Chapter 7
Agronomic, Soil Quality and Environmental Consequences of Using Compost in Vegetable Production

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Abstract This chapter summarises many of the findings from a long term compost vegetable field experiment at Camden in south western Sydney, Australia. Large applications of garden organics compost resulted in significant improvements to soil quality (physical, chemical and biological) compared to farmer practice. These included soil structural stability, soil carbon, cation exchange capacity, pH and microbial biomass carbon. However, conventional tillage with the rotary hoe eroded away these improvements over time by accelerating the loss of soil carbon and pulverising the soil structure. The compost treatment matched the farmer practice treatment in terms of crop yield for all crops, and exceeded it for some crops. The compost treatment was found to be an economic alternative to farmer practice in the Sydney basin, with additional environmental benefits. Targeted applications of compost and minimum tillage may help optimise benefits. A repeat application of compost resulted in a more significant and sustained response in the soil biology.

Keywords Soil quality · Soil health · Food security

7.1 Introduction

Reports of the beneficial effects of composts on crop growth go back as far as 800 BC in the Mediterranean (Semple 1928). But the use of compost and other organic amendments went out of favour in the 1960's and 1970's during a period commonly referred to as the "green revolution" where there was a widespread adoption

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of soluble inorganic NPK fertilizers and chemical pesticides/herbicides by farmers (Lal 2010a). A three fold increase in food production was attributed to this change (Childers et al. 2011). However, since that time there have been many research publications highlighting the importance of organic C to soil quality and function including soil structure, water-holding capacity, drainage, aeration, cation exchange capacity and biological activity (Feller et al. 2010).

Food security is now a major challenge for agriculture in the twenty first century, with there being a need to increase food production by more than 60 % over the next 50 years (Bruinsma 2009) in order to be able to feed a projected world population of 9.2 billion people (UNESA 2008). Improving soil quality by increasing soil organic C levels is seen as one potential way of improving food security (Lal 2004, 2010a). Increasing soil carbon levels in intensive agricultural systems has proven difficult (Heenan et al. 2004; Chan et al. 2011a), but composts have been identified as a potential source of stable organic carbon for this purpose (Gibson et al. 2002). Recent research has also reported reductions in greenhouse gas emissions in association with the application of green waste compost (Dalal et al. 2009, 2010; Vaughan et al. 2011). Composts have potential to improve soil biological function (e.g., nutrient cycling) and have also been found to suppress some soil borne pathogens for vegetables and other crops (Termorshuizen et al. 2006; van der Gaag et al. 2007; Pane et al. 2013; Suárez-Estrella et al. 2013).

During the year 2005 a long term compost vegetable field trial was started at the Centre for Recycled Organics in Agriculture (CROA) at Camden in south western Sydney to evaluate the benefits and risks associated with using compost in vegetable production systems. Data from this field trial provides a valuable case study for the use of compost in intensive horticulture and this will form the basis for much of the following discussion in this chapter. This field trial was commissioned for a number of reasons. Firstly, a survey of the soils of the vegetable farms of the Sydney Basin found that many of these soils had severely depleted levels of soil carbon, degraded soil structure and very high levels of available phosphorus compared to adjacent non-farmed soils (Chan et al. 2007a). As such, it was apparent that there was a need for organic C inputs and improved nutrient management in these systems. However, there was little information available on this particularly for the longer term. Secondly, the successful diversion of garden organics waste from its previous destination of landfill to composted garden organics (cGO) via government legislation and strategies, was starting to generate large quantities of cGO (i.e., ~0.3 mt/year) in the Sydney basin (Figs. 7.1 and 7.2) and these quantities are predicted to increase (Chan et al. 2007b, 2008). Around 87 % of the recycled organics generated in the area was utilised in the urban amenity market segments which included landscaping and domestic gardens, but this was thought to be approaching saturation (DEC 2004). In contrast, only ~4 % of the cGO was being used in agriculture, and as such it was thought that there was great potential for its use in agriculture around the Sydney Basin. This was the other driving force behind setting up the compost vegetable field trial.

The following sections are on the results of the long term compost vegetable field experiment at CROA and their implications for the beneficial use of compost in vegetable production systems.

Fig. 7.1 Source separated garden organics (i.e., grass clippings and shrub pruning's) ready for composting at a commercial composting facility, collected from suburban 'green lid bin' kerbside collections

Fig. 7.2 Source separated green-waste compost ready for distribution to farmers at an urban composting facility in south western Sydney

7.2 CROA Compost Field Experiment Design

The field trial was located at the NSW Department of Primary Industries 'Centre for Recycled Organics in Agriculture' (CROA) near Camden (150°42′32″E, 34°05′45.6″S), NSW, Australia, at a site with a long history of intensive cropping prior to the experiment. The soil at the site was a Chromosol/Dermosol inter-grade (Isbell 1996) [Lixisol (FAO 2006)] with topsoil which was hard-setting with low organic C levels and a silt-clay-loam texture and chemistry as presented in Table 7.1.

The field trial design is outlined in detail in Chan et al. (2008). Briefly, it consisted of seven treatments in a randomised complete block design with 4 replicates of each treatment. The treatments were; T1 = high soil P and conventional farmer practice (half poultry manure and half chemical fertilizer); T2 = high soil P and full compost; T3 = high soil P and compost and chemical fertilizer (half:half); T4 = low soil P and conventional farmer practice (half poultry manure and half chemical fertilizer); T5 = low soil P and full compost; T6 = low soil P and compost and chemical fertilizer (half:half); T7 = control (nil inputs).

