Chapter 3. Influence of corn residue incorporation in organic and conventional soil management systems on the yields and nutrient uptakes by sweet corn and cabbage, and on weed biomass and soil nutrients

Abstract

Inappropriate management of synthetic inputs in conventional soil management systems (SMS) leads to environmental degradation. Organic SMS is an alternative that is claimed to prevent or mitigate such negative environmental impacts. Vegetable production systems rely on frequent tillage to prepare beds and manage weeds, and are also characterised by little crop residue input. The use of crop residues and organic fertilisers may counteract the negative impacts of intensive vegetable production. To test this hypothesis, we evaluated the effect of sweet corn (*Zea mays* L. var. *rugosa*) residue incorporation in a corn-cabbage (*Brassica oleracea* L.) rotation on crop yields, nutrients uptake, weed biomass, soil nutrients and soil structural stability for organic and conventional SMS in two contrasting soil types (a Chromosol and a Vertosol). Yields of corn and cabbage under the organic SMS were not lower than the conventional SMS possibly due to the equivalent N, P and K nutrients applied. Macro-nutrient uptake between the organic and conventional SMS did not differ for corn stover (except P) and cabbage heads. Corn residue incorporation reduced the average in-crop weed biomass in cabbage crops by 22% in 2010 and by 47% in 2011. Corn residue-induced inhibitions on weed biomass may be exploited as a supplementary tool to mechanical weed control for the organic SMS potentially reducing the negative impacts of cultivation on soil organic carbon. Residue incorporation and the organic SMS increased the average total N by 7% and 4% compared to the treatments without residue and the conventional SMS, respectively, indicating the longer-term fertility gains of these treatments. Exchangeable K, but not Colwell P in the soil was significantly increased by residue incorporation. The effect of treatments on soil structural stability was not detected due to short study period and/or heavy rainfall distorting results. The clayey Vertosol conserved higher levels of nutrients and had better soil structural stability than the sandy Chromosol.

3.1 Introduction

Concerns about declining soil organic C (SOC) and increased greenhouse gas emissions due to farming practices such as intensive tillage, excessive rates of N fertiliser and bare fallows have encouraged adoption of conservation agricultural practices such as no-tillage, crop rotations and residue retention (Johnson *et al.* 2007, Smith *et al.* 2008, Luo *et al.* 2010b, Sanderman *et al.* 2010). However, whilst no-till farming is suited for broadacre crops it is unsuitable for most vegetable crops. The latter rely on tillage to perform basic management operations like preparation of beds and management of weeds. These tillage operations disrupt soil aggregates exposing the physically protected soil organic matter (SOM) leading to loss of SOC (Angers *et al.* 1993, Six *et al.* 1999, von Lützow *et al.* 2006) and lead to declines in soil productivity.

Crop residue management (RM) plays an important role in maintaining SOC in horticulture, especially where annual crop rotations rely on frequent tillage. There are several options for management of crop residues based on the requirement of the farmers. The options include removal from the field, incorporated into the soil, burned *in situ*, composted, or used as mulch for succeeding crops (Wilhelm *et al.* 2004, Yadvinder *et al.* 2005). The removal crop residues from the field is mainly driven by the demand for other farm uses (Valzano *et al.* 2005, Yadvinder *et al.* 2005) or for industrial purposes such as biofuel production (Blanco-Canqui and Lal 2007, Hoskinson *et al.* 2007). Stubble retention, incorporation and burning are, however, the main three stubble management practices in Australian conditions (Valzano *et al.* 2005). Retention of crop residue can help increase yields, improve soil nutrients and conserve soil water for semi-arid conditions (Wilhelm *et al.* 2004, Johnson *et al.* 2006).

A vegetable system returns very small quantities of its residue while at the same time it is more susceptible to soil degradation due to its dependence on heavy tillage (Jackson *et al.* 2004, Chan *et al.* 2007). Maintenance of soil quality is reported to be enhanced by crop rotation with grain crops such as rye (*Secale cereale* L.) or inputs of organic waste materials in combination with zero or reduced tillage (Mochizuki *et al.* 2008, Dong 2009, van Groenigen *et al.* 2011). Organic soil management systems (SMS) use organic sources (like crop residue and compost) for fertilisation but conventional SMS use mineral fertilisers as the main source of crop nutrition (Mondelaers *et al.* 2009, Chirinda *et al.* 2010). The slower nutrient releasing property of organic fertilisers may help in retaining nutrients in soil (Berry *et al.* 2002, Marinari *et al.* 2010a) compared with the soluble mineral fertilisers. The former may reduce the amount of nutrients escaped into the environment via leaching (Poudel *et al.* 2002, van Diepeningen *et al.* 2006) or in gaseous forms (Bouwman *et al.* 2002). Soil nutrient reserves and underlying nutrient cycling processes in organically cropped soils are similar to that in conventionally managed soils, however the former holds nutrients in less-available forms (Berry *et al.* 2002, Stockdale *et al.* 2002), which is of greater significance.

Organic crop producers have limited tools for managing weeds unlike conventional producers who use herbicides (Bond and Grundy 2001, Chirinda *et al.* 2010). Weed management is ranked as the number one constraint to organic production and research on weeds management is a top priority by the UK farmers (Turner *et al.* 2007). Mechanical cultivation is most the common method of managing weeds in organically managed farms (Bond and Grundy 2001) which not only impacts negatively to the SOM and soil structure and but also involves use of fossil fuel negating the advantages of organic farming (Wood *et al.* 2006). Hand removal of weeds is tedious and too labour intensive to be a commercially viable option. Research studies examining alternative management strategies of using cover crop residues for suppression of weeds in vegetables are reported in the literature (Fisk *et al.* 2001, Mennan *et al.* 2009). The strategy exploits allelopathic properties of these residues to suppress weeds due to release of phytotoxins from decomposing residue (Weston 1996) and hence we undertook to study the effect of corn residue incorporation on the weed biomass.

Performance of farming systems is widely assessed using crop yield as an indicator and high yields are essentials to achieving food security because land resources are finite (Foley *et al.* 2011). Individual studies comparing yields between organic and conventional systems (Poudel *et al.* 2002, Pimentel *et al.* 2005, Teasdale *et al.* 2007) reported varied results from one study to another. A global scale review and synthesis by Badgley *et al.* (2007) concluded that organic agriculture balanced, or even exceeded, conventional yields, and could provide sufficient food on current agricultural land. However, critics have questioned the validity of the method adopted for yield comparisons by the former authors (Connor 2008). Moreover, Trewavas (2001) argued that organic (Org) agriculture may have lower yields and would thus need more land to produce the same quantity of food as conventional (Conv) farms. Hence more research is needed to understand the yield differences between the two systems.

Generally held perception among food consumers is that organically produced crops possess higher nutritional quality than those produced conventionally (Herencia *et al.* 2011). However, the literature on food nutrition reports a lack of clear, consistent differences between the nutrient contents of organic and conventional produce (Biao *et al.* 2003, Hoefkens *et al.* 2009). In the light of this inconclusive evidence, macro-nutrient uptake by corn stover and cabbage grown under the two systems was studied.

The focus of this paper is on understanding the soil and plant responses to residue incorporation (in Conv and Org SMS), using sweet corn (*Zea mays* L. var. *rugosa*)/ cabbage (*Brassica oleracea* L.) as a model through a two-year field trial. Sweet corn not only produces about 1.7 times more biomass C than most other grain crops (Wilhelm *et al.* 2004) but also has a relatively high economic value and is a compatible rotation crop in a vegetable enterprise. Annual sweet corn production is estimated at 62,575 t from the total area of 5,942 ha and the annual cabbage production is estimated at 81,563 t from the total area of 2020 ha in Australia (Rab *et al.* 2008). The macro-nutrients supplied by organic and mineral fertilisers (Hoffmann *et al.* 2006) were balanced since comparative studies on conventional and organic farming rarely balance the nutrient inputs in farming systems research (Wells *et al.* 2000, Leifeld *et al.* 2009, Marinari *et al.* 2010a).

The specific objectives were to examine the effect of SMS (Conv and Org) with corn residue management (incorporation = +RES or removal = –RES) on:
a) yields and biomass production of sweet corn and cabbage,
b) nutrients uptake by corn stover and cabbage heads,
c) weed biomass production,
d) soil nutrients, and
e) soil structural stability.

3.2 Materials and methods

3.2.1 Site and climate

A soil management systems field trial was conducted over 24 months at two sites in the Armidale area of New South Wales, Australia with two contrasting soil types: a mottled, dystrophic, Brown Chromosol, medium, loamy, non-gravelly (referred to hereafter as Chromosol) and a haplic, self-mulching, Black Vertosol, very fine (referred to hereafter as Vertosol) in the Australian soil classification system (Isbell 2002). These correspond to Alfisol and Vertisol, respectively, in the USDA classification (Soil Survey Staff 2010). Selected soil properties for the two soils are given in Table 3.1. The coordinates for the Chromosol site are 30° 29.23′ S and 151° 38.08′ E at an elevation of 1,011 m and that of

Vertosol site are 30° 28.55′ S and 151° 38.93′ E at an elevation of 1,077 m. The two sites were about 2 km apart.

Table 3.1. Mean values for selected soil properties for 0-10 cm depth of field trial sites (n = 4).

