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Changes in Soil Properties and Carbon Content Following Compost Application: Results of On-farm Sampling

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A field survey was conducted to quantify the benefits of applying compost to agricultural soils in California. Soil samples were collected from farm sites with a history of compost use. Soils were analyzed for total organic carbon and nitrogen, Mehlich III extractable nutrients, bulk density, microbial activity (measured as CO_2 evolution), water infiltration rate and gravimetric water at 1 bar tension. Across all sites, compost application increased soil organic carbon by 3x in comparison to control soils. Significant changes were also observed in soil microbial activity (2.23 x control), gravimetric water (1.57 x control), and bulk density (0.87 x control). Nutrient availability in compost amended soils was similar to availability in conventionally managed soils. Infiltration times were significantly reduced in compost amended soils in comparison to control soils. High rates of compost application showed more significant benefits in comparison to low rates of compost application and control soils. At lower application rates, compost amended soils were statistically similar to controls for most variables. Increases in water holding capacity were significant in coarser textured soils in comparison to finer textured soils. Results from this sampling confirm results from replicated field trials on benefits associated with compost use in agricultural soils.

Introduction

In the emerging effort to reduce greenhouse gasses, landfill diversion of organics has primarily been recognized as a means to reduce methane emissions into the atmosphere (Brown *et al.* 2008; USEPA 2006, 2007a, 2007b, Pipatti *et al.* 2006, Clean Development Mechanism 2008; Chicago Climate Exchange 2009). However, there is a growing recognition of the indirect GHG benefits associated with using organic amendments on soils. These are based both on smaller, yet significant, GHG benefits as well as increased soil health in cases where organic amendments are regularly applied. A large number of studies have shown increased soil carbon concentrations when manures, composts or municipal biosolids are land applied (Aggelides *et al.* 2001; Albaladejo *et al.* 2008; Favoino and Hogg 2008; Izaurralde *et al.* 2001; Kong *et al.* 2005; Schroder *et al.* 2008; Smith *et al.* 2007). Increasing soil carbon is a cost-effective means to sequester carbon that provides a range of ancillary benefits. These potential benefits include increased water holding capacity, increased water infiltration rates, reduced bulk density, improved soil tilth (i.e., health and workability of soil), reduced erosion potential, decreased need for herbicides and pesticides, reduced fertilizer requirements, and improved yields and/or crop quality (eg. Cogger *et al.* 2008; Favoino and Hogg 2008; Izaurralde *et al.* 2001; Khaleel *et al.* 1981; Recycled Organics Unit 2006). In combination, these benefits can result in sustainable management of agricultural soils as well as increased profitability and competitiveness for agriculture.

The potential for expanded use of organic soil amendments is particularly pertinent for agriculture in California. Organic materials (leaves, grass, food scraps, etc,) comprise a significant category of recyclable wastes being disposed of in California landfills, despite an aggressive landfill diversion mandate. A statewide waste characterization study (California Integrated Waste Management Board 2004) identified that seven of the top ten materials disposed in California landfills were organic materials (many of which could be composted. Diverting organic materials from landfills is a key aspect of achieving and maintaining California's 50 percent recycling goal set by AB 939, the Integrated Waste Management Act (http://www.calrecycle.ca.gov/Laws/Legislation/calhist/1985to1989.htm). Diverted organics can be used as feedstocks for the production of compost for use as a soil amendment. Quantifying benefits associated with use of compost in agricultural soils is a key component to creating market demand for compost produced from landfill-diverted organics. Agriculture is a major industry in

California. California is the world's fifth largest supplier of foodstuffs. In 2006, sales of fruits, nuts, vegetables, melons, nursery and floriculture crops in California totaled over $20 billion (California Department of Agriculture 2006).