Table 7.1 Properties of the soil (T=0), poultry manure and compost used in the compost vegetable field trial

Treatment	pHCa[a]	EC[b]	TOC	TN	C/N	Colwell P	Exchangeable cations [cmol (+) kg^{-1}]			
		dS m^{-1}	g 100 g^{-1}	g 100 g^{-1}		mg kg^{-1}	Na	K	Ca	Mg
Field trial soil (0–10 cm)	5.2	0.13	1.1	0.11	10	29	0.12	0.29	5.35	1.25
	pHw[b]	EC[b]	TOC	TN	C/N	Colwell P	TP	N:P ratio		
		dS m^{-1}	g 100 g^{-1}	g 100 g^{-1}		mg kg^{-1}	g 100 g^{-1}			
Compost no. 1 (crop 1)	5.6	3.14	21	1.1	19.1	1200	0.38	2.9		
Poultry manure (crops 1–10)	8.1	9.20	32	3.1	10.3	7500	2.60	1.2		
Compost no.2 (Crop 6)	6.9	5.3	30	1.6	18.8	2200	0.72	2.2		

[a] pH in 1:5 soil/0.01 M $CaCl_2$
[b] Electrical conductivity and pHw in 1:5 soil: water extract
TOC total organic carbon, *TP* total P

Fig. 7.3 The garden organics compost (cGO) being weighed out for distribution to compost treatment plots for the second application of compost prior to planting crop 6—capsicum at the CROA field experiment site

High and low initial levels of soil extractable P was included as a factor in the experimental design because high P levels were found to be typical of vegetable farm soils in the Sydney basin (Chan et al. 2007a, b) and as such it was considered important to assess the impact on vegetable production (Chan et al. 2008). For the high P treatments (T1, T2 and T3), triple superphosphate was applied to each plot at a rate equivalent to 680 kg P ha^{-1} and incorporated to 0.10 m, to raise the soil extractable P concentrations to levels similar to those observed in vegetable farm soils (~250 mg/kg in 0.10 m, Chan et al. 2007a, 2008) prior to the commencement of the field experiment. The site soil had a low initial concentration of bicarbonate extractable P (29 mg/kg) and as such ensured the other treatments (T4, T5, T6, T7) were representative of new vegetable farms with no prior history of high fertilizer inputs.

The compost used was derived from source separated garden organics blended with 10% poultry (laying chickens) manure that was composted according to the Australian Standard AS 4454-2003. The properties of the compost and poultry manure used in this field trial are presented in Table 7.1. The compost used in the experiment is shown in Fig. 7.3 along with its application to the compost treatment plots prior to incorporation in Fig. 7.4.

In the case of these treatment descriptions, half refers to half the recommended dosage of total chemical NPK fertilizer application rates which was based on crop specific industry expert recommendations for each crop (NSW DPI Agfact/Primefact series (Agfact/Primefact Series 2013) and district horticulturalist advice). For the two organic amendments, poultry manure and compost, the rate was based on their total nitrogen (N) and an assumed availability index of 0.60 and 0.10 for poultry manure and compost respectively (i.e., it was assumed that, 60% of the poultry manure total N and 10% of the compost total N would be available to the crop) according to Evanylo and Sherony (2002). For the chemical fertilizers, phosphorus was applied as Triple superphosphate and incorporated into the soil to a depth of 0.10 m prior to crop seedling planting, whilst potassium and nitrogen were applied as muriate of potash and urea respectively, in split surface applications over the

Fig. 7.4 The garden organics compost (cGO) being spread out on the compost treatment plots prior to incorporation into the soil with a rotary hoe, prior to the planting of crop 6—capsicum, at the CROA field experiment site

duration of the crop. Poultry manure was applied with P for treatments T1 and T4 and incorporated into the soil prior to the planting of each crop.

The compost was applied to the compost treatments in a single application prior to the first crop. The full compost application rate for treatments T2 and T5 was determined to be 125 dry t ha^{-1} based on the recommended agronomic rate for N for the first crop (broccoli), the total N content of the compost, and the availability index of 0.10 for compost (Evanylo and Sherony 2002). The half compost rate for treatments T3 and T6, was, therefore, 62.5 dry t ha^{-1}. For the full compost treatments (T2 and T5), urea was only applied when petiole sap test results confirmed crop observations of low nitrate levels compared to the farmer practice treatments (T1 and T4). Applications of inorganic N fertilizer were not required for the first two crops of the full compost treatments (T2 and T5), but were required for crops 3 to 5. The full compost treatments received no muriate of potash over the course of the trial. The inorganic chemical and organic fertilizer inputs for each treatment for each of the first five crops is summarised in Table 7.2. Following the first 5 vegetable crops, a repeat application of compost was applied to the compost treatments, and a further 5 crops were grown. For the purpose of the following discussions, treatments T1 and T4, T2 and T5, T3 and T6, and T7 will be referred to collectively as 'farmer practice', 'compost', 'mixed' and 'control' treatments respectively.

The cropping sequence for this experiment was; 1. Broccoli (*Brassica oleracea* var. *botrytis* L.), 2. Egg-plant (*Solanum melongena* L.), 3. Cabbage (*Brassica oleracea* L.), 4. Capsicum or bell pepper (*Capsicum annuum* L.), 5.Leek (*Allium ampeloprasum* var. *porrum* L.), 6. Capsicum or bell pepper ('*Capsicum annuum* L.'), 7. Broccoli (*Brassica oleracea* var. *botrytis* L.), 8. lettuce (Lactuca sativa var. *capitata*), 9. Cabbage (*Brassica oleracea* L.) (Figs. 7.5 and 7.6), and 10. Sweet corn (*Zea mays*) (Fig. 7.7). After the harvesting of each crop, all of the non-harvestable crop residues on each plot were incorporated into the soil by rotary hoeing. Crops were managed following recommendations from the NSW Department of Primary Industries (Agfact/Primefact Series 2013) and an industry handbook (Salvestrin 1998).

Fig. 7.5 Cabbage seedlings (crop 9), shortly after being transplanted into the experiment plot beds

Fig. 7.6 Harvesting the cabbages at the end of crop 9 at the CROA long term compost-vegetable field trial site

The crops were drip irrigated with irrigation scheduling based on gypsum blocks (G bug) soil moisture monitoring of plots. More details of the field trial management are provided in Chan et al. (2008) and Chan et al. (2010).

7.3 Impacts of Compost on Intensive Vegetable Production Systems

Intensive vegetable production systems can degrade soil quality and function, and as a consequence lead to a decline in crop yields over time. Inputs of compost have been found to improve a number of measures of soil quality, sometimes resulting in crop yield benefits. Some of these impacts are outlined in the following sections.