Soil property	Units	Chromosol	Vertosol
Total organic C		1.28	2.41
Total N		0.13	0.2
Sand	g/100g	74.3	22.4
Silt		10.6	15.6
Clay		14.5	62.3
Exchangeable K		0.38	0.59
Exchangeable Ca	$cmol_c/kg$	1.74	21.71
Exchangeable Mg		0.65	12.9
Exchangeable Na		0.07	0.18
Bulk density	Mg/m^3	1.47	1.22
pH $(H_20)_{1:5}$		5.6	5.5

Monthly rainfall and minimum and maximum temperatures (daily averages) during the experiment are presented in Figure 3.1 (Bureau of Meteorology 2012) which details the climatic conditions of the two sites. The climatic data is from nearest weather station, Armidale (Tree Group Nursery) in the Armidale town which was approximately 5 km away from both trial sites. The rainfall is summer dominant with hottest weather in January-February period and the coldest in June-July period (Bureau of Meteorology 2012).

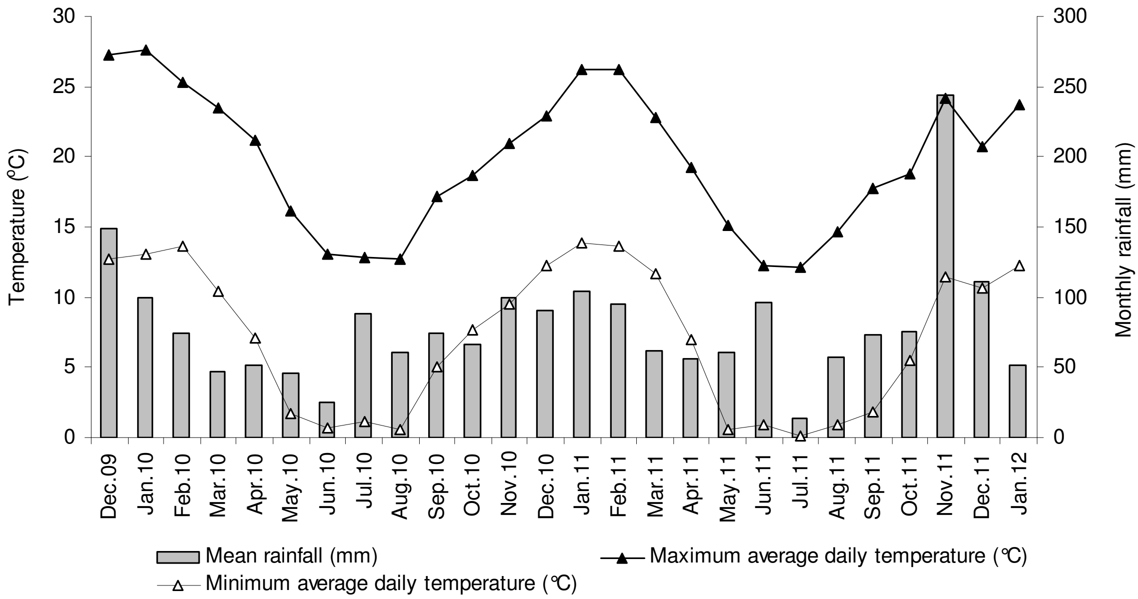


Figure 3.1. Monthly rainfall and minimum and maximum temperature during the experiment (Bureau of Meteorology 2012).

3.2.2 Experimental design and set up

A sweet corn (variety: Early Leaming) (summer) and cabbage (variety: Sugarloaf) (winter) rotation with two SMS (organic or conventional), and two residue management practices (+RES, or -RES) were carried out in the Chromosol and Vertosol sites (Figure 3.2 and Figure 3.3). The experiment commenced in December 2009 and ended in December 2011 completing four cropping seasons. A completely randomized design with a two-way factorial was adopted at each site and each treatment had four replications. Each plot was 6 m x 2 m in size. Corn was sown on 14th December 2009 and 15th November 2011 using a tractor-mounted seeder and the planting density was maintained at 70,000 plants/ha in four rows spaced 0.5 m apart.

Figure 3.2. Sweet corn in early February 2011 at the Chromosol site.

Figure 3.3. Cabbage seedlings are transplanted into ± residue plots at the Chromosol site.

Corn was fertilised in the organic and conventional SMS at the recommended rate of 200:50:40 kg/ha N:P:K (NSW DPI 2009). The fertiliser combinations to meet the nutrient requirement for corn are in Table 3.2. Commercially available organic fertilisers (New Era High N and Organic Life Garden Food) were applied pre-sowing for organic SMS, whilst urea, trifos and muriate of potash were used in the conventional SMS. Half of the fertilisers were banded along the four rows and the other half spread evenly over each plot. Half of the N fertiliser in conventional SMS was applied at sowing and the rest as a top dressing one month after sowing. Weeds in organic SMS were managed using a chipping hoe at three and seven weeks after sowing. Weeds in conventional SMS were managed using 2 L/ha atrazine ($C_8H_{14}ClN_5$) (480 g/L of S-triazine as active ingredient) at pre-emergence and three weeks after sowing. No other crop protection was required for corn in both years. The crop was irrigated using drip irrigation. After harvesting cobs on 23 April 2010 and 21 March 2011, corn stover was shredded mechanically with a mulching machine, spread evenly across the +RES plots at 14.8 t dry weight/ha (estimated average yield) and incorporated using rotary hoe to a depth of 15-20 cm. Average carbon input through corn stover was 6.1 and 6.2 t/ha for 2010 and 2011, respectively. The stover had the average C:N ratios of 43:1 in 2010 and 53:1 in 2011.

Table 3.2. Nutrient composition of organic and mineral fertilisers and the rates applied to corn crop.

	Fertiliser	Nutrient (kg/ha)						
	(kg/ha)	N	P	K	Ca	S	Mg	C
Organic fertilisers								
Organic Life Garden Food	1000	40	30	20	48	0	0	233
New Era High N	2000	160	20	20	20	5	3	752
Total (kg/ha)	3000	200	50	40	68	5	3	985
Mineral fertilisers								
Urea	435	200	0	0	0	0	0	0
Trifos	242	0	50	0	36	24	0	0
Muriate of potash	80	0	0	40	0	0	0	0
Total (kg/ha)	757	200	50	40	36	24	0	0

Cabbage seedlings were raised in a greenhouse. At eight weeks, the seedlings were manually transplanted in the +RES or –RES plots at 40,000 plants/ha (four rows per plot) on 4 May 2010 and 7 April 2011. The cabbages were fertilised with 120:65:45 kg/ha N:P:K (NSW DPI 2006) using the same products as in the corn. The fertiliser combinations to meet this nutrient requirement for cabbage are shown in Table 3.3. As for corn, half of the fertilisers were banded along the four rows and the other half spread evenly over each plot. Half the N fertiliser in the conventional SMS was applied as top dressing one month after transplanting. Like corn, cabbage crops were also irrigated by drip irrigation. Gypsum was applied (330 kg/ha) as a sulphur supplement in mid-June to all plots (Table 3.3). To avoid introducing another herbicide (that may potentially confound with other factors) in the plots, weeds in conventional plots were managed by manually pulling out the weeds with minimum soil disturbance at three and seven weeks after transplanting. Although manual weeding is not a generally practised by conventional farmers, but it is a permitted method for conventional SMS. Weeds in organic plots were managed using a chipping hoe at three and seven weeks after transplanting. Cabbage moth (*Mamestra brassicae* L.) and cabbage white butterfly (*Pieris brassicae* L.) caterpillars were controlled using Dipel® (active ingredient = 4320 international units of potency/mg of *Bacillus thuringiensis* var. *kurstaki*) twice in September 2010 with a 15 days interval in all plots, but there was no need for insect control with the 2011 crop.

3.2.3 Crop and weed sampling and determination of dry weights

Both corn and cabbage were harvested manually from 1 m x 1 m random quadrat in the two centre rows, leaving 0.5 m on four sides of plot as the edge buffers. Corn cobs were removed and the remaining plant parts (stover) were collected by cutting the plant at the soil surface. Any fallen leaves of corn were collected with stover and not mixed with weeds. From each plot, corn cobs, corn stover, and weeds were collected separately in April 2010 and March 2011. From each of the crop harvested-quadrat, all weeds were collected by cutting at the ground level. The fresh weight of all components were measured, oven-dried at 70°C to a constant weight and reweighed.

Table 3.3. Nutrient composition of organic and mineral fertilisers and the rates applied to cabbage crop.

	Fertiliser	Nutrient (kg/ha)						
	(kg/ha)	N	P	K	Ca	S	Mg	C
Organic fertilisers								
Organic Life Garden Food	2000	80	60	40	96	0	0	467
New Era High N	500	40	5	5	5	1	1	188
Gypsum	333	0	0	0	70	52	0	0
Total (kg/ha)	2833	120	65	45	171	53	1	655
Mineral fertilisers								
Urea	261	120	0	0	0	0	0	0
Trifos	314	0	65	0	47	31	0	0
Muriate of potash	90	0	0	45	0	0	0	0
Gypsum	333	0	0	0	70	52	0	0
Total (kg/ha)	998	120	65	45	117	83	0	0

Cabbages were harvested with one inner wrapper leaf on both sides of the head and the cabbage trash (any above ground component of cabbage left after removing head) by cutting at ground level. Cabbage roots were dug out with 0.2 m × 0.2 m × 0.2 m of soil intact, gently broken to remove roots and washed gently. From each plot, cabbage heads, cabbage trash, cabbage roots and weed biomass were collected in 14th October 2010 and 16th September 2011. From each quadrat, all weeds were collected by cutting at the ground level and separated by each species. The fresh weight of each component was measured, oven-dried at 70°C to a constant weight and reweighed.

Plant tissue analysis

Ground (< 0.5 mm) sub-sample for cabbage head and corn stover were used to determine the concentrations of total P and K with inductively coupled plasma-optical emission spectrometer (ICP-OES) after extraction with a 7:3 70% perchloric acid/30% hydrogen peroxide solution using the sealed chamber digestion method (Anderson and Henderson 1986). Another sub-sample (< 0.5 mm) of the dried plant samples were analysed by a complete combustion method at 950°C furnace (TruSpec Carbon and Nitrogen Analyser, LECO Corporation) for determination of total C and N. Nutrient uptake by corn stover and cabbage heads from the soil were calculated using the measured nutrient concentrations and the amount of corresponding dry biomass.