Prior research on changes in soil properties as a result of compost amendments has focused on data collected from replicated field trials. Benefits associated with compost use on working farms has not been widely demonstrated. A soil survey/sampling was conducted to quantify the benefits associated with compost use on working farms in California. The variables tested in the sampling included total soil organic carbon and nitrogen, available nutrients, bulk density, soil microbial activity, water holding capacity, water infiltration rate and soil texture. Using actual working field sites can lack the background scientific data and precision offered in replicated trials. Higher variability is also anticipated when working with actual farms in comparison to replicated field trials. However, working directly with farmers presents an opportunity to get a 'real world' view of current compost use and its' associated benefits in California across a wide range of sites, cultural practices, soils, and crops.

Materials and Methods

Site Selection

Sampling sites were identified collaboratively with compost producers in Riverside, Ventura, Kern, Stanislaus, and Monterey counties. Sites used in this study are representative of agricultural regions and types of crops where compost use is common (Table 1). Information on the different farming operations was garnered through discussions with the farmer and/or the compost supplier. For almost all cases, precise application histories were not available. Compost was applied on a wet weight basis and percent solids for each material applied wasn't known. A solids content of 50% was assumed to calculate dry application rates. For orchard crops compost was generally applied as a band under the trees. Here an application rate was estimated based on the width of the work row in comparison to the orchard crop. The crop row for all sites covered about 50% of the total land area. Generally, it was assumed that compost was applied to about 50% of the soil surface. Based on these assumptions, an application of 24 wet Mg ha was taken to be 12 dry Mg ha. Applied to 50% of the soil surface gives a total application to the treated area of 24 dry Mg ha. Reported rates throughout the remainder of the report represent dry loading rates. Total rates presented here should be considered as general approximations rather than precise loading figures.

A list of the properties visited with short descriptions of each site follows.

Site Descriptions

Riverside County

Two farms were sampled in Riverside County: Rucker and HMS Agricultural. Both are organic orchards and have a history of compost use. In this case the compost was commercially produced using both municipal green material as well as food processing wastes. The Rucker farm is located on a Myoma fine sand. Compost is applied under trees as a mulch. Compost is the sole source of fertilizer on the farm. Soil samples were collected from a grape and a lemon

TABLE 1.
Sample sites for soil collection. Farm, County, crop, tillage practice, soil series, compost application rate and cumulative compost loading for all farms sampled in this survey. Compost application rate and total application rates are approximate values based on the best recollection of the compost supplier and or the farmer. Composts were produced from a range of feedstocks including green waste, food scraps and soiled paper.

Farm	County	Crop	Till	Control	Soil Series	Compost Application Mg ha	Years of Application	Total Application dry Mg ha
Bruce Rucker	Riverside	Grapes, Lemons	no	on site	Myoma fine sand	24	10+	448
HMS	Riverside	Mango	no	on site	Cochella fine sand	18-24	5+	168
Limoneira	Ventura	Lemon	no	on site	Mocho clay loam	34	4-Mar	224
The Grapery	Kern	Grapes	no	on site	McFarland silty loam	6.72	15	100
Kochergan	Kings	Almonds	no	on site	Lethent clay loam	25	2	100
Grover	Stanislaus	Apricots	no	off site	Zacharias clay loam	9	5+	45
					Vernalis clay loam	Control		
T&A	Monterey	Row crop	yes	on site	Pico fine sandy loam	11.2	9	100
						5.7	10+	56

orchard with control samples collected from the work rows in each orchard. Compost had been applied to the site at 24 Mg ha for 10 years. HMS Agricultural is located on a Cochella fine sand soil. Compost had been applied for a minimum of 5 years under the trees with each application of approximately 18-24 dry Mg ha. A mixture of green and food waste compost and composted chicken manure was used to provide sufficient fertility to the site. The primary motivation for compost use at this site is to provide fertilizer to the trees. Secondary reasons for using compost include reduced water stress on trees, increased water holding capacity in soils and increased soil health. Control samples for this site were collected from the work row.

