/100g	5.93	5.69	6.29	5.67	0.146	0.57
Exc. Magnesium	meq/100g	1.80	1.71	1.97	1.79	0.325	0.27
Exc. Potassium	meq/100g	1.75	1.71	1.63	1.74	0.385	0.14
Exc. Sodium	meq/100g	0.12	0.08	0.14	0.09	0.03	0.05

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.6 Summary of the interactions between the farming systems in 2004 (10-30cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System				F pr	lsd
		CC	CT	PP	RT		
Ammonium Nitrogen#	mg/Kg	3.30	3.35	4.06	3.08	0.331	1.07
Nitrate Nitrogen#	mg/Kg	10.75	12.30	11.81	14.00	0.668	5.43
Phosphorus Colwell	mg/Kg	5.95	4.80	4.63	4.70	0.392	1.78
Potassium Colwell	mg/Kg	498.50	506.50	542.56	515.15	0.708	75.83
Sulphur	mg/Kg	6.89	6.31	6.42	6.99	0.619	1.25
Organic Carbon	%	0.74	0.72	0.98	0.85	0.004	0.15
Conductivity	dS/m	0.06	0.06	0.07	0.07	0.71	0.02
pH Level (CaCl2)	pH	5.26	5.34	5.46	5.22	0.643	0.39
pH Level (H2O)	pH	6.19	6.21	6.30	6.10	0.607	0.29
DTPA Copper	mg/Kg	1.43	1.48	1.34	1.37	0.109	0.12
DTPA Iron	mg/Kg	17.00	16.21	15.76	16.43	0.89	3.12
DTPA Manganese	mg/Kg	24.40	29.46	30.61	29.66	0.56	9.59
DTPA Zinc	mg/Kg	0.60	0.87	2.10	0.99	<0.001	0.51
Exc. Aluminium	meq/100g	0.11	0.10	0.09	0.13	0.507	0.04
Exc. Calcium	meq/100g	5.36	5.63	6.24	5.84	0.456	1.09
Exc. Magnesium	meq/100g	1.97	2.12	2.17	2.18	0.679	0.39
Exc. Potassium	meq/100g	1.25	1.25	1.28	1.27	0.964	0.14
Exc. Sodium	meq/100g	0.19	0.22	0.21	0.18	0.849	0.09

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.7 Summary of the interactions between the farming systems in 2004 (30-50cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen#	mg/Kg	2.18	2.08	1.97	2.18	0.918	0.65
Nitrate Nitrogen#	mg/Kg	6.55	10.00	5.00	8.05	0.008	2.86
Phosphorus Colwell	mg/Kg	2.00	2.20	2.19	2.20	0.821	0.51
Potassium Colwell	mg/Kg	613.90	584.25	627.69	583.50	0.847	117.60
Sulphur	mg/Kg	4.07	4.65	3.76	4.53	0.058	0.70
Organic Carbon	%	0.38	0.40	0.52	0.45	<0.001	0.06
Conductivity	dS/m	0.09	0.09	0.07	0.08	0.53	0.03
pH Level (CaCl2)	pH	6.52	6.40	6.41	6.26	0.394	0.31
pH Level (H2O)	pH	7.42	7.23	7.28	7.18	0.317	0.27
DTPA Copper	mg/Kg	1.61	1.46	1.45	1.42	0.098	0.17
DTPA Iron	mg/Kg	11.36	10.07	10.43	11.63	0.337	2.00
DTPA Manganese	mg/Kg	15.11	18.30	17.60	18.21	0.188	3.39
DTPA Zinc	mg/Kg	0.35	0.50	0.87	0.46	<0.001	0.17
Exc. Aluminium	meq/100g	0.11	0.12	0.12	0.11	0.804	0.03
Exc. Calcium	meq/100g	7.87	7.89	8.45	7.59	0.554	1.16
Exc. Magnesium	meq/100g	5.51	5.12	5.44	5.29	0.899	1.11
Exc. Potassium	meq/100g	1.39	1.35	1.42	1.38	0.949	0.21
Exc. Sodium	meq/100g	1.02	0.89	0.84	0.86	0.749	0.36