3.2.4 Soil sampling, processing and chemical analysis

Soil samples were collected using a soil corer from within centre 1 m x 10 m area of each plot, leaving 0.5 m on four sides of each plot as the edge buffers. In each plot, soil samples were collected from four random places to a depth of 0.3 m and divided into three depths with 0.1 m interval and bulked for each interval to make a representative sample. Soil samples were collected prior to commencing the experiment for baseline data on 11 December 2009. After initiation the experiment soil samples were collected in 15/16 October 2010, 29/30 March 2011 and 29/30 December 2011. The samples were dried at 40°C and sieved through < 2 mm sieve to remove > 2 mm fractions like crop roots, stones and soil fauna in preparation to conduct laboratory analyses. In this paper, soil results for 0.1 m depth for October 2010 and December 2011 are reported.

Cation exchange capacity

The soil samples were air-dried and passed through a < 2-mm screen and analysed for exchangeable cations following a procedure adopted from Rayment and Higginson (1992). A 2.000 g of soil sample was tumbled with 40 mL of 1 M NH_4Cl adjusted to pH 7 (with 20% NH_4OH) for one hour and filtered with Whatman No. 42. The filtrate was analysed in the ICP-OES for the determination of exchangeable cations Ca, Mg, Na and K.

Soil EC and calculation of ESP and ESI

Soil electrical conductivity (EC) was analysed on 1:5 soil:water suspension using electrode method (Rayment and Higginson 1992). Exchangeable Na percentage (ESP) was determined using Equation 1 to compute electrochemical stability index (ESI). ESI was then the ratio determined by dividing the EC (dS/m) by the corresponding ESP value. ESI is an index of soil structural stability whose critical value for Australian cotton soil is 0.05 (McKenzie 1998) and this value is assumed as the critical value in this study.

$$ESP = \text{Exchangeable } [(Na)/(Ca + Mg + K + Na)] \times 100 \qquad (1)$$

Soil total C, total N and ammonium

The soil samples were ground to <0.5 mm and analysed by a complete combustion method at $950^{o}C$ furnace by LECO for determination of total organic C and N. No $CaCO_3$-C was determined as pH of the soils was acidic (Table 3.1) and the total C determined by LECO was assumed as the total organic C concentration in the soil. Ammonium was determined in air-dried soil (< 2 mm) extracted with 2M KCl solution using the method adopted from Keeney and Nelson (1982). A 2.000 g of soil sample was tumbled with 20 mL of 2M KCl solution for one hour and filtered with Whatman No. 42. The filtrate was analysed by an automated procedure in the Skalar.

Colwell P

Colwell P estimates available P in soil. Colwell P in soil was determined in 0.5 M $NaHCO_3$ of sample extract at pH 8.5. The determination was done based on the absorbance readings of treated extract (shaken with 1 M H_2SO_4 acid followed by additions of polyvinyl alcohol and malachite green reagents) on a spectrophotometer at 630 nm using the established method (Motomizu *et al.* 1983, Rayment and Lyons 2011).

3.2.5 Statistical analysis

A four-way fixed effect analysis of variance (ANOVA) was used to assess the effects of RM, SMS, soil type and year on the components of corn and cabbage, weed biomass, nutrient uptake (N, P and K) by corn stover and cabbage heads and soil nutrients using R version 2.11

(R Development Core Team 2010). Variance homogeneity was checked by plotting residual vs. fitted values and the q-q plots to assess the normality assumptions of ANOVA. Data were transformed to stabilise variance where assumptions were not met. *P*-values < 0.05 were considered significant. Mean values of data are presented along with 95% confidence intervals (standard error × 1.96) (Brandstätter 1999). Correlation analysis was done to assess the relationship between the fresh and dry weights of crop components and weed biomass.

3.3 Results

3.3.1 Corn phases

Stover and cob yields and weed biomass

Dry weights only are reported as the correlation coefficients (r^2) with fresh weights were relatively high for corn: stover = 0.68, cobs = 0.74 and in-crop weeds = 0.89.

Stover yield

The ANOVA on the corn stover yield (dry weight) was performed on log transformed data to stabilise variances. Note that no residue had been applied to the field sites during the 2010 corn cropping period. Corn stover yield (Figure 3.4) varied significantly for soil type and year as did their interaction ($P < 0.001$). The effects of residue incorporation and SMS were not significant, nor were any of the other interaction terms. Stover yield was reduced in 2011 compared with 2010 by 40% (5.8 t/ha) in the Chromosol and by 75% (10.5 t/ha) in the Vertosol presumably due to heavy rain during the crop establishment phase.

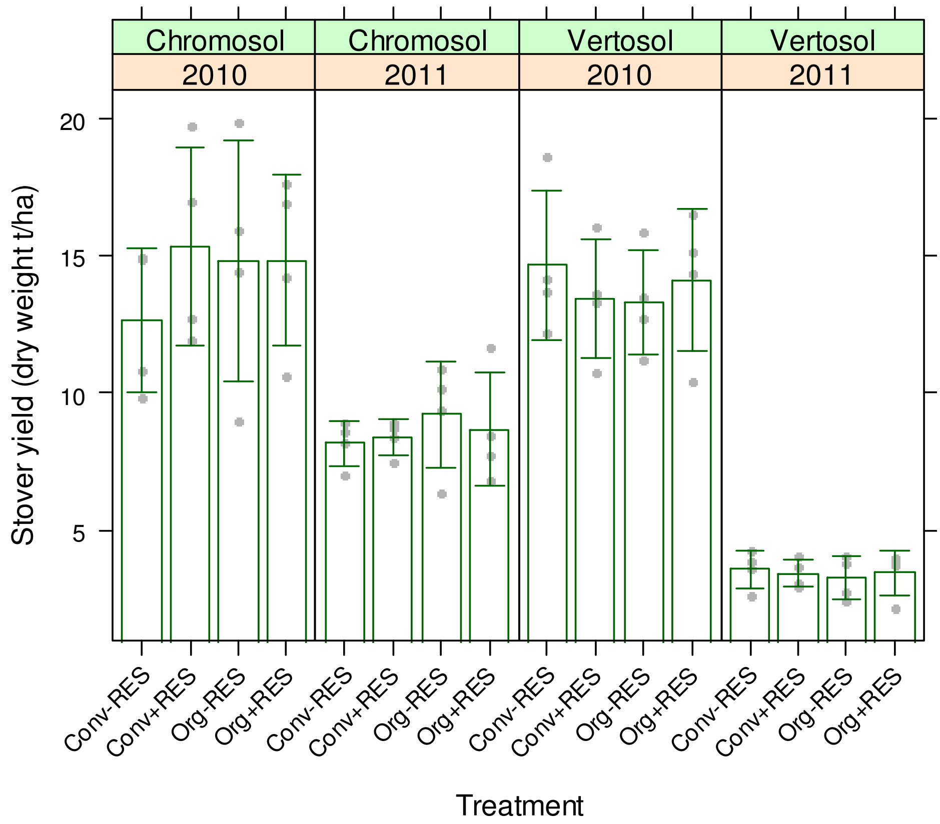


Figure 3.4. Effect of soil type, residue and SMS treatments on corn stover yield in 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Cob yield

The ANOVA on the cob yield (dry weight) was performed on log transformed data to stabilise variances. Cob yield (Figure 3.5) varied significantly for soil type and year as did their interaction ($P < 0.001$). The effects of residue incorporation and SMS were not significant, nor were any of the other interaction terms. Cob yield was increased in 2011 compared with 2010 by 153% in the Chromosol; however the corresponding increase was only 14% in the Vertosol site.

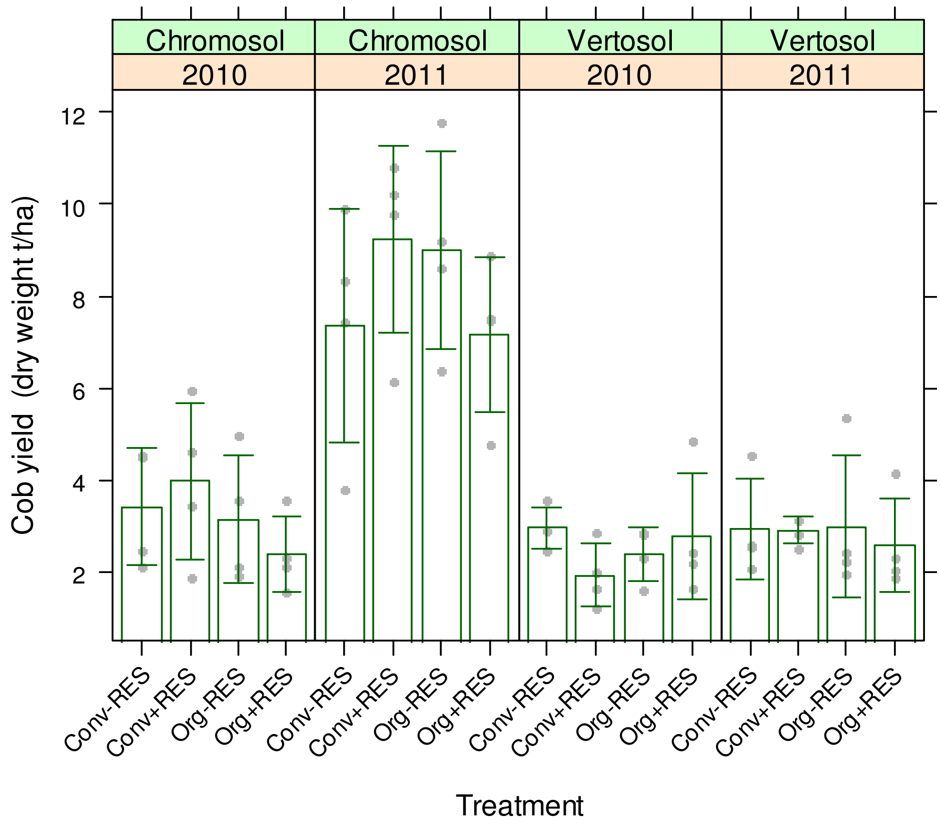


Figure 3.5. Effect of soil type, residue and SMS treatments on corn cob yield in 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Weeds in corn

Weed biomass in the corn crop (Figure 3.6) varied significantly for soil type and year as did their interaction ($P < 0.001$), similar to that of stover and cob yields. The effects of residue incorporation and SMS were not significant, nor were any of the other interaction terms. Weed biomass decreased by 61% in 2011 at the Chromosol site but only by 6% at the Vertosol site. There was a very low correlation between corn stover yield and weed biomass ($r^2 = 0.02$) suggesting that the presence of weed did not affect stover yield.