Ventura County

Soil samples were collected from a lemon orchard where compost had been applied as a mulch at 34 Mg ha for 3-4 years. Soil at the site was classified as a Mocho clay loam. Application was banded directly under the trees. The primary reason for compost application was to improve quality of the fruit. Control samples were collected directly under the trees of another lemon orchard on the same farm where synthetic fertilizers had been used on a similar soil series, Mocho loam.

Kern County

Soil samples were collected from a conventionally managed grape orchard. The farmer currently applies about 6.7 Mg ha of compost banded on the grapes as a mulch. Compost has been applied annually to the soil since 1991 with the exception of two years of missed applications. Compost is applied to improve fruit quality, to maintain healthy vines, and to reduce water and fertilizer use. Control samples from this site were collected from the work rows. The soil at this site was classified as a McFarland silty loam.

Kings County

Soil samples were collected from an almond orchard that was in the process of becoming certified organic. Compost had been surface applied to the soil (Lethent clay loam) under the trees in two previous applications of 22 dry Mg ha and a single application of 6.5 dry Mg ha over a 3 year period. Compost was applied to meet the fertilizer needs of the trees. Control soils were collected from the work rows.

Stanislaus County

Soil samples were collected from under the trees in an organic apricot orchard. Compost had been applied under the trees as a mulch to supply the nutrients for the fruit at a rate of 9 Mg ha for a minimum of 5 years. Soil at this site is classified as a Zacharias clay loam. Control samples were collected from another apricot orchard that was managed conventionally. The soil series for the control was a Vernalis clay loam

Monterey County

In Monterey County three sites were sampled from high production, tilled row crop farms. One of these fields was certified organic and compost had been applied at 11 dry Mg ha for 9+ years. The other was managed conventionally and had had compost applied at 5.6 dry Mg ha for 10+ years. The control soils for this series were sampled from a neighboring field that was also used for row crop production, was managed conventionally, and was the same soil series, Pico fine sandy loam. Crops had just been harvested from all three sampling sites.

Soil Sample Collection

Soil samples were collected as follows. For total carbon and nitrogen analysis, soil cores were collected at the 0-15 cm and 15-30 cm depths. A minimum of 4 cores, collected from random locations, were composited for each sample. Available nutrients (Cu, Fe, Mn, Mg, P, and Zn) were also measured on the 0-15 cm samples collected for total carbon and nitrogen analysis. Bulk density samples were collected using a hammer-driven core sampler that collected a 3 cm deep x 5.4 cm core (Grossman and Reinsch 2002). One bulk density core was collected from each sampling site. For each location two to three bulk density measures were averaged to produce a mean value for each treatment. Water infiltration was measured using a single ring falling-head procedure (Soil Quality Institute, 1999). Infiltration rates were measured 2 times per sampling site. The second measure was used for all sites for analysis, as by the second measure, both irrigated and control soils had reached similar saturation levels. Water holding capacity and soil microbial function were measured on intact cores collected using a 15 cm long x 5 cm diameter pipe section that was hammer driven into the soil. As with the other measures, 2-3 intact cores were collected and analyzed for each compost amended or control site.

Complete sets of soil samples (paired topsoil and subsoil) were collected from three separate locations in compost amended soils with two to three complete sets of samples collected from control areas at each site. Compost samples were collected from soils directly under the crops for orchard sites and randomly within the treated areas for row crops. Control samples were collected either from the work row of the compost amended sites or from nearby orchards (Deurer *et al.* 2008).

Soil Analysis

All soil analysis was conducted by Soil Control Labs in Watsonville, California. Total carbon and nitrogen were measured by combustion. Intact samples were analyzed for total carbon. Acid was then added to the soil to volatilize any carbon associated with carbonates. The remaining soil was re-analyzed. The % carbon in the second combustion was taken as the organic carbon content of the soil. Available nutrients were analyzed using the Mehlich III extract (Mehlich 1984). Bulk density was measured as the weight of oven dry soils per known volume. Soil water holding capacity was measured at 1 bar soil moisture tension on intact cores. Soil microbial activity (as CO_2 evolution) was measured as follows: a soil core maintained at 1 bar moisture tension was incubated at 27°C for 48 hours. The soil core was then placed in a 1 liter jar and incubated for 24 hours. CO_2 evolved after 24 hours was measured using an IR detector.