Fig. 7.7 Sweet Corn (crop 10), just prior to harvest at the CROA long term field experiment

7.3.1 Agronomic and Economic Impacts

The marketable yield data (fresh weight in t ha^{-1}) from the first five crops of the field trial revealed that the large one off application of 125 dry t ha^{-1} of compost associated with the full compost treatments (T2 and T5) induced a crop yield response which matched the farmers practice treatments (T1 and T4) for four of the first five crops and exceeded it for one crop (Chan et al. 2008, 2011a, b). No significant difference ($p<0.05$) was found between the mean yields of farmer practice and full compost treatments for crops namely broccoli, eggplant, cabbage and leek whilst the yields of the full compost treatments for capsicum or bell pepper and was found to be 22 % higher than that of the comparable farmer practice treatments (Chan et al. 2008, 2011a, b). Over the period of the first five crops, the compost treatment also resulted in significant savings from reduced fertilizer use compared to farmer practice (Table 7.2), with a 36 % saving in urea as well as a 100 % saving for K and P fertilizers (Chan et al. 2011b). The economic analysis of the yield and inputs for the first five crops determined that the full compost treatment had a benefit cost ratio (BCR) of 1 compared to farmer practice, indicating that this compost practice was very close to breaking even for the first five crops (Chan et al. 2011b). Although, a BCR of 1 on its own may not seem that encouraging for those considering practice change, it was thought at the time, that given the additional benefits measured for soil quality (Chan et al. 2008) and the environment with reduced water quality risk (Chan et al. 2010), that this was a fairly encouraging result. In contrast, the mixed compost treatment (½(half compost; half chemical fertilizer) with a one off application of 62.5 dry t ha^{-1} of cGO compost at the start of the field trial, although matching the yields of the farmer practice treatment for the first four crops, had a significantly lower ($p<0.05$) yield for the leek crop which was 64 % of that of farmers practice (Chan et al. 2008, 2011b). This resulted in a negative BCR of −1.15 for the economic analysis of the mixed compost treatment versus farmer practice,

Table 7.2 Organic and inorganic fertilizer inputs applied to each treatment for each of the first 5 crops grown at the compost-vegetable field trial (Comp = garden organic compost; Mix = garden organic compost and inorganic fertilizer ½:½; FP = farmers practice (1/2 inorganic fertilizer and ½ poultry manure). (Adapted from Chan et al. 2011b)

Input1	1. Broccoli				2. Eggplant				3. Cabbage				4. Capsicum				5. Leek			
	Comp	Mix	FP	Cont	Comp	Mix	FP	Cont	Comp	Mix	FP	Cont	Comp	Mix	FP	Cont	Comp	Mix	FP	Cont
Compost (kg ha^{-1})	125	62.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Poultry manure (kg ha^{-1})	–		4.03	–	–	–	3.24	–	–	–	4.3	–	–	–	3.25	–	–	–	3.62	–
Urea (kg ha^{-1})	–	163	163	–	–	130	130	–	133	200	200	–	200	266	266	–	425	425	425	–
Triple P (kg ha^{-1})	–	143	143	–	–	200	200	–	–	190	190	–	–	119	119	–	–	72	72	–
Muriate of Potash (kg ha^{-1})	–		–	–	–	47	47	–	–	57	57	–	–	43	43	–	–	–	58	–

[1] Note high P and low P treatments received the same fertilizer inputs after the initial adjustment of P levels at the start of the trial

which suggested that the lower compost application rate was not as economic as the larger application rate over a time frame of five crops, at least (Chan et al. 2011b).

In 2008, prior to the growing capsicum, the compost applications were repeated for the compost treatments (T2 and T5) and the mixed compost treatments (T3 and T6). A further five vegetable crops were grown in the field trial following the experiment protocols of the first five crops. The detailed results for these crops (currently unpublished), again found that the marketable yields for the full compost treatment matched or exceeded the yields of the farmer practice for crops capsicum, broccoli, lettuce, cabbage and sweet corn. The most extraordinary result was for the crop 6 (capsicum) which was the first crop grown following the second compost application. For this crop, the full compost treatment achieved yields which were almost double the farmers practice ($p<0.05$), whilst the mixed compost treatment (62.5 dry t cGO ha^{-1}) attained a mean yield which was more than 50% higher than the farmer practice yield (Fig. 7.8). To put the extent of the response of the capsicum crop to the compost treatment (i.e., a yield of ~60 t ha^{-1}) into context, the farmer practice mean yield of around 32 t ha^{-1} for this experiment was only just below the perceived potential yield for capsicums of 40 t ha^{-1} (Bartha 1983). The compost treatments, therefore, helped the capsicum crop achieve its optimal level of production. The only other crop where the full compost treatment had a significantly higher mean yield than the farmer practice treatment was crop 8 (lettuce) where the compost yield was ~22% higher than farmer practice. The benefit cost ratios (BCR) from the financial analysis of this experiment over ten crops with two applications of compost for the full compost and mixed compost treatments (currently unpublished) using the same methodology and assumptions outlined in Chan et al. (2011b), were well over 1 for both the full compost and mixed compost treatments. This was largely due to the fact that capsicum or bell pepper (i.e., the crop which had a significant yield response to the compost treatment) was a high value crop (Dorahy et al. 2013). These results demonstrate that such high compost input systems can be economical for vegetable growers over the 10 crop cycle, provided crops that are responsive to improvements in soil quality are selected for planting early in the cropping sequence following the application of the compost.

The yield results from the ten crops grown in this compost vegetable trial demonstrated that large applications (62.5 and 125 dry t ha^{-1}) of a blended garden organics green-waste compost product (80–90% garden organics composted with 10–20% chicken manure) supplemented with inorganic N fertilizer was able to match the current farmers practice (half inorganic fertilizer; half poultry manure) for the Sydney Basin region based on vegetable crop marketable yields. The results also demonstrated that some crops, in terms of their marketable yield, are more responsive to soil quality improvements than others. This experiment revealed that capsicum was one such crop. It is, therefore, important to evaluate local crops to establish which crops are more responsive to soil quality improvements, and ensure that they are planted as the first crops following the application of compost. If these are also high value crops like capsicum, then the chance of maximising economic return may also be increased.