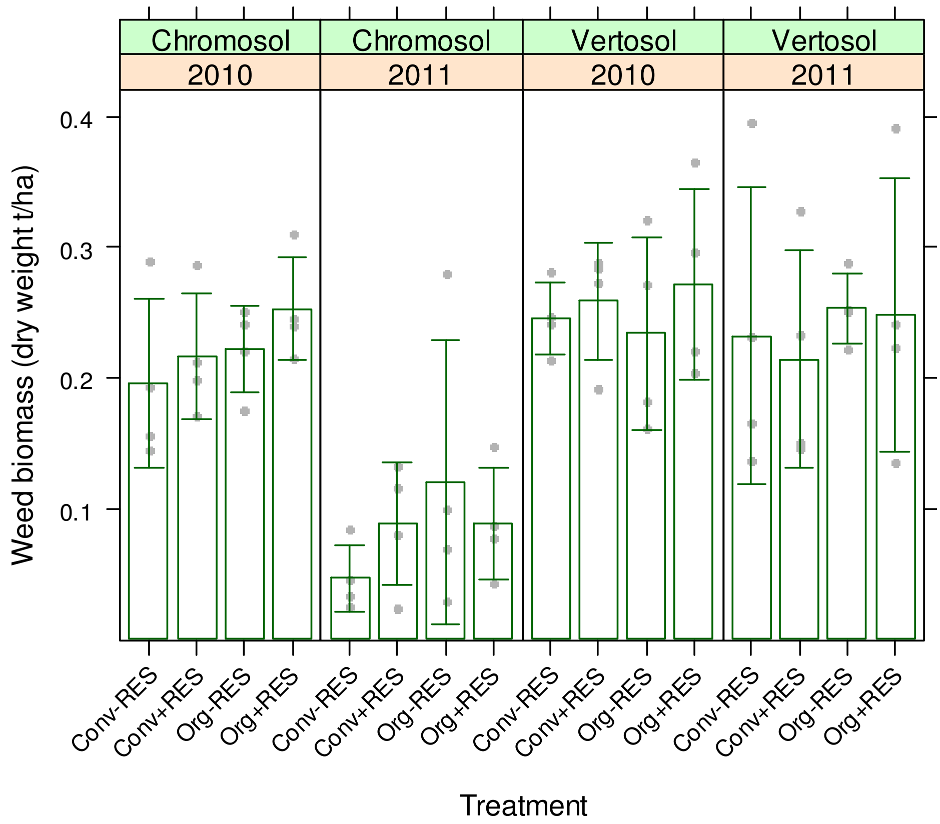


Figure 3.6. Effect of soil type, residue and SMS treatments on weed biomass in corn 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Nutrient uptake by corn stover

Nutrient uptake was measured for corn stover in both years to estimate the amount of nutrients associated with the corn stover incorporation or removal from the plots. The tabulated result N, P and K uptake is presented in Table 3.4 with treatment means accompanied by the 95% confidence intervals of the treatment means.

The ANOVA on uptake of N, P and K by corn stover was performed on log transformed data to stabilise variances. Uptake of N by the corn stover varied significantly ($P < 0.001$) for soil type and year. Other main terms were not significant. Except for SMS × year ($P < 0.05$), no interaction were significant. The average N uptake in the Chromosol site was 56% greater than at the Vertosol site. Between years the average uptake was 69% less in 2011 compared with 2010. The average uptake of N in conventional SMS decreased by 64% in 2011 but in organic SMS the uptake decreased by 74% in the same period resulting in the significant interaction.

Table 3.4. Treatment means of nutrients uptake by corn stover for two soil types in 2010 and 2011. Means ± 95% confidence intervals shown. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Corn stover	Nutrient uptake (kg/ha)			
	C	N	P	K
Chromosol, 2010				
Conv+RES	6281	143.6	8.2	212.1
Conv-RES	5106	137.0	8.8	176.1
Org+RES	5963	210.8	15.7	233.6
Org-RES	6094	175.2	11.1	208.5
95% CI	±509.6	±33.15	±3.30	±23.26
Vertosol, 2010				
Conv+RES	5654	100.5	10.5	155.9
Conv-RES	6123	96.3	10.3	169.3
Org+RES	5685	103.4	13.5	189.0
Org-RES	5402	110.9	13.1	173.5
95% CI	±293.3	±6.04	±1.64	±13.38
Chromosol, 2011				
Conv+RES	3506	43.4	10.0	125.0
Conv-RES	3462	50.5	8.5	102.9
Org+RES	3656	47.2	10.0	118.2
Org-RES	3887	50.4	9.4	122.8
95% CI	±187.7	±3.27	±0.67	±9.78
Vertosol, 2011				
Conv+RES	1424	39.3	6.9	49.9
Conv-RES	1489	39.5	12.0	47.8
Org+RES	1433	30.1	8.8	44.9
Org-RES	1367	29.4	9.4	45.0
95% CI	±49.0	±5.44	±2.08	±2.35

Uptake of P by the corn stover varied significantly ($P < 0.05$) for the SMS and year. The other main terms and all interactions were not significant. The average uptake of P in the organic SMS was 21% higher than that of the conventional SMS. Between two years, the uptake decreased by 18%, on average in 2011 over 2010.

Uptake of K by the corn stover varied significantly for soil type and year, as did their interaction ($P < 0.001$). Neither the other main terms nor any other interactions were significant. The average uptake of K in the Chromosol site decreased by 44% in 2011, whilst the decrease in the Vertosol site was more pronounced at 73% in the same period resulting in the significant interaction between soil type and year.

Atmospheric C assimilated by corn stover

The ANOVA on the atmospheric CO_2-C assimilated by corn stover was performed on log transformed data to stabilise variances. Assimilated C by the corn stover (Table 3.4) varied significantly ($P < 0.001$) for soil type and year. Other main terms were not significant. Except for soil type × year ($P < 0.001$), no interaction were significant. The average assimilated C in the Chromosol site decreased by 38% (2,233 kg/ha) in 2011 over 2010 figures but the corresponding decreased in the Vertosol site was 75% (4,288 kg/ha) in 2011 over 2010 figures resulting in the significant interaction between two soils types and two years. The total C assimilated by corn stover is important as the corn stover/residue is incorporated in soil at 14.8 t/ha (oven-dry equivalent).

3.3.2 Cabbage phases

Cabbage yield, roots and weed biomass

Dry weights only are reported for cabbage yield and roots, and weed biomass as the correlation coefficients (r^2) with fresh weights were relatively high for cabbage crop: heads = 0.78, cabbage trash = 0.84 and in-crop weeds = 0.92. No fresh weights were recorded for cabbage roots.

Cabbage yield (heads)

The dry matter of cabbage heads was highly influenced by year ($P < 0.001$) and the other terms were not significant (Figure 3.7). The only significant interaction was between soil type and year ($P < 0.001$). The average cabbage yield decreased by 58% in 2011 in the Chromosol site but there was an increase of 3% at the Vertosol site over the same period. There was a very low correlation between the cabbage yield and weed biomass ($r^2 = 0.05$) suggesting that the presence of weeds did not affect cabbage yield.

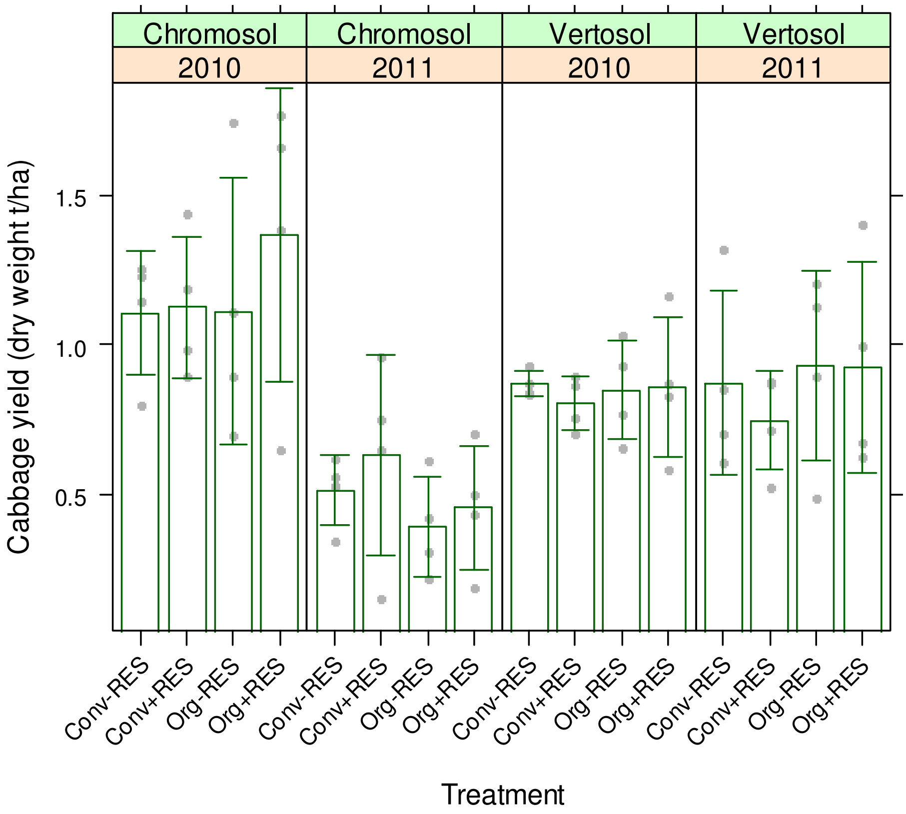


Figure 3.7. Effect of soil type, residue and SMS treatments on cabbage yield in 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Cabbage roots