Data Analysis

Data was analyzed using SPSS version 16 (SPSS 2005). Statistics for all main effects were compared using analysis of variance (Anova) with $p < 0.05$. Means were separated using the Duncan Waller procedure following a significant ANOVA. Variables measured included soil organic carbon, bulk density, microbial activity, water holding capacity, total nitrogen, water infiltration rate, and Mehlich III extractable nutrients. The significance of each of these variables as a function of treatment, site and treatment x site were examined. Site, treatment and treatment x site were generally significant at $p < 0.05$. In order to be able to assess the effect of treatment across all sites, the data was transformed to create a more normal distribution. A ratio variable was created that measured the response of each parameter at a site in the treated soils to the average value of that parameter in the control samples for that site (Brown *et al.* 2004). Use of the ratio variables enabled comparison of response to compost addition across a wide range of soil series. Ratio variables were used for organic carbon, bulk density, soil microbial activity, and water holding capacity.

Results

Summary Results – Across All Sites

Nutrient Availability

In addition to adding carbon to soils, compost contains a range of macro and micro- nutrients.

When used to meet the nitrogen needs of a crop, compost will also potentially satisfy at least a portion of plant requirements for phosphorus (P), zinc (Zn), iron (Fe), copper (Cu), manganese (Mn) and potassium (K). For nutrient availability, compost would be expected to increase nutrient content in amended soils comparison to samples taken from the non-amended work row. For samples where the control was collected from other orchards or managed soils, nutrients in the compost- amended soils would be expected to be similar to the control sites that would have received synthetic fertilizers. For this sampling, in cases where control samples were collected from other orchards or managed fields, available Fe, Mg, Mn, P, and Zn concentrations were statistically similar in compost amended and control sites (Table 2). There was a tendency for increased availability of Mn, P and Zn in the compost amended soils in comparison to the control but this was not statistically significant. There was also a tendency for higher

TABLE 2.
Mehlich III available nutrient concentrations (mg kg^{-1}) for compost and control soils.
Means ± standard error are shown. Within column pairs, values in bold with an * are significantly different (p<0.05).
For work row/same soil series, n=40, for other orchard/soil series n=10.

	Iron		Potassium		Magnesium		Copper		Manganese		Phosphorus		Zinc	
	mg kg													
	Control from other orchard/soil series													
Compost	243	±38.9	583*	±199	1560	±428	46.5*	±7.29	276	±135	104	±64	33.9	±23.3
Control	332	±101	276*	±104	1500	±508	25.3*	±4.5	206	±91	52	±14	9.2	±1.4
	Control from work row/same soil series													
Compost	423*	±124	636	±477	984*	±393	18	±24	163*	±36	409*	±222	46*	±41
Control	334*	±146	596	±520	736*	±305	7.1	±9.8	120*	±53	186*	±100	13*	±9.7

available Fe in the control soils, but again, this was not significant at $p<0.05$. Available K and Cu were increased in the compost-amended soils in comparison to the control.

For cases where the control sample was collected from the work row, compost amendment increased available nutrient concentration for Fe, Mg, Mn, P and Zn in comparison to the control soils. The mean value of extractable K and Cu were also higher in the compost amended soils, however, samples showed high variability and so these increases were not statistically significant. These results suggest that compost amended soils contain comparable concentrations of plant available nutrients to conventionally fertilized soils and elevated concentrations of nutrients in comparison to control soils. It should be noted that appropriate extracts to determine available nutrients will vary by crop and soil series. This extract was used to provide a general measure of nutrient availability rather than to provide crop or farm specific nutrient evaluations.