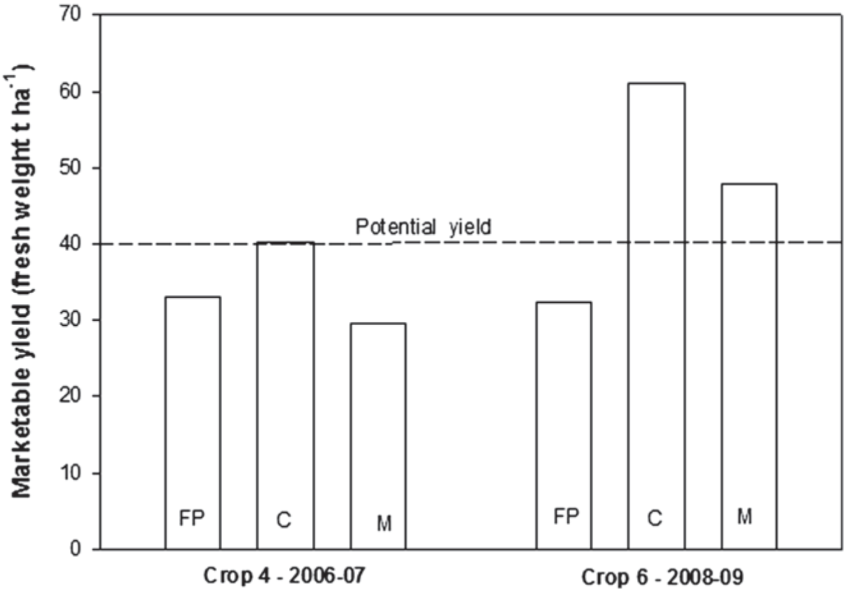

Fig. 7.8 Capsicum yields for the two capsicum crops grown at the field trial for the farmers practice (FP), compost (C), and mixed (M) treatments. Crop 4 was the fourth crop following the first compost application, while crop 6 was the first crop following the repeat compost application. The perceived maximum crop yield of 40 t ha^{-1} (Bartha 1983) is presented as a dashed line

In summary, the lessons gained from the yield and economic data on these crops were; (a) that certain crops are more responsive than others to improvements in soil quality, (b) it is important to work out which crops are responsive and which are not, (c) that it is important to plant responsive crops early in the cropping sequence following compost amendments in order to maximise yield benefits, especially if the responsive crops are high value crops, (d) that yield responses from responsive crops may be greater following repeat applications of compost than they were initially following the first application, possibly due to enhanced response by soil microbiology, as observed in the CROA experiment, and (e) that alternative vegetable production systems based on significant inputs of compost can be an economical alternative to conventional systems based on chicken manure and synthetic inorganic fertilizers.

7.3.2 Impact of Composts on Soil Quality

Soil quality includes the physical, chemical and biological properties of the soil which together influence soil function which is vital for sustainable agriculture. Improving soil quality is very important for maintaining and improving food production from agricultural land.

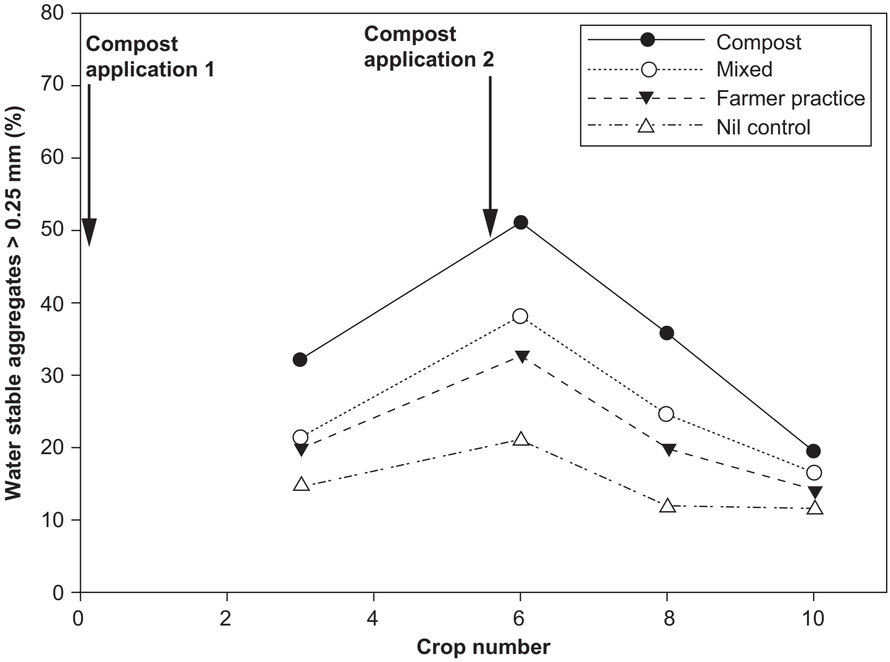

Fig. 7.9 The mean proportion of the soil as water stable aggregates >0.25 mm for each treatment over the cropping sequence at the CROA vegetable-compost field trial

7.3.2.1 Physical Soil Quality

Soil structural stability is important for maintaining pore spaces in the soil to help with soil drainage, aeration and crop root growth. The application of compost (and its associated organic matter) at a high rate was found to greatly improve the soil physical structure in the compost treatments of the field trial, resulting in a significantly ($p < 0.05$) higher proportion of the soil as water stable aggregates which was still evident in the third crop following the first application of compost (Chan et al. 2008). The second application of compost similarly improved the soil structure in the compost treatment soils relative to the farmer practice treatment soils (Figs. 7.9 and 7.10) where the compost treatment had more than 50 % of its mass present as water stable aggregates >0.25 mm. Kremer and Hezel (2013) in another field trial in Missouri also found that organic inputs including composted vegetative residues had similar benefits for soil structural stability, increasing soil water stable aggregates by up to 72 % compared to conventional farming systems.