The dry matter of cabbage roots was influenced by soil type only ($P < 0.01$) (Figure 3.8). The two interactions, SMS × soil type ($P < 0.01$) and the SMS × soil type × year ($P < 0.001$) were significant. The conventional and organic SMS in the Chromosol site had 22% and 33% more root biomass than at the Vertosol site, respectively, in 2010; however in 2011, conventional and organic SMS in the Chromosol had 44% and 161% less root biomass than at the Vertosol site, respectively.

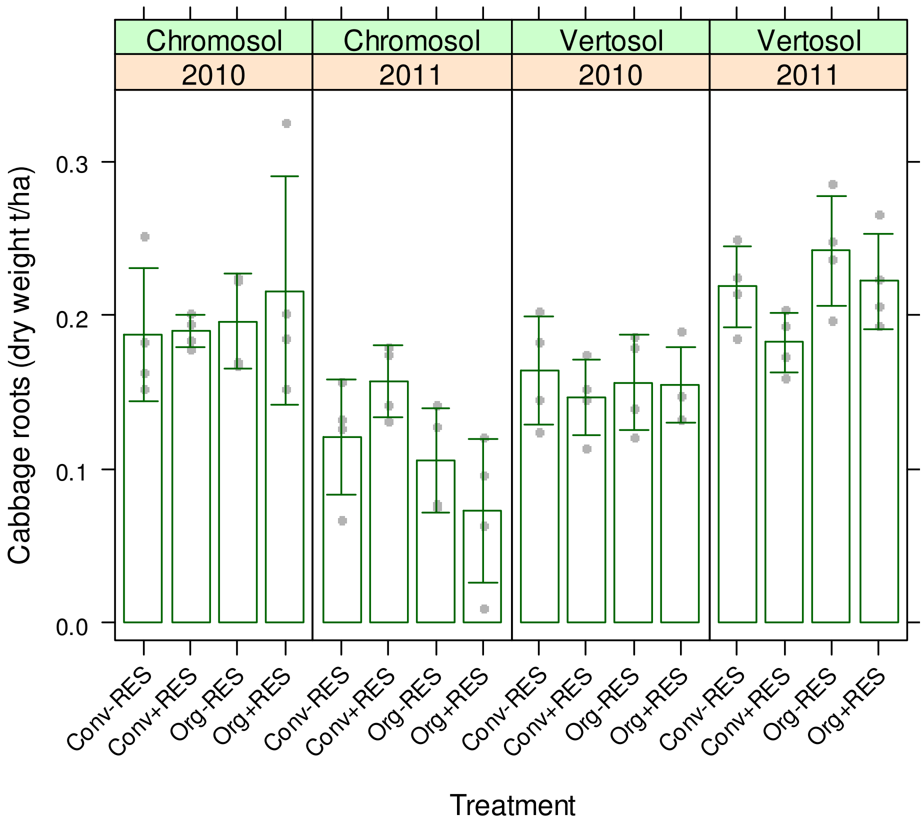


Figure 3.8. Effect of soil type, residue and SMS treatments on cabbage roots in 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

Weeds in cabbage

The ANOVA of weed biomass in cabbage was performed on log transformed data. Weed biomass was highly significant ($P < 0.001$) for the residue incorporation and soil type was moderately significant ($P < 0.01$) for the SMS (Figure 3.9 and Figure 3.10). The only two interactions, SMS × soil type ($P < 0.05$) and residue × year ($P < 0.01$) were significant. The role of incorporated residue as a management tool for weed suppression was evident by the fact that the residue incorporated treatments reduced the average weed biomass by 37% (or 0.41 t/ha) compared with the treatments without residue. Average weed biomass in the conventional SMS was reduced by 41% in the Vertosol site compared to the Chromosol site. However, in the organic SMS, the corresponding reduction was much higher at 66%.

The detail of weed biomass per each species of weed (ANBG 2012) is presented in Table 3.5 for the Chromosol site and in Table 3.6 for the Vertosol site.

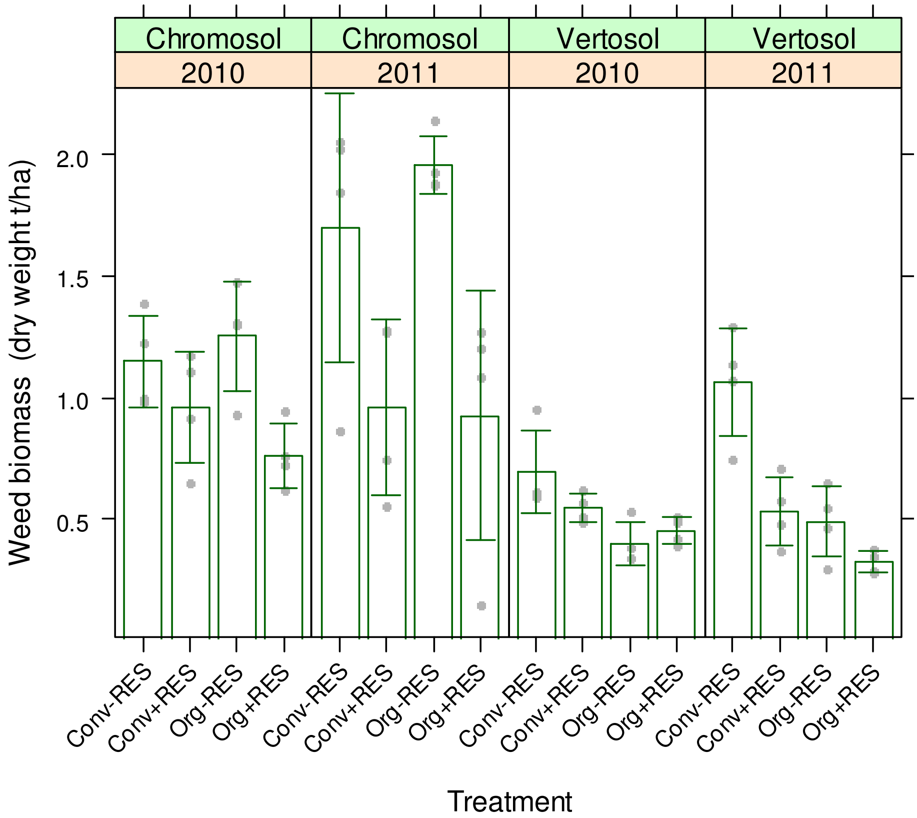
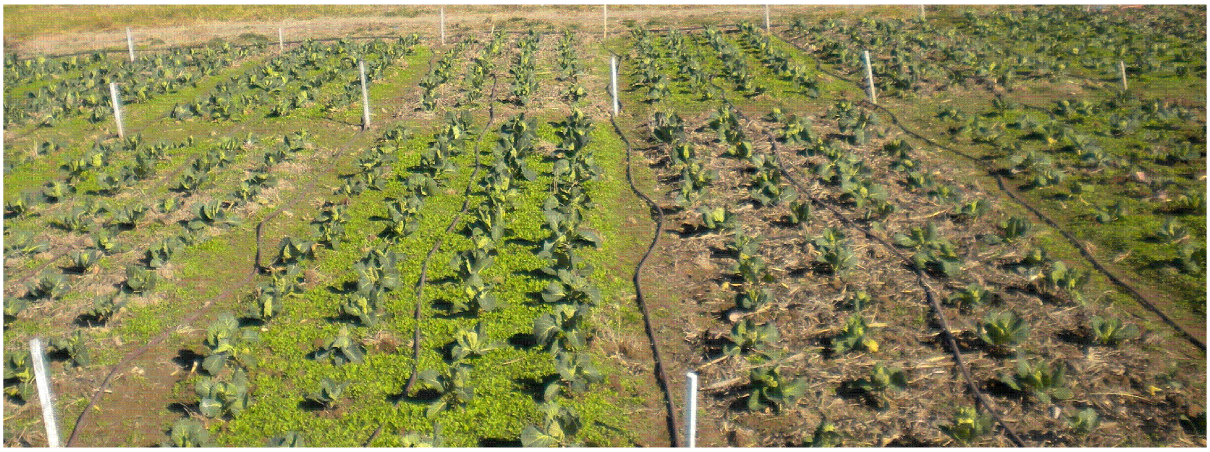


Figure 3.9. Effect of soil type, residue and SMS treatments on in-crop weed biomass in cabbage in 2010 and 2011. Means ± 95% confidence intervals shown. Grey dots are raw data points.Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.



Without residue more weeds   Residue incorporated less weeds

Figure 3.10. Cabbage in early May 2011 at the Chromosol site; residue incorporation has reduced weeds.