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.8 Summary of the interactions between the farming systems in 2004 (50-70cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen#	mg/Kg	1.38	1.90	1.28	1.25	0.046	0.52
Nitrate Nitrogen#	mg/Kg	5.35	5.85	5.13	5.45	0.864	1.70
Phosphorus Colwell	mg/Kg	1.25	1.40	1.56	1.15	0.432	0.51
Potassium Colwell	mg/Kg	753.15	726.85	717.44	742.35	0.944	123.90
Sulphur	mg/Kg	4.72	4.15	4.90	4.50	0.441	0.95
Organic Carbon	%	0.19	0.23	0.39	0.29	<0.001	0.06
Conductivity	dS/m	0.13	0.11	0.13	0.11	0.34	0.04
pH Level (CaCl2)	pH	7.47	7.29	7.39	7.22	0.33	0.30
pH Level (H2O)	pH	8.30	8.19	8.25	8.18	0.846	0.32
DTPA Copper	mg/Kg	1.37	1.31	1.41	1.33	0.176	0.09
DTPA Iron	mg/Kg	5.71	6.33	5.86	5.81	0.797	1.36
DTPA Manganese	mg/Kg	7.17	8.99	9.88	10.69	<0.001	1.75
DTPA Zinc	mg/Kg	0.31	0.46	1.46	0.57	<0.001	0.36
Exc. Aluminium	meq/100g	0.11	0.13	0.13	0.12	0.527	0.03
Exc. Calcium	meq/100g	9.06	8.89	10.16	9.03	0.036	0.91
Exc. Magnesium	meq/100g	7.46	6.77	7.53	7.12	0.401	0.98
Exc. Potassium	meq/100g	1.63	1.55	1.63	1.67	0.626	0.19
Exc. Sodium	meq/100g	1.67	1.35	1.43	1.35	0.567	0.55

mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.

Table A3.8 Summary of the interactions between the farming systems in 2008 (0-10cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	5.60	6.50	7.38	7.30	0.047	1.41
Nitrate Nitrogen[#]	mg/Kg	26.45	20.78	14.41	19.10	0.157	10.28
Phosphorus Colwell	mg/Kg	26.10	17.80	7.50	16.95	<0.001	3.46
Potassium Colwell	mg/Kg	792.95	816.85	802.31	818.50	0.825	64.27
Sulphur	mg/Kg	11.04	9.52	8.00	10.70	0.006	1.77
Organic Carbon	%	1.73	1.65	1.55	2.03	0.009	0.29
Conductivity	dS/m	0.09	0.08	0.07	0.07	0.289	0.02
pH Level (CaCl2)	pH	5.19	5.22	5.38	5.17	0.116	0.18
pH Level (H2O)	pH	6.09	6.12	6.29	6.08	0.041	0.16
DTPA Copper	mg/Kg	1.31	1.35	1.30	1.35	0.882	0.15
DTPA Iron	mg/Kg	22.25	23.02	23.94	25.01	0.138	2.45
DTPA Manganese	mg/Kg	80.80	86.35	62.02	90.47	<0.001	11.95
DTPA Zinc	mg/Kg	5.61	6.76	3.27	10.50	0.015	4.33
Exc. Aluminium	meq/100g	0.05	0.04	0.04	0.04	0.541	0.01
Exc. Calcium	meq/100g	6.08	6.03	6.19	5.94	0.873	0.59
Exc. Magnesium	meq/100g	1.77	1.67	1.86	1.67	0.463	0.27
Exc. Potassium	meq/100g	1.86	1.91	1.79	1.87	0.456	0.14
Exc. Sodium	meq/100g	0.11	0.08	0.14	0.08	0.016	0.04

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.8 Summary of the interactions between the farming systems in 2008 (10-30cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	2.85	3.25	3.38	3.00	0.395	0.66
Nitrate Nitrogen[#]	mg/Kg	6.33	8.28	6.22	8.03	0.668	4.25
Phosphorus Colwell	mg/Kg	6.80	4.75	3.31	4.85	0.032	2.25
Potassium Colwell	mg/Kg	519.40	530.35	522.38	525.20	0.967	45.64
Sulphur	mg/Kg	7.31	7.02	4.39	8.29	<0.001	1.26
Organic Carbon	%	0.90	0.86	0.82	0.93	0.366	0.12
Conductivity	dS/m	0.06	0.05	0.05	0.05	0.858	0.02
pH Level (CaCl2)	pH	5.55	5.48	5.46	5.29	0.624	0.42
pH Level (H2O)	pH	6.43	6.38	6.38	6.18	0.447	0.33
DTPA Copper	mg/Kg	1.19	1.23	1.30	1.28	0.298	0.13
DTPA Iron	mg/Kg	16.06	16.20	19.68	18.53	0.015	2.55
DTPA Manganese	mg/Kg	20.78	30.21	26.38	27.58	0.049	6.96
DTPA Zinc	mg/Kg	1.27	2.21	1.18	1.72	0.456	1.43
Exc. Aluminium	meq/100g	0.08	0.09	0.09	0.09	0.899	0.04
Exc. Calcium	meq/100g	6.09	6.10	5.86	5.88	0.939	0.98
Exc. Magnesium	meq/100g	1.91	2.00	2.16	1.90	0.45	0.34
Exc. Potassium	meq/100g	1.32	1.33	1.29	1.30	0.909	0.11
Exc. Sodium	meq/100g	0.16	0.17	0.27	0.15	0.018	0.08