However, the benefit of investigating soil structural stability over successive crops can be seen in Figs. 7.9 and 7.10 where it is apparent that the structural stability of the soil is gradually being degraded over time across all treatments including the compost treatment. By the tenth crop there was little difference in the structural stability of the soils across the treatments, and the structure of the soil across all

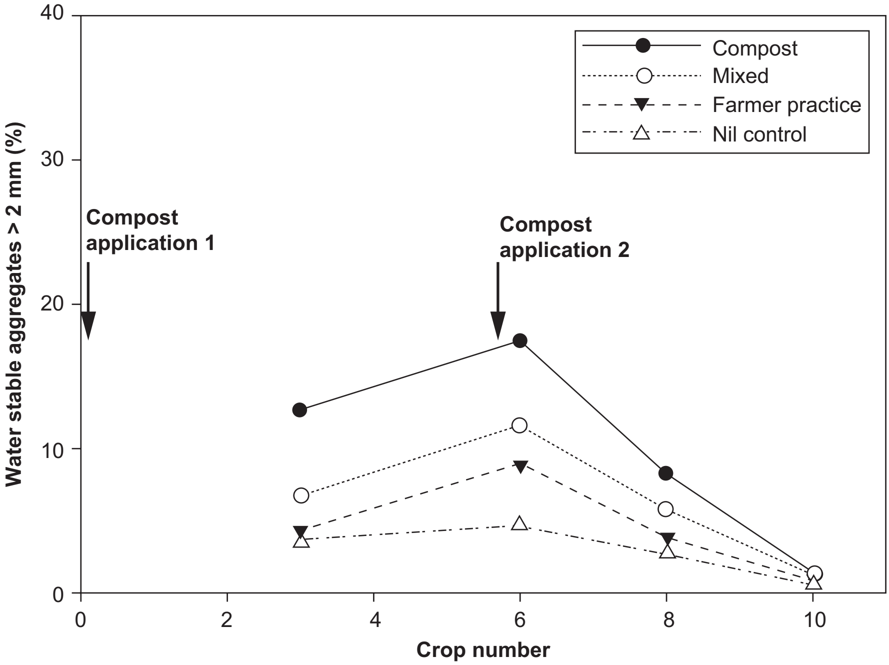

Fig. 7.10 The mean proportion of the soil as water stable aggregates >2 mm for each treatment over the cropping sequence at the CROA vegetable-compost field trial

treatments was degraded with less than 25 % of the soil as water stable aggregates >0.25 mm and less than 2 % of the soil as water stable aggregates >2 mm. This result largely reflects the influence of tillage on soil structure. The tillage in this study was done by rotary hoe which is a fairly aggressive tillage implement and is the standard practice for vegetable production in the Sydney basin. The results illustrate very well how the longevity of the benefits of the compost application to soil structure can be undermined by aggressive tillage which accelerates the breakdown of organic C and also physically pulverises the soil (Chan et al. 2007a, 2011a). It thus seems from these results that a minimum tillage regime may help extend the longevity of the benefits to soil quality that come from compost application.

Another soil physical property that is important to crop growth is soil strength or resistance to penetration, as it affects the ease with which roots can grow and explore the soil for nutrients and water. This property was measured to a depth of 45 cm in the experiment plots after the harvest of capsicum using a penetrometer (Rimik®) as described in Chan et al. (2006). The mean penetration resistance for each treatment in the experiment presented in Fig. 7.11 where the effect of the compost on soil strength is very apparent down the whole 45 cm profile for both the full compost (125 dry t ha^{-1}) and the mixed (62.5 dry t ha^{-1}) treatments. The compost applications reduced the penetration resistance of the soil, which has implications for effective root growth and crop access to nutrients and moisture in the soil. It is

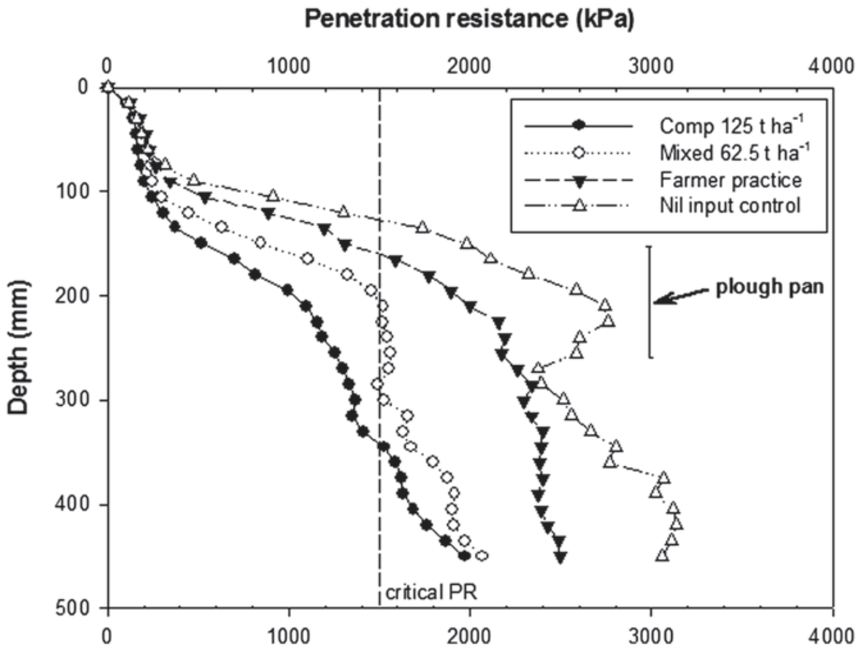

Fig. 7.11 Average penetration resistance (kPa) within the top 45 cm of the soil profile for each treatment

also apparent in, that a 'plough pan' or compaction layer is already present at 15 to 20 cm depth in the control treatment soil and appears to be starting to form in the farmers practice treatment soil at a similar depth. Absence of 'plough pan' formation in the compost treatment is thought to be a consequence of better drainage due to improvements in soil structure, which has resulted in a lower soil moisture content at plough depth, and as such less shearing stress and compaction of the soil at the plough depth during tillage operations.