Table 3.5. Dry weights of weed biomass in cabbage crop at Chromosol site for 2010 and 2011. Mean dry weights ± standard errors (se) presented. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

		Mean ± se biomass (kg/ha) in 2010 by treatment				Mean ± se biomass (kg/ha) in 2011 by treatment			
Common name	Scientific name	Conv+RES	Conv-RES	Org+RES	Org-RES	Conv+RES	Conv-RES	Org+RES	Org-RES
Sherpherd's purse	*Capsella bursa-pastoris*	632±128.2	710±166.3	487±90.6	736±136.1	689±176.7	1228±365.5	653±211.6	1198±348
Deadnettle	*Lamium amplexicaule*	51±30.2	43±28.8	37±24.2	160±115.5	31±21.5	69±39.9	43±25.4	488±453.1
Winter grass	*Poa annua*	57±19.7	30±19.7	33±20.4	6±6.1	47±15.8	48±9.6	38±14.4	6±6.2
Clammy goosefoot	*Dysphania pumilio*	20±20.2	169±109.9	33±32.9	80±70	18±18.3	114±80.8	5±5.3	39±38.7
Rat-tail grass	*Sporobolus* sp	15±14.8	117±73.3	39±29.1	36±33.2	36±24.1	118±49.6	68±31.1	66±52.7
Spear thistle	*Cirsium vulgare*	71±26.4	0±0	24±15.6	24±14.6	31±25.7	11±11.1	15±9.4	39±18.3
Cotula	*Cotula australis*	10±10.1	3±3	26±17.2	10±7.1	0±0	6±6.1	24±24.4	0±0
Phalaris	*Phalaris aquatica*	0±0	3±3.1	18±14.7	15±8.7	0±0	0±0	11±6.2	6±6.2
Cat's ear	*Hypochaeris radicata*	21±12	0±0	4±4.1	8±7.5	8±8.5	0±0	0±0	11±10.7
Dandelion	*Taraxacum officinale*	0±0	0±0	0±0	8±7.5	0±0	0±0	0±0	11±10.8
Mouse-ear chickweed	*Cerastium glomeratum*	13±12.6	21±7.4	0±0	0±0	23±22.8	38±21.7	0±0	0±0
Other broadleaves		71±22.4	52±10.9	59±8.4	47±15.4	76±23.4	68±4.9	68±18.2	94±17.4
	Total weed biomass	960±117.6	1148±96.9	760±68.6	1129±158.3	960±184.8	1699±282.2	926±262	1958±61.8

Table 3.6. Dry weights of weed biomass in cabbage crop at Vertosol site for 2010 and 2011. Mean dry weights ± standard errors (se) presented. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

		Mean ± se biomass (kg/ha) in 2010 by treatment				Mean ± se biomass (kg/ha) in 2011 by treatment			
Common name	Scientific name	Conv+RES	Conv-RES	Org+RES	Org-RES	Conv+RES	Conv-RES	Org+RES	Org-RES
Deadnettle	*Lamium amplexicaule*	396 ± 9.4	496 ± 85.8	306 ± 29.5	239 ± 19.9	411 ± 65.2	808 ± 130.6	212 ± 18	300 ± 27.4
Wireweed	*Polygonum aviculare*	100 ± 25.2	139 ± 15.4	73 ± 15.2	107 ± 21.4	83 ± 4.8	219 ± 37.3	58 ± 16.7	139 ± 44.2
Barnyard grass	*Echinochloa crus-galli*	8 ± 8.2	23 ± 13.7	29 ± 23.2	6 ± 5.6	8 ± 8.4	15 ± 9.8	31 ± 25.5	3 ± 2.8
Sherpher's purse	*Capsella bursa-pastoris*	5 ± 5.1	6 ± 5.5	8 ± 8.1	8 ± 4.9	9 ± 8.6	7 ± 6.8	4 ± 4.3	2 ± 1.6
Spear thistle	*Cirsium vulgare*	8 ± 7.9	0 ± 0	16 ± 10.1	10 ± 6.5	0 ± 0	0 ± 0	9 ± 4.6	6 ± 3.6
Stagger weed	*Stachys arvensis*	0 ± 0	13 ± 7.6	2 ± 2.4	4 ± 4	0 ± 0	0 ± 0	0 ± 0	6 ± 5.7
White clover	*Trifolium repens*	14 ± 9.6	10 ± 6	0 ± 0	14 ± 14	9 ± 8.6	0 ± 0	0 ± 0	15 ± 14.7
Perennial rye grass	*Lolium perenne*	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	4 ± 4.5	0 ± 0	0 ± 0
Yellow burr-weed	*Amsinckia calycina*	0 ± 0	4 ± 4.3	10 ± 6	0 ± 0	8 ± 8.4	9 ± 9	7 ± 4.4	6 ± 5.9
Sow thistle	*Sonchus oleraceus*	15 ± 5.4	0 ± 0	0 ± 0	5 ± 2.6	0 ± 0	0 ± 0	0 ± 0	3 ± 2.9
Curled dock	*Rumex crispus*	0 ± 0	0 ± 0	2 ± 2.4	0 ± 0	4 ± 4.3	0 ± 0	0 ± 0	0 ± 0
Turnip weed	*Rapistrum rugosum*	0 ± 0	0 ± 0	3 ± 2.6	4 ± 4	0 ± 0	0 ± 0	0 ± 0	9 ± 8.7
	Total weed biomass	547 ± 29.9	690 ± 86.9	450 ± 28.2	397 ± 46.2	533 ± 71.5	1063 ± 114.6	321 ± 22.4	488 ± 73.8

Nutrient uptake by cabbage heads

The result for uptake of N, P and K by cabbage heads is presented in Table 3.7. The ANOVA for the N, P and K uptake by cabbage head showed that none of the main terms were significant nor any interactions except for the soil type × year, which was significant at $P < 0.01$. The average uptake of N, P and K in the Chromosol site was reduced by 27, 19 and 32%, respectively, in 2011 whilst there was an increase of 49, 45 and 31% respectively in the Vertosol site in the same period.

Table 3.7. Treatment means of nutrients uptake (kg/ha) by cabbage heads for two soil types in 2010 and 2011. Means ± 95% confidence intervals shown. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

	2010			2011		
	N	P	K	N	P	K
Chromosol						
Conv+RES	20.7	3.9	30.3	21.0	4.3	28.6
Conv-RES	18.6	3.7	22.3	14.8	3.2	18.3
Org+RES	24.9	4.5	37.5	14.2	3.0	18.9
Org-RES	20.6	4.0	30.5	11.7	2.6	16.5
95% CI	±2.62	±0.34	±6.10	±3.86	±0.73	±5.32
Vertosol						
Conv+RES	16.0	3.3	18.9	22.7	3.9	24.0
Conv-RES	15.7	3.2	19.2	24.9	4.6	25.7
Org+RES	16.1	3.2	21.5	25.3	5.3	28.9
Org-RES	15.7	3.1	20.2	21.8	4.8	26.0
95% CI	±0.20	±0.06	±1.17	±1.66	±0.54	±1.98

3.3.3 Effect of treatments on soil properties

Total- and ammonium-N and Colwell P

Soil total N status after cabbage harvest varied significantly for residue and soil type at $P < 0.001$, and for the SMS and year at $P < 0.05$ (Table 3.8). No interaction terms were significant. The residue incorporated treatments, on average, increased the status total N by 7% compared with the treatments without residue. The difference in soil type was a result of the Vertosol soil having 77% more total N compared to the Chromosol soil. The organic SMS had 3.6% total N compared to the conventional SMS. Between the two years, 2011 had 4.3% more total N than in 2010.

Ammonium-N was significantly ($P < 0.01$) influenced by residue treatment and by the year (Table 3.8). No other main terms and interactions were significant. The residue incorporated treatments had 39% more NH_4-N than the treatments without residue. Between two years, there was 35% more NH_4-N in 2011 compared with the values in 2010. Due to the use of air-dried samples NO_3-N measured was negligible and is not reported.

Colwell P in soil was significantly ($P < 0.001$) influenced by soil and year (Table 3.8). No other main terms and interactions were significant. The Vertosol site had 153 % more Colwell P than the Chromosol site. There was a 43% increase in Colwell P values for 2011 than for 2010.

Cation exchange capacity of soil

Exchangeable Ca and Mg in soil were highly influenced by soil type and year ($P <0.001$), as did their interaction ($P <0.001$ for Ca and $P <0.05$ for Mg) (Table 3.8). Other factors and interactions were not significant for exchangeable Ca and Mg. On average, exchangeable Ca for 2010 was 16.7% lower than that for 2011 in Chromosol; however Vertosol had 9.7% higher quantity of exchangeable Ca over the same period, which produced the significant interaction between soil and year. The significant interaction between soil and year for exchangeable Mg was due to 34.4% average reduction in 2011 compared to 2010 in the Chromosol, whilst the average reduction of 18.4% occurred in the Vertosol.

Exchangeable K in the soil was significantly influenced by residue incorporation and soil type at $P < 0.001$ and by the year at $P <0.01$ (Table 3.8). The two-way interactions, residue × soil type and soil type × year were highly significant ($P <0.001$) and residue × soil type was moderately significant ($P <0.01$). The increase of exchangeable K due to the incorporated residue was greater in the Vertosol site than at the Chromosol site, i.e. 71% in the Vertosol vs. 24% in the Chromosol, on average. The increase in exchangeable K in 2010 due to the residue incorporation was 74% in 2010 as compared with the treatments without residue. The corresponding increase in 2011 was only 39%, which is about half the increase in 2010.