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.9 Summary of the interactions between the farming systems in 2008 (30-50cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	2.10	3.20	2.56	2.35	0.02	0.73
Nitrate Nitrogen[#]	mg/Kg	5.63	9.23	6.06	10.43	0.069	4.27
Phosphorus Colwell	mg/Kg	2.05	2.05	1.56	2.10	0.348	0.64
Potassium Colwell	mg/Kg	567.05	570.30	599.38	576.45	0.912	93.29
Sulphur	mg/Kg	5.44	4.79	3.34	4.79	<0.001	0.66
Organic Carbon	%	0.45	0.45	0.46	0.51	0.25	0.07
Conductivity	dS/m	0.08	0.07	0.07	0.07	0.87	0.02
pH Level (CaCl2)	pH	6.65	6.48	6.60	6.21	0.021	0.30
pH Level (H2O)	pH	7.54	7.39	7.51	7.17	0.038	0.28
DTPA Copper	mg/Kg	1.30	1.27	1.45	1.33	0.159	0.16
DTPA Iron	mg/Kg	10.54	10.81	13.50	12.60	0.014	2.03
DTPA Manganese	mg/Kg	13.37	15.92	17.83	16.84	0.109	3.72
DTPA Zinc	mg/Kg	0.76	0.81	0.66	0.92	0.538	0.35
Exc. Aluminium	meq/100g	0.09	0.11	0.12	0.09	0.14	0.03
Exc. Calcium	meq/100g	8.31	8.16	8.71	7.89	0.607	1.19
Exc. Magnesium	meq/100g	5.39	4.95	5.49	4.90	0.668	1.17
Exc. Potassium	meq/100g	1.42	1.43	1.47	1.39	0.913	0.22
Exc. Sodium	meq/100g	0.98	0.84	1.05	0.79	0.52	0.38

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.10 Summary of the interactions between the farming systems in 2008 (50-70cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen[#]	mg/Kg	1.58	2.55	1.94	2.23	0.011	0.60
Nitrate Nitrogen[#]	mg/Kg	7.95	8.45	4.31	9.88	0.006	2.99
Phosphorus Colwell	mg/Kg	1.20	1.20	1.06	1.05	6.27	0.31
Potassium Colwell	mg/Kg	662.80	674.50	714.38	710.70	0.667	100.40
Sulphur	mg/Kg	5.82	4.43	4.08	4.55	<0.001	0.87
Organic Carbon	%	0.26	0.25	0.22	0.25	0.573	0.05
Conductivity	dS/m	0.13	0.12	0.12	0.11	0.511	0.03
pH Level (CaCl2)	pH	7.47	7.51	7.59	7.27	0.131	0.27
pH Level (H2O)	pH	8.40	8.43	8.49	8.22	0.303	0.30
DTPA Copper	mg/Kg	1.17	1.14	1.32	1.21	0.118	0.15
DTPA Iron	mg/Kg	6.24	6.63	7.62	7.61	0.054	1.21
DTPA Manganese	mg/Kg	7.20	7.14	6.87	8.44	0.218	1.62
DTPA Zinc	mg/Kg	0.90	0.72	0.54	0.73	0.379	0.39
Exc. Aluminium	meq/100g	0.10	0.11	0.12	0.10	0.558	0.03
Exc. Calcium	meq/100g	9.39	10.17	10.18	9.44	0.212	1.00
Exc. Magnesium	meq/100g	7.26	6.73	7.22	7.09	0.74	1.06
Exc. Potassium	meq/100g	1.63	1.67	1.64	1.66	0.972	0.20
Exc. Sodium	meq/100g	1.62	1.25	1.55	1.34	0.476	0.53

[#] *mineral N analysis is unreliable due to time the archived samples were stored, the 2012 is the only reliable analysis.*

Table A3.11 Summary of the interactions between the farming systems in 2010 (0-10cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