7.3.2.2 Soil Chemistry

The application of blended cGO compost at high rates (125 dry t ha^{-1}) resulted in improvements to many key soil chemical properties generally associated with soil quality including cation exchange capacity (eCEC) important for nutrient storage, total organic C, plant available potassium (exch. K), exchangeable calcium (exch. Ca), plant available phosphorus, and pH, and many of these benefits persisted for several crops (Eldridge et al. 2014). The soil test results (0–15 cm depth) for the compost field trial treatments are presented in Table 7.3 for crops 1 and 4 and in Table 7.4 for crop 3. The main disadvantage of large applications of compost was a moderate increase in soil salinity in the short term immediately after application (Table 7.3). This means that crops sensitive to salt such as lettuce should be avoided

Table 7.3 Comparison of farming system means for key soil properties in crop 1 (broccoli) and crop 4 (capsicum). (Adapted from Eldridge et al. 2014)

Treatment	Total OC g 100 g^{-1}		eCEC[a] cmol (+) kg^{-1}		Exch. K cmol (+) kg^{-1}		Exch. Na cmol (+) kg^{-1}		pHca		EC dS m^{-1}	
	Crop 1	Crop 4	Crop 1	Crop 4	Crop 1	Crop 4	Crop 1	Crop 4	Crop 1	Crop 4	Crop 1	Crop 4
Farmer practice —low P	1.23c	1.43b	8.26b	11.49a	0.45c	0.85a	0.181c	0.403a	5.187c	5.387b	0.185bc	0.384a
Compost (125 t ha^{-1}) —low P	2.10a1	2.00a	11.81a	12.30a	1.18a	0.62b	0.439a	0.271b	5.725a	5.663a	0.388a	0.298a
Mixed (62.5 t ha^{-1}) —low P	1.59b	1.59b	9.47b	10.03b	0.73b	0.49b	0.283b	0.253b	5.475b	5.300b	0.259b	0.296a
Nil input control	1.13c	1.18c	7.01c	7.96c	0.29d	0.24c	0.118c	0.218b	5.175c	5.300b	0.130c	0.158b
l.s.d. ($p=0.05$)	0.20	0.166	0.95	1.16	0.15	0.12	0.075	0.069	0.134	0.109	0.088	0.091

[a] Different lower case letters down each column indicate a significant difference ($p=0.05$) in soil property means between treatments

Table 7.4 Soil quality (chemical) under the different treatments at the transplanting of crop 3 (cabbage). (Adapted from Chan et al. 2008)

Treatment	EC	pH	N	C	C/N	Exchangeable cations [cmol (+) kg^{-1}]				
	dS m-1	$CaCl_2$	g 100 g^{-1}	g 100 g^{-1}		Ca	K	Mg	Na	eCEC[a]
Farmer practice—low P	0.31	5.43	0.16	1.35	8.4	6.13	0.64	1.73	0.41	8.96
Compost (125 t $ha^{-}1$)—low P	0.17	5.88	0.20	2.03	10.2	7.78	0.65	2.00	0.23	10.69
Mixed (62.5 t $ha^{-}1$)—low P	0.22	5.30	0.18	1.68	9.3	6.83	0.41	1.56	0.23	9.01
Nil input control	0.15	5.33	0.14	1.20	8.6	5.65	0.24	1.43	0.23	7.55
l.s.d. (p=0.05)	0.11	0.17	0.04	0.26	–	0.81	0.17	0.38	0.09	1.27

[a] Effective cation exchange capacity

early in the cropping sequence after compost application (Eldridge et al. 2014). The field trial results also showed some soil carbon sequestration benefits from the compost treatments relative to the farmer practice for the Sydney basin, being 38.5% higher for the third crop (Chan et al. 2008). However, the benefits of compost in this regard, could be extended with the adoption of a minimum tillage approach, as rotary hoe tillage within the CROA experiment was relatively intensive.

7.3.2.3 Nutrient Cycling and the Environment

The experimental data from the CROA field trial also provides some valuable insights into the sustainability of both the current farmer practice and the other trial treatments in terms of the nutrient cycling for the important plant macro-nutrients NPK and associated environmental risk. A partial mass balance was determined for the phosphorus nutrient for each treatment in the experiment by Chan et al. (2010) and this is presented in Table 7.5. It is apparent in Table 7.5 that the farmer practice, compost and mixed treatments as farming systems, are all loading the soil up with P in excess to crop requirements, with only 6, 9, and 9% respectively being removed from each treatment in harvested crop produce. None of these systems are sustainable in the long term without adjustment, which in part reflects the problem of applying organic amendments at N fertilizer rates when they have N:P content ratios (see Table 7.1) that are much lower than the crop uptake N:P ratio. As such P can accumulate in the soil over time, eventually posing a risk to water quality and the environment. In some situations it might, therefore, be more appropriate to use crop P requirements and soil available P levels as the criteria for determining compost application rates.

An assessment of the relative environmental risk posed by the farmer practice and compost treatments was done by Chan et al. (2010) at the end of the first five vegetable crops by a simulated rainfall study and analyses of soil P and runoff water samples. It was found that the compost and mixed compost treatment soils had significantly lower levels of available P (Colwell and $CaCl_2$) and total P than the

Table 7.5 Phosphorus inputs (kg ha^{-1}) from inorganic fertilizer, poultry litter, and compost and removal of P (kg ha^{-1}) by the harvesting of vegetable crops for the different treatments for the first 5 vegetable crops in the field trial. Numbers in brackets are the removal of P by harvesting expressed as a % of total P inputs. (Adapted from Chan et al. 2010)

Treatment	Inorganic fertilizer	Poultry litter	Compost	Total inputs	Total removal by crops	Partial balance
kg ha^{-1}						
Farmers practice —low P	151.9	493.4	0.0	645.3	38.4 (6%)	607
Compost (125 t ha^{-1})—low P	0.0	0.0	487.5	487.5	43.4 (9%)	441
Mixed (62.5 t ha^{-1}) —low P	151.9	0.0	243.8	395.7	36.3 (9%)	359
Nil input control	0.0	0.0	0.0	0.0	11.9	−11.9

Table 7.6 Phosphorus levels in the soil and runoff water (rainfall simulations) from field trial treatment plots after the fifth vegetable crop. Within columns values followed by the same letter are not significantly different at $p = 0.05$; $^{**}p < 0.01$: $^{***}p < 0.001$. (Adapted from Chan et al. 2010)