Exchangeable Na was significantly influenced by SMS ($P <0.01$) and soil type ($P <0.001$) (Table 3.8). The only two significant interactions were SMS × year ($P <0.05$) and soil type × year ($P <0.001$). On average, exchangeable Na in organic SMS was 22.1% and 3.5% higher in 2010 and 2011, respectively, which produced the significant interaction between SMS and year. Soil type and year significantly interacted because the average exchangeable Na increased by 84.0% in 2011 for the Chromosol, but decreased by 20.9% during the same for the Vertosol.

Exchangeable Na percentage and electrochemical stability index

Soil structural stability was assessed by ESP and ESI. The main terms of residue and SMS were not significant, but soil type and year were highly significant (P <0.001) for ESP (Table 3.8). No interactions were significant except soil type × year (P <0.001). The ESP values for both soils were < 6%. The average ESP for the Chromosol was 2% and that of the Vertosol 0.6%. The soil type and year interacted significantly because the ESP values for the Chromosol in 2011 were higher than in 2010, but the reverse was the case for the Vertosol.

Similar to ESP, the main terms of residue and SMS were not significant, but soil type (P < 0.001) and year (P < 0.01) were highly significant for ESI (Table 3.8). Just as for the ESP, only soil type × year (P <0.001) was significant. The average ESI values for Chromosols were ≤ 0.05, the critical value; however the Vertosols were ≥ 0.08. The soil type and year interacted significantly because the ESI values for the Chromosols in 2011 were lower than in 2010, but the reverse was the case for the Vertosols.

Table 3.8. Soil nutrients and other properties for 0-0.1 m depth for the two sites by two sampling times. $EC_{1:5}$ = Electrical conductivity in 1:5 soil:water solution, ESP = Exchangeable Na percentage, ESI = Electrochemical stability index. Treatment means with 95% confidence interval (CI) of means (standard errors ×1.96) presented. Conv±RES = conventional soil management treatments with or without residue incorporation; Org±RES = Organic soil management treatments with or without residue incorporation.

	Total N (%)	NH_4-N (µg/g)	Colwell P (µg/g)	Exch. K ($cmol_c$/kg)	Exch. Ca ($cmol_c$/kg)	Exch. Mg ($cmol_c$/kg)	Exch. Na ($cmol_c$/kg)	$EC_{1:5}$ (dS/m)	ESP	ESI
	Chromosol Oct. 2010									
Conv+RES	0.117	3.75	28.26	0.269	2.36	0.95	0.040	0.04	1.13	0.04
Conv-RES	0.120	2.78	31.87	0.211	2.43	0.76	0.032	0.03	0.92	0.05
Org+RES	0.130	4.22	24.88	0.298	2.57	1.01	0.053	0.04	1.44	0.04
Org-RES	0.125	3.60	26.30	0.181	2.51	0.91	0.053	0.04	1.53	0.03
95% CI	±0.006	±0.587	±2.969	±0.052	±0.088	±0.106	±0.010	±0.005	±0.279	±0.007
	Chromosol Dec. 2011									
Conv+RES	0.134	5.42	42.41	0.287	2.03	0.59	0.076	0.05	2.59	0.02
Conv-RES	0.120	2.99	39.95	0.242	1.80	0.56	0.083	0.04	3.22	0.01
Org+RES	0.150	7.36	44.68	0.264	2.28	0.67	0.077	0.05	2.38	0.02
Org-RES	0.133	3.71	40.48	0.265	2.11	0.57	0.090	0.05	3.01	0.02
95% CI	±0.012	±1.908	±2.100	±0.018	±0.196	±0.049	±0.006	±0.004	±0.377	±0.004
	Vertosol Oct. 2010									
Conv+RES	0.236	4.79	66.93	1.053	22.27	16.99	0.237	0.06	0.58	0.10
Conv-RES	0.221	3.93	74.39	0.548	22.37	19.08	0.260	0.06	0.62	0.09
Org+RES	0.230	4.48	86.92	0.931	21.98	18.98	0.281	0.06	0.67	0.08
Org-RES	0.221	4.46	66.17	0.527	22.50	16.90	0.308	0.06	0.77	0.08
95% CI	±0.007	±0.352	±9.430	±0.262	±0.220	±1.180	±0.030	±0.003	±0.077	±0.007
	Vertosol Dec. 2011									
Conv+RES	0.236	7.54	105.61	0.712	26.53	14.70	0.207	0.05	0.49	0.11
Conv-RES	0.217	4.12	101.33	0.401	26.60	14.72	0.216	0.05	0.52	0.09
Org+RES	0.237	6.07	105.50	0.735	26.45	14.61	0.211	0.06	0.50	0.11
Org-RES	0.229	5.82	99.49	0.534	27.06	14.71	0.225	0.06	0.53	0.11
95% CI	±0.009	±1.375	±3.003	±0.155	±0.269	±0.047	±0.008	±0.004	±0.017	±0.008

3.4 Discussion

3.4.1 Agronomic outcomes for corn and cabbage

In general, corn produces 1.7 times more biomass than most other cereal crops (Wilhelm *et al.* 2004) which is advantageous not only for biotic C sequestration but also for abundant quantities of stover available for incorporation in soil or for other farm uses such as livestock feed or bedding (Stumborg *et al.* 1996), ultimately recycling C back to soil as manure. In a vegetable enterprise, sweet corn is a compatible rotation crop that not only has relatively high economic value, but also produces a large quantity of stover for retention on the soil surface or for incorporation in soil (Valzano *et al.* 2005, Yadvinder *et al.* 2005) reducing the likelihood of declining SOM in vegetable systems (Jackson *et al.* 2004, Chan *et al.* 2007).

In this research, neither there were significant differences between the SMS treatments for the yields of sweet corn cobs and stover, nor for the yields of cabbage head and root biomasses. This observation to some extent could be attributable to the equivalent quantities N, P and K nutrients applied (Hoffmann *et al.* 2006) to both the organic and conventional SMS. However, the lack of synchrony between nutrient release and crop demand in organic SMS (Chirinda *et al.* 2010) was anticipated to reduce yield in organic SMS. Crop yields in organic systems are generally lower than the yields from conventional systems, mainly due to use of readily soluble nutrients and use of pesticides in conventional systems (Pimentel *et al.* 2005, Azadi *et al.* 2011). Average corn yield of a chisel-plough based organic system was reported to be 28% less than the no-till conventional system (Teasdale *et al.* 2007). In another study, average corn yields of the organic systems were lower, similar and higher than the conventional systems for the initial five year phase, after a five-year transition period and for five drought years period, respectively in the Rodale Institute experiment (Pimentel *et al.* 2005).

A meta-analysis comparing yield performance of organic and conventional vegetable production systems reported that, on overall average, yields in organic systems were 33% lower than conventional systems (Seufert *et al.* 2012). However, under rain-fed legumes and perennials on weak-acidic to weak-alkaline soils, the yields of organic systems were reported to be only 5% lower compared to yields in conventional systems (Seufert *et al.* 2012). Lotter *et al*. (2003) suggested that improved soil water holding capacity may be related to the higher organic yields in drier seasons, while crop losses due to weed competition may contribute to lower organic yields. Rainfall was adequate for corn in 2010 and both cabbage crops, but was excessive in 2011 for corn.

It should be noted that the short implementation period of the organic SMS (two years) may not have been sufficient to produce the expected yield differences because the nutrient levels in the soils may not have reached the limiting levels upon imposition of the treatments (Seufert *et al.* 2012). Lower crop productivity in organic systems reported in literature could be ascribed to limited N supply restricting growth (Berry *et al.* 2002). Pest and diseases levels were either negligible or easily controlled in both SMS, so crop losses due to pest and diseases were not different between SMS treatments. It is therefore assumed that the standard agronomic requirements of nutrients, water and crop protection were satisfactory in both SMS.

Corn residue incorporation rates were reported to have no significant effect on wheat (*Triticum aestivum* L.) grain yields for a two-year study, but obtained highest yield with chisel-plough treatment, 25–50% corn residue incorporation and application of 150 kg N/ha (Alijani *et al.* 2012). Contrastingly, Shafi *et al.* (2007) reported a significant increase in grain and stover yields of maize following a post-harvest incorporation of corn residue in both years of a two-year study.

The limited effect of residue incorporation on yield components of cabbage head, trash and roots may be attributed to high average C:N ratios of residue (43:1 in 2010 and 53:1 in 2011) immobilising N (Trinsoutrot *et al.* 2000a, Moritsuka *et al.* 2004).

In 2010, the cob and stover yields between the sites were similar. In 2011, average stover yield decreased and the average cob yield increased at both sites. The stover yield reduction was more drastic in the poorly drained Vertosol as there was heavy, intermittent rain during the growing season. Water did not easily drain away in the clay Vertosol (42% v/v water holding capacity) compared with the sandy Chromosol (16% v/v water holding capacity) where water drained away relatively faster (Isbell 2002) which caused the between-sites and between-years yield differences. In 2010, the Chromosol site was affected by frost during the grain-filling period whilst slight lodging hampered the crop at Vertosol site manifesting as cob yield differences between the two years.

The difference in soil types was associated with greater root biomass in the easily penetrable sandy Chromosol compared to the clayey Vertosol. The cabbage yield was decreased by 58% in 2011 compared to 2010 in the Chromosol site, but increased by 3% in the Vertosol site during the same period. The most likely reason could be the differences in weed competition as revealed by weed biomasses at the two sites.