Soil Nitrogen

Across all compost amended sites where the control was taken from the work row, compost application increased total nitrogen in the 0-15 cm horizon of the soil in comparison to the control. Total N increased from 0.1±0.02% in the work row soils to 0.21±0.03% in the compost amended soils. There was no difference in total N in the compost amended soils (0.095%) in comparison to the control soils (0.094%) when the control sample was taken from another farm with a different soil series. There were also no significant differences in total soil N for the compost-amended soils in comparison to either type of control at the 15-30 cm depth. As a portion of the compost amended soils that were sampled were on conventionally managed farms, there is a potential for a fraction of the total N in the soils to originate from synthetic fertilizers. To correct for this, total N in organic managed farms was compared to total N in conventionally managed farms. This comparison tests for the N contribution from compost alone versus N from synthetic fertilizers. Here also, the increase in soil nitrogen was significant in the compost amended compared to the control soils.

Soil Carbon

Across all cases where the control samples were collected from the same soil series as the compost amended soils, the ratio variable showed significantly increased soil organic carbon ($p < 0.0001$)(Figure 1). Mean organic carbon in the compost amended soils measured 3 times that in the control soils. This difference was in the surface 0-15 cm soil horizon. There

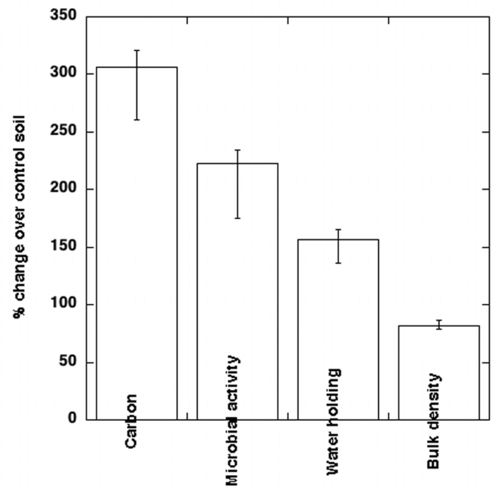

FIGURE 1. The ratio of soil organic carbon, microbial activity, water holding capacity and bulk density in compost amended soils in comparison to control soils (control soils taken from work row or other crop area with the same soil series). A value > 1 shows a positive response to compost addition, while a value < 1 shows a negative response or decrease in response to compost addition (in the case of bulk density, a decrease is an improvement).

was no significant difference in organic soil carbon in the 15-30 cm soil depth. Across all sites, the average % C in the 0-15 cm depth for both compost amended and control soils was 1.5± 1.2. In the 15-30 cm depth the average % C was 0.49 ± 0.33%.

Soil Microbial Activity

Compost application also increased microbial activity ($p < 0.009$) in comparison to the control soils. Microbial activity was 2.23 times greater in the compost-amended soils in comparison to the control soil (Figure 1). The organic matter in compost provides food for microorganisms. All of the work rows that were sampled had a grass cover crop or organic mulch that would also have provided a substrate for microbial growth. It is likely that control soils with no plant cover or mulch would have had even lower microbial activity in comparison to the compost- amended soils.

Water Holding and Bulk Density

Increased water holding capacity ($p < 0.01$) as well as decreased bulk density ($p < 0.004$) were also observed in the compost- amended soils (Figure 1). Water holding capacity was 1.57 x that of the control soils and bulk density was 0.82 times the control soils. Results and standard errors for each variable are shown below (Figure 2).

It should be noted that site was also significant for each of these variables as was the site x treatment interaction. This means that the response to compost addition varied by site. Because of the wide range of sites, soil series and application rates included in this sampling, this interaction would be expected.