Treatment	Soil Colwell P	Soil $CaCl_2$ P	Soil total P	Runoff total P	Runoff soluble P
	mg kg^{-1}			mg L^{-1}	
Farmers practice —low P	235b	17.6ab	800b	14.5ab	2.88c
Compost (125 t ha^{-1}) —low P	99c	3.2cd	600c	4.6c	0.53d
Mixed (62.5 t ha^{-1}) —low P	116c	3.5cd	500cd	10.4bc	0.82d
Nil input control	26d	0.5d	300d	4.1c	0.07e
Significance	***	***	***	**	***

farmer practice treatment, and that this translated into significantly lower levels of soluble P in the runoff water (Table 7.6). On this basis, Chan et al. (2010) concluded that replacing poultry manure with blended garden organics compost could pose less risk to water quality from vegetable production systems. But nevertheless, soil P levels can also build up over time with such large applications of blended garden organics compost (i.e., 125 dry t ha^{-1}), and this in the end becomes the environmental limit for this system when using low contaminant compost. It is also worth noting that the second compost applied in this experiment (Table 7.1) had almost double the amount of total and available P which was believed to be due to a higher proportion of poultry manure in the compost blend (i.e., around 20% instead of the 10% for compost 1), and this compost application resulted in a proportionally larger increase in soil P levels (Dougherty and Chan 2014). Thus, the soil P level results from the CROA experiment indicate that although such large applications of compost have great value in rejuvenating soil quality, environmental considerations suggest that their application at such rates should not be done on a continual basis, but rather as an occasional treatment to rejuvenate soil quality. Although, as with all farming systems, the soil nutrient levels and properties need to be monitored and adjustments made to inputs accordingly. The effect of a large initial application of compost followed by regular smaller targeted applications (e.g., along the plant lines in beds) should be explored further.

It is apparent from the level of exchangeable K in the compost treatment soil at the start of the first crop broccoli (Table 7.3) that the blended garden organics compost product supplied large reserves of available K to the soil raising it to 1.2 cmol (+) kg^{-1} soil from its original level of 0.29 cmol (+) kg^{-1} soil (Table 7.1). However, by the fourth crop of this experiment (Table 7.3), the substantial reserves of K that were present in the soil at the start of the experiment for the compost treatment were almost halved to 0.62 cmol (+) kg^{-1}. This loss of K reserves reflects the susceptibility of K to leaching when applied at large rates (Huang 2005). As such, it does raise the question of whether applying compost at such large rates is the most efficient way of using the nutrient reserves within the compost product, from a nutrient use efficiency perspective.

The field trial records suggest that the Evanylo and Sherony (2002) assumption of 10 % of the total N in compost being available for the first crop, provided a reasonable estimate of the plant available N (PAN) supply for the blended garden organics compost (i.e., composted blend of 90 % garden organics and 10 % chicken manure) used in this field trial, as evident in the petiole sap test results and crop monitoring for crop 1. In addition, the full compost and the incorporated crop 1 residues provided sufficient PAN supply for crop 2 as well, for the full compost treatment. For the repeat application of 125 dry t ha^{-1} of compost after the harvesting of crop 5, sufficient PAN was supplied for the first crop (i.e., crop 6 capsicum) only, with supplementary inorganic N (urea) required for all subsequent crops. However, it is worth noting that the compost treatments only received half the available N fertiliser that was applied to the farmer practice treatments (i.e., only the same amount of urea as the farmer practice treatments, but with no poultry manure N) and this represented an N fertiliser use efficiency gain in the compost treatment relative to farmer practice. This may have been due to improved N cycling by the soil microorganisms in the compost treatment soils. However, the PAN supply for this compost product was dependent on prompt incorporation of the compost immediately following delivery and spreading, so as to minimise N loss to the atmosphere via ammonia volatilisation. At some of our demonstration sites where the same product was used but was not immediately incorporated into the soil, supplementary inorganic N fertilizer was required for the first crop. Other demonstration trials using composts of predominantly garden organics (i.e., > 90 % garden organics green-waste), revealed significant N immobilisation in the soil (i.e., 'N drawdown') throughout the early crop phases and a real need for inorganic N fertilizer. For these composts it is best to assume negligible PAN supply and a need for supplementary inorganic N fertilizer. In contrast, studies have found that composts derived from largely vegetable food waste (e.g. source separated municipal solid waste compost) or animal manures (composted broiler litter) generally have been found to yield > 10 % of their total N as PAN for the first crop (Pratt and Castellanos 1981; Sims and Stehouwer 2008). This is generally correlated with their total N content and their C/N ratio which usually reflects differences in their molecular composition which influences their decomposition and N mineralisation (Eldridge et al. 2013). Given the difficulty in predicting the mineral N or PAN supply from composts, sound advice for compost use in agriculture and horticulture, would be to always monitor crop condition carefully, and be ready to apply supplementary inorganic N fertilizer when required. The use of inorganic N fertilizer strips (i.e., applying inorganic N fertiliser at the recommended rate to a small area of the field) is also highly recommended as a strategy for the early detection of 'N drawdown' or inadequate N supply symptoms in crops in fields receiving compost. This practice can allow an early response to crop N deficiency with inorganic N fertilizer applications and as such minimise the risk of 'N drawdown' impacts on crop yield.

7.3.2.4 Soil Microbiology

Basic soil biological properties were measured for each crop in the CROA field trial to examine the effect of the compost treatments compared to farmer practice and these included soil respiration, microbial biomass carbon, and the hydrolysis of fluoroscein diacetate (FDA). The results for the first seven crops are presented in Table 7.7 and Fig. 7.12.

Soil respiration in the compost treatment (see Table 7.7) was found to be significantly higher ($p<0.05$) than the farmer practice treatment for broccoli, the first crop following the initial application of 125 dry t ha^{-1} compost, but there were no significant differences found between the treatments for the soils of the subsequent four crops (Donovan et al. 2014). The soil respiration of the compost treatments was again found to be significantly higher than that of farmers practice in the capsicum crop (crop 6) which followed the repeat application of 125 dry t ha^{-1} compost, and this significant difference was still observed in the soil of crop 7 (broccoli). The elevated soil respiration most likely reflects the substantial increase in available carbon substrate for the soil micro-organisms to utilise, which results from such a large application rate.