3.4.2 Nutrient uptake

Uptake of N, P and K by both sweet corn stover and cabbage heads showed no significant difference between the SMS and RM treatments except for P uptake by corn stover. The average uptake of P by corn stover in the organic SMS was 21% higher than that of the conventional SMS. This finding is consistent with the literature on food nutrition which commonly reports a lack of clear, consistent differences between the nutrient contents of organic and conventional produce (Biao *et al.* 2003, Hoefkens *et al.* 2009, Smith-Spangler *et al.* 2012). A review of 223 studies comparing of nutrient levels of organically and conventionally produced foods found that no nutritional benefits except for higher P levels in organic food (Smith-Spangler *et al.* 2012). The higher P content in crops from organically fertilised soil is consistent with findings reported in literature (Worthington 2001, Herencia *et al.* 2011, Smith-Spangler *et al.* 2012), but such difference was absent in the case of cabbage heads. Organic crops were shown to contain significantly more P (and other elements) and significantly less nitrates than conventional crops (Worthington 2001). A meta-analysis of 39 papers comparing nutrient composition reported that only nitrate was significantly lower in organic carrot, lettuce and potato, higher in organic spinach and no difference for other nutrients (Hoefkens *et al.* 2009). In a more recent study, nitrate concentration in the edible parts was significantly lower in crops grown in organically fertilised plots and a tendency for lower N and higher P content in organic crops cultivated in same crop cycle was also reported (Herencia *et al.* 2011).

3.4.3 Residue incorporation reduces weed biomass

Irrespective of two different weed control methods employed for the two SMS, the in-crop weed biomass for cabbage was significantly affected by the residue incorporation, soil type and SMS. The average in-crop weed biomass was decrease by 22% in 2010 and the corresponding reduction was even higher at 47% in 2011. Reduction of weed biomass over and above the effects two different weed control methods indicates the ability of decomposing corn residue in suppression of weeds (Weston 1996). Crop residue incorporation could be a supplementary weed management strategy (Fisk *et al.* 2001, Mennan *et al.* 2009) to mechanical cultivation available to organic growers (Bond and Grundy 2001, Turner *et al.* 2007). Soil incorporation or mulching on the soil surface of allelopathic crop residues affects weed dynamics which either reduces or delays weed seed germination and establishment, and also suppresses individual plant growth resulting in the overall decline in the density and vigour of weed community (Gallandt *et al.* 1999). Phytotoxins that are released during the decomposing process of corn residue may have been allelopathic to weeds (Weston 1996). Various crops or cover crop residues are reported in the literature to have suppressed different weeds. Cheema and Khaliq (2000) reported that *in situ* soil incorporation of sorghum (*Sorghum bicolor* [L.] Moench) whole plant or its various parts, alone or mixed to have significantly suppressed weed growth in wheat. Sorghum and hairy vetch (*Vicia villosa* Roth) cover crop residue incorporation is found to reduce weed species, density and total dry biomass in kale (*Brassica aleracea* L. var. *acephala*) crop (Mennan *et al.* 2009). Oilseed rape (*Brassica napus* L.) residue incorporation is reported to have reduced 50 to 96% weed biomass in potato (*Solanum tuberosum* L.) crop (Boydston and Hang 1995). Therefore, the residue-induced inhibitions on weed growth may be used as a supplement to mechanical control for organic agriculture potentially reducing the negative impacts of cultivation on SOC and also saving on the costs of cultivation and herbicide in organic and conventional agriculture, respectively.

Hand weeding to control weeds in the conventional cabbage plots may not have been as effective as use of herbicide possibly leading to increased weed competition thereby balancing out on the slower N release effect reducing yield in the organic SMS. Hand weeding was implemented in order to minimally disturb the soil to simulate herbicide use in the conventional SMS, whereas cultivation by chipping hoe in the organic SMS is more likely to negatively impact on soil C. Non-chemical weed control methods in cabbage like mulching and cultivation are reported to be as effective as herbicides in the US (Dillard *et al.* 2004). The most dominant weed species in the Chromosol site was shepherd's purse (*Capsella bursa-pastoris*) followed by deadnettle (*Lamium amplexicaule*) and the most dominant weed at the Vertosol site was deadnettle followed by wireweed (*Polygonum aviculare*). Average weed biomass in the conventional SMS was reduced by 41% in the Vertosol site compared to the Chromosol site due to differences in number of years cropped after conversion from pasture (i.e. land use record of the two sites). Weed density in the Vertosol were observed be lower as the site has been intensively cropped for trials for several decades, whereas the Chromosol site was converted from pasture to infrequent cropping about seven years prior to initiation of the experiment. In the organic SMS, the corresponding reduction was much higher at 66% possibly due to mismatch of synchrony between nutrients release from organic fertilisers and the demand by the weeds (Chirinda *et al.* 2010) compared with the release of nutrients in the conventional SMS.

3.4.4 Soil nutrients

Soil total N status after cabbage harvest was impacted positively by the incorporated residue and the SMS due to the N input through residue and organic fertilisers. The slower mineralisation rate of N in organic fertilisers (Berry *et al.* 2002, Marinari *et al.* 2010a) than in the mineral N-fertiliser may have increased the average total N in the organic SMS. While sources of N in organically grown crops affect crop productivity by limiting the amount of available N to meet the crop demand (Berry *et al.* 2002, Stockdale *et al.* 2002), organic systems have the potential to meet the N requirement if sources of N (leys, N-rich residues and uncomposted manure), timing of supply and choices of crops are carefully matched (Berry *et al.* 2002). Organic management also is reported to have significantly lower levels of nitrate and soluble N in soil compared with conventional management (van Diepeningen *et al.* 2006). From the standpoint of mineral fertiliser, the faster mineralisation rate of fertiliser in conventional SMS may have emitted higher amounts of N_2O (Bouwman *et al.* 2002) leading to lower levels of total N. Furthermore, N mineralisation rates of a conventional system in a study is reported to be 100% higher than the organic system (Poudel *et al.* 2002). Therefore, organic SMS can hold more N to increase N use efficiency and at the same time reduce the release N into the environment.

The release of N from the decomposed residue increased the average total N and NH_4-N levels compared with the treatments without residue. Due to an accumulative effect across years, 2011 had higher total N and NH_4-N levels than in 2010, on average. This observation was possible because the increase in soil temperature could have stimulated decomposition and microbial transformation of N, as the soil samples in 2011 were collected in December, a relatively warmer month December compared with October in 2010. The treatments in the Vertosol had higher levels of average total N due to Vertosol's inherent higher N status than the Chromosol (Isbell 2002).

Colwell P in soil was not influenced by the residue and SMS but was affected by the soil type and year. Exchangeable K levels in soil were positively impacted by the incorporated residue, soil type and year. The effect of soil type is simply due to the nutrient-rich Vertosol having higher levels of Colwell P and exchangeable K compared to the relatively poor Chromosol. The effect of year is due to a accumulative effect similar to that mentioned for total N levels. While a timeframe of two years may be too short to produce significant changes in P levels, Nachimuthu *et al.* (2012) reported that there was a major overlap between P inputs for organic and conventional vegetable farms in Eastern Australia since conventional vegetable farmers were also found to apply organic inputs such as green manure and composts. They also found high levels of labile P in both farming systems in all study sites and so concluded that the organic vegetable farms were not nutritionally deficient. In another study of organic vegetable production systems in Australia, two alternative vegetable systems that received high inputs of compost were reported to increase SOC, soil total N, total P, exchangeable nutrient cations compared with three conventional systems and the high mineral fertiliser recipient treatment had highest potentials to release P into the environment (Wells *et al.* 2000). Vegetable systems in greater Sydney metropolitan region of NSW are reported to accumulate exchangeable cations (Ca, Mg, and K) and P as a consequence of high rates of inorganic fertilisers and poultry manure inputs as well as excessive cultivation (Chan *et al.* 2007). Hence, to reduce the burden on external supply of organic materials to maintain soil fertility and to counteract negative effect of excessive cultivation for weed control, sweet corn is suggested as a rotation crop in a vegetable system.

3.4.5 Soil structural stability

Residue and SMS were not significant for ESP presumably due to the limited period of 2 years of experimentation and possible distortion of results by unusually more rainfall prior to samplings. The average ESP for Chromosol was 2% and that of Vertosol 0.6%. The presence of higher amounts of exchangeable Na in the Chromosol causes higher rate of clay dispersion than in the Vertosol. The higher rates of dispersion occurring in the Chromosol decreases structural stability and vice-versa. The interaction between soil types and year was due to textural differences determining varied leaching patterns of exchangeable Na in the two soil types by the rain water.

Further to ESP, ESI was pursued as it is more sensitive indicator of soil structural stability than the ESP (Hulugalle and Finlay 2003). The effect of residue and SMS were not significant, this may be due to the same reasons mentioned for ESP. Although not significant, residue incorporated treatments generally had higher average ESI values suggesting the positive influence of residue on the soil aggregate stability (Six *et al.* 2002a, Blanco-Canqui and Lal 2004). Average ESI values for the Vertosol were ≥0.08, much greater than the critical value of 0.05 indicating better soil structural stability; however Chromosol had average values ranging from 0.01-0.05, indicating poor structural stability as most values were lower than the critical value (McKenzie 1998).

3.5 Conclusion

Yields of corn and cabbage under the organic SMS were equivalent to the conventional SMS as opposed to what is generally reported in the literature. In other words, performance in the organic SMS can be matched to that in the conventional SMS if the macro-nutrients are balanced. The short experimental period of two years may have been insufficient to produce the anticipated yield differences reported in the literature. No clear differences in the nutrient uptake between the organic and conventional SMS was found and is consistent with the literature.

Corn residue-induced inhibitions on weed biomass may be used as a supplementary tool to mechanical weed control for the organic SMS, potentially reducing the negative impacts of cultivation on SOC. Further, it could potentially reduce the costs of herbicides used in conventional SMS. Soil incorporation of residue and organic SMS are separately capable of improving total N and exchangeable K indicating the long-term fertility gains of these treatments. The slower nutrient releasing characteristics of organic fertiliser can not only reduce nutrient losses to the environment but also benefit successive crops. The clayey Vertosol conserves higher levels of nutrients and has better soil structural stability than the sandy Chromosol.