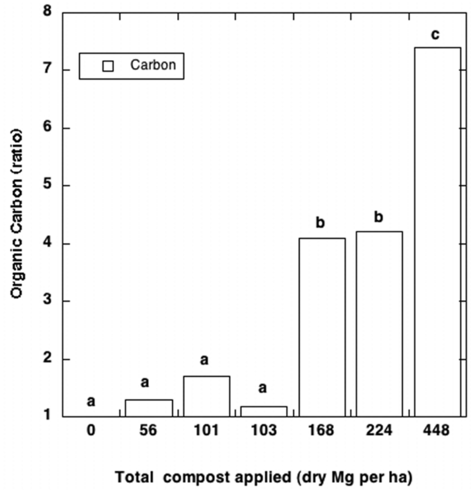

FIGURE 2. Total organic carbon in the 0-15 cm soil horizon as a function of total compost applied. Rates with the same letter are statistically similar ($p<0.05$).

Results – Effect of Rate for Compost

The effect of compost application rate on each of these variables was also examined. Here the results are less clear, however there is a strong tendency towards more pronounced differences with higher application rates of compost. In addition to application rate, other factors such as soil texture will influence measured variables (Brady and Weil 2002; Khaleel *et al.* 1981:Rawles *et al.* 2003). Because this study is focused on working farms, the sampled sites do not allow direct comparisons of the interaction between compost application rate and other soil factors for the measured variables. It is likely that if there had been more control of other factors including soil type that a more linear response to increased compost application rate would have been observed. It is likely that in a controlled study with multiple application rates over time at a single site, the effect of rate would be more pronounced and it would be possible to distinguish differences between rates in a more predictable manner.

Carbon Related Variables

Total Carbon

Significant increases in soil carbon were only observed in sites with high cumulative loading rates of compost (Figure 2). There was a slight but not statistically significant increase in carbon in the soil that had received a cumulative loading of 56 dry Mg ha. This trend was more pronounced for the two locations where a total of 101 Mg ha of compost had been applied. The sites that had the highest rates of compost application showed the most significant increases in soil carbon. At low cumulative loading rates, there was no significant increase in soil carbon concentrations as a result of compost addition. Previous studies have shown increases in soil carbon at higher amendment loading rates. Albaladejo et al (2008) observed a doubling of soil carbon concentrations following application of 260 Mg ha of uncomposted organic municipal solid waste. In another study, two types of compost were applied to vineyards over a 16 year period (Morlat and Chausson 2008). After a cumulative loading rate of 256-320 Mg ha of compost, carbon concentrations in the control soil had doubled in the surface horizon. Carbon concentrations in the subsoil also increased in the compost amended treatments beginning at year 16 of sampling. The observed increase in soil carbon at higher compost loading rates in this study were greater than those reported in previous studies.

It should be noted that increases in soil carbon were visible on all sites where compost had been surface applied. However, soil analysis only showed statistically significant increases in total soil carbon for sites that had received higher loading rates, with no significant increases in total carbon for sites that had received lower cumulative loading rates of compost. These results may be due in part to how soil samples were collected. For this study, surface soil samples were defined as the top 15 cm of the soil. A dark surface horizon was visible on all sites that had received mulch compost amendments in comparison to the control sites. Increases in total carbon in the top portion of the soil may have been diluted by mixing the surface 15 cm of the soil for analysis.

Bulk Density

Soil bulk density followed a predictable pattern with decreased bulk density at increasing rates of compost application (Figure 3). Soil bulk density is a measure of weight per unit area, normally expressed as g cm^3. Low bulk density indicates increased pore space and is indicative of improved soil tilth. Previous studies have consistently shown that adding organic matter to soils reduces bulk density (Khaleel *et al.* 1981, Aggelides & Londra 1999, Pengcheng *et al.* 2007, Price & Voroney 2007, Evanylo *et al.* 2008, Ozenc & Ozenc 2008, Curtis & Claassen 2009). Organic amendments also improve soil bulk density by aggregating soil mineral particles. As the added organic matter is decomposed, exudates are formed that are able to increase soil aggregation (Six *et al.* 2004). In addition, the organic fraction is much lighter in weight than the mineral fraction in soils. Increases in the organic fraction decrease the total weight and bulk density of the soil.