Donovan et al. (2014) found no significant differences between the soil microbial biomass carbon levels of the compost and farmer practice treatments for any of the five crops following the first application of compost at the CROA field trial (Fig. 7.12). However, the second application of 125 dry t ha^{-1} compost did result in significantly higher ($p<0.05$) microbial biomass C levels for the compost treatment compared to the farmer practice treatment for crop 6 (capsicum) and crop 7 (broccoli) (Donovan et al. 2014). In fact the microbial biomass C levels in the soil of the compost treatment was found to be up to 100 % higher than that of the comparable farmer practice soil (Fig. 7.12). The FDA results in contrast found few significant ($p<0.05$) differences between the compost and farmer practice treatment soils (Donovan et al. 2014). The microbial biomass results from the second application of compost suggest some benefit in repeat applications of compost. The initial application may have had a priming effect on the biological community allowing it to be more responsive to subsequent later additions of compost applications.. There may be merit in following up an initial large application of compost to rejuvenate soil quality, with smaller more frequent applications of compost to provide sustained potential benefits to soil biology. Other studies (Kremer and Hezel 2013; Reeve et al. 2010) found that organically managed agricultural systems with high organic inputs significantly increased soil microbial activity. Kremer and Hezel (2013) also found that organic systems with high inputs of composted vegetable residues significantly increased ($p<0.05$) soil enzyme activity and soil function. The impact of compost amendments on soil function and the transformation of organic matter and the cycling of nutrients and carbon is certainly an area of research which requires more attention.

Table 7.7 Effect of compost application on basal soil respiration in 7 vegetable crops in soil samples collected at time of crop planting or harvest in a long-term vegetable field trial (means followed by the same letter are not significantly different). (Adapted from Donovan et al. 2014)

Mean soil respiration rates (µg CO2-C/g o.d.e[a] soil/h)

Treatment	1. Broccoli (Planting)	2. Eggplant (Planting)	3. Cabbage (Planting)	4. Capsicum (Planting)	5. Leek (Planting)	5. Leek (Harvest)	6. Capsicum (Planting)	6. Capsicum (Harvest)	7. Broccoli (Planting)
Farmer practice—low P	2.154 de	1.632 b	0.715 a	0.573 a	0.689 ab	0.964 a	0.7299 b	0.4332 cd	0.6341 cd
Compost (125 t $ha^{-}1$)—low P	4.549 a	1.762 ab	0.720 a	0.574 a	0.959 a	0.866 a	1.6683 a	0.7692 a	1.2166 a
Mixed (62.5 t $ha^{-}1$)—low P	3.492 bc	1.512 b	0.712 a	0.497 a	0.750 ab	0.827 a	0.6808 b	0.5298 bc	0.598 cd
Nil input control	1.598 e	1.264 c	0.568 a	0.286 b	0.668 b	0.587 a	0.4133 b	0.2608 d	0.3947 d
l.s.d. ($p=0.05$)	0.722	0.314	0.209	0.147	0.304	0.391	0.4881	0.2143	0.3210

[a] o.d.e = oven dry equivalent weight of fresh soil

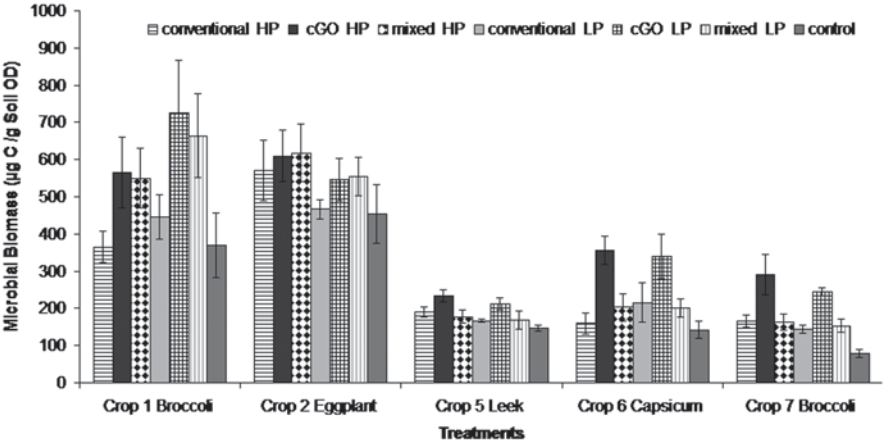

Fig. 7.12 Effect of compost application on microbial biomass carbon in soil samples collected at time of planting in a long-term vegetable field trial (data shown for 5 out of 7 crops grown, SE bars shown). (Adapted from Donovan et al. 2014). Conventional farmer practice treatment (inorganic fertilizer and poultry manure)

7.3.3 Contaminants Issue

The composts used in the long term compost–vegetable field trial at CROA were composts made from source separated garden organics waste (i.e., domestic grass clippings and pruning's) and chicken manure, and these composts met the Australian Standard (AS4454) for composts, which meant they were low contaminant composts. To protect food quality and human health, it is imperative that the composts that are applied to agricultural soils are low in chemical contaminants such as heavy metals and pesticides which can persist in the environment. Separating waste streams at the source (i.e., waste generation and collection point) and government regulation can help to achieve this. Composts made from non-source separated mixed municipal solid waste streams, should generally be avoided, as they often contain high levels of contaminants. However, the organic food scraps component of domestic municipal solid waste, if kept separate from other wastes at the household collection point and then all the way through to composting (i.e., to minimise contaminant levels), has great potential as an input for compost production.

7.4 Conclusions

It is apparent from the results of the field experiment at CROA, that the application of compost at large rates (i.e., >62 dry t ha^{-1}) can significantly improve a number of measures of soil quality (physical, chemical, and biological), and that such improvements can result in yield benefits for certain crops, with positive economic outcomes for farmers. Environmental benefits from incorporating compost inputs in vegetable productions systems were also noted. Vigorous tillage with rotary hoes was found to undermine some of these soil quality benefits by accelerating soil carbon losses.

The challenge is to further refine our use of composts in the farming systems to maximise the potential benefits. Combinations of compost applications with minimum tillage may help to further extend the soil quality benefits. More information on the yield response of the different crops in any given farming system to compost applications along with economic analyses, analysis can potentially help farmers to make decisions that will maximise financial outcomes and improve the environmental performance of their farms.

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