		Farming System					
Analysis	Units	CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen	mg/Kg	6.10	7.25	5.81	6.85	0.213	1.49
Nitrate Nitrogen	mg/Kg	4.90	4.05	1.12	3.75	0.006	2.05
Phosphorus Colwell	mg/Kg	36.50	16.05	6.63	16.35	<0.001	3.44
Potassium Colwell	mg/Kg	723.15	822.70	781.75	771.30	0.112	82.57
Sulphur	mg/Kg	6.17	5.55	4.01	5.74	<0.001	0.87
Organic Carbon	%	1.50	1.60	1.79	1.57	0.135	0.24
Conductivity	dS/m	0.04	0.05	0.04	0.04	0.344	0.01
pH Level (CaCl2)	pH	4.96	5.19	5.40	5.08	<0.001	0.16
pH Level (H2O)	pH	5.94	6.18	6.38	6.07	<0.001	0.15
DTPA Copper	mg/Kg	1.81	1.63	1.79	1.95	0.371	0.37
DTPA Iron	mg/Kg	40.29	41.71	48.52	47.66	0.183	9.05
DTPA Manganese	mg/Kg	42.55	44.10	42.32	52.88	0.017	7.55
DTPA Zinc	mg/Kg	1.92	1.48	2.26	1.56	0.032	0.55
Exc. Aluminium	meq/100g	0.12	0.06	0.04	0.09	<0.001	0.03
Exc. Calcium	meq/100g	5.62	5.78	6.23	5.86	0.123	0.49
Exc. Magnesium	meq/100g	1.60	1.70	1.97	1.74	0.005	0.20
Exc. Potassium	meq/100g	1.63	1.85	1.86	1.88	0.002	0.14
Exc. Sodium	meq/100g	0.08	0.07	0.09	0.07	0.069	0.02

Table A3.12 Summary of the interactions between the farming systems in 2010 (10-30cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

		Farming System					
Analysis	Units	CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen	mg/Kg	3.95	4.35	4.56	3.75	0.73	1.56
Nitrate Nitrogen	mg/Kg	3.33	2.85	0.91	2.80	0.049	1.73
Phosphorus Colwell	mg/Kg	7.30	6.10	4.13	5.10	0.003	1.65
Potassium Colwell	mg/Kg	527.20	545.90	553.31	526.15	0.629	49.43
Sulphur	mg/Kg	5.74	5.01	3.22	5.17	<0.001	0.88
Organic Carbon	%	0.83	0.89	0.97	0.81	0.139	0.14
Conductivity	dS/m	0.05	0.05	0.04	0.03	0.189	0.01
pH Level (CaCl2)	pH	5.56	5.50	5.52	5.31	0.489	0.35
pH Level (H2O)	pH	6.47	6.43	6.46	6.28	0.48	0.28
DTPA Copper	mg/Kg	1.57	1.55	1.58	1.76	0.361	0.28
DTPA Iron	mg/Kg	25.11	25.87	30.24	30.62	0.038	4.75
DTPA Manganese	mg/Kg	13.57	18.76	16.91	17.77	0.028	3.65
DTPA Zinc	mg/Kg	1.05	0.71	0.95	0.74	0.119	0.34
Exc. Aluminium	meq/100g	0.10	0.11	0.09	0.14	0.132	0.04
Exc. Calcium	meq/100g	6.02	5.96	5.88	5.86	0.977	0.80
Exc. Magnesium	meq/100g	2.20	2.25	2.47	2.33	0.701	0.46
Exc. Potassium	meq/100g	1.29	1.32	1.35	1.32	0.824	0.11
Exc. Sodium	meq/100g	0.21	0.24	0.32	0.19	0.138	0.11

Table A3.13 Summary of the interactions between the farming systems in 2010 (30-50cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen	mg/Kg	3.63	3.25	2.88	3.55	0.551	1.10
Nitrate Nitrogen	mg/Kg	4.90	2.35	1.16	2.80	0.006	2.05
Phosphorus Colwell	mg/Kg	3.25	2.90	2.00	2.65	<0.001	0.48
Potassium Colwell	mg/Kg	603.65	581.15	634.38	589.60	0.717	94.06
Sulphur	mg/Kg	4.51	4.13	3.14	4.46	0.004	0.78
Organic Carbon	%	0.47	0.45	0.47	0.42	0.394	0.07
Conductivity	dS/m	0.08	0.08	0.07	0.07	0.719	0.02
pH Level (CaCl2)	pH	6.57	6.62	6.59	6.55	0.966	0.30
pH Level (H2O)	pH	7.49	7.56	7.56	7.48	0.902	0.28
DTPA Copper	mg/Kg	1.50	1.47	1.47	1.63	0.157	0.16
DTPA Iron	mg/Kg	18.13	15.25	16.50	18.69	0.09	3.02
DTPA Manganese	mg/Kg	9.54	9.85	11.04	10.92	0.27	1.83
DTPA Zinc	mg/Kg	0.36	0.27	0.38	0.39	0.252	0.14
Exc. Aluminium	meq/100g	0.14	0.14	0.15	0.16	0.863	0.05
Exc. Calcium	meq/100g	8.26	8.33	8.37	8.51	0.979	1.24
Exc. Magnesium	meq/100g	5.65	5.22	6.09	5.53	0.492	1.09
Exc. Potassium	meq/100g	1.50	1.39	1.57	1.48	0.498	0.23
Exc. Sodium	meq/100g	1.00	0.97	1.20	0.88	0.449	0.39

Table A3.14 Summary of the interactions between the farming systems in 2010 (50-70cm soil profile), showing the average result for each farming system (CC, CT, PP and RT), significant difference, and least significant difference (lsd 5%)

Analysis	Units	Farming System CC	CT	PP	RT	F pr	lsd
Ammonium Nitrogen	mg/Kg	2.58	2.78	2.81	2.75	0.96	0.95
Nitrate Nitrogen	mg/Kg	6.30	3.43	1.72	4.03	0.002	2.26
Phosphorus Colwell	mg/Kg	1.15	1.45	1.13	1.15	0.176	0.34
Potassium Colwell	mg/Kg	692.90	660.20	672.19	701.00	0.761	86.30
Sulphur	mg/Kg	4.43	4.11	4.67	4.45	0.639	0.86
Organic Carbon	%	0.23	0.24	0.24	0.20	0.558	0.06
Conductivity	dS/m	0.11	0.12	0.14	0.12	0.554	0.03
pH Level (CaCl2)	pH	7.43	7.44	7.52	7.56	0.788	0.31
pH Level (H2O)	pH	8.40	8.40	8.49	8.54	0.768	0.31
DTPA Copper	mg/Kg	1.36	1.61	1.38	1.25	0.763	0.14
DTPA Iron	mg/Kg	10.49	9.96	11.58	11.09	0.687	2.77
DTPA Manganese	mg/Kg	5.66	5.72	5.83	5.56	0.964	0.99
DTPA Zinc	mg/Kg	0.28	0.28	0.33	0.34	0.521	0.10
Exc. Aluminium	meq/100g	0.13	0.14	0.14	0.14	0.923	0.04
Exc. Calcium	meq/100g	9.00	9.31	9.46	10.21	0.074	0.96
Exc. Magnesium	meq/100g	7.34	6.99	7.51	7.43	0.964	0.88
Exc. Potassium	meq/100g	1.64	1.58	1.63	1.71	0.62	0.20
Exc. Sodium	meq/100g	1.58	1.55	1.75	1.48	0.768	0.51

Appendix 4 Interactions between phases

Table A4 Significant differences found between phases (crop rotation) each measurement period for the three different rotational cropping farming systems (0-10cm soil profile)

Analysis	Units	1999	2004	2008	2012
Continuous Cropping Farming System					
Sulphur	mg/Kg	0.002	nsd	nsd	nsd
DTPA Copper	mg/Kg	nsd	0.048	nsd	nsd
DTPA Manganese	mg/Kg	nsd	nsd	nsd	0.028
Exc. Magnesium	meq/100g	0.039	nsd	nsd	nsd
Exc. Sodium	meq/100g	0.014	nsd	nsd	nsd
Conventional Tillage Farming System					
Ammonium Nitrogen	mg/Kg	0.016	nsd	nsd	nsd
Nitrate Nitrogen	mg/Kg	<0.001	0.004	0.034	0.004
Phosphorus Colwell	mg/Kg	nsd	nsd	<0.001	nsd
Sulphur	mg/Kg	0.002	nsd	nsd	<0.001
Conductivity	dS/m	<0.001	0.006	nsd	nsd
Reduced Tillage Farming System					
Nitrate Nitrogen	mg/Kg	<0.001	nsd	<0.001	nsd
Phosphorus Colwell	mg/Kg	nsd	nsd	nsd	0.004
Sulphur	mg/Kg	0.001	nsd	0.046	0.008
Conductivity	dS/m	0.008	nsd	0.004	0.016
pH Level (CaCl2)	pH	nsd	nsd	nsd	0.009
pH Level (H2O)	pH	nsd	nsd	nsd	0.017
Exc. Aluminium	meq/100g	nsd	nsd	nsd	0.001
Exc. Calcium	meq/100g	nsd	nsd	nsd	0.048
Exc. Magnesium	meq/100g	nsd	nsd	nsd	0.035
Exc. Potassium	meq/100g	nsd	nsd	nsd	0.015

only elements where significant differences were found are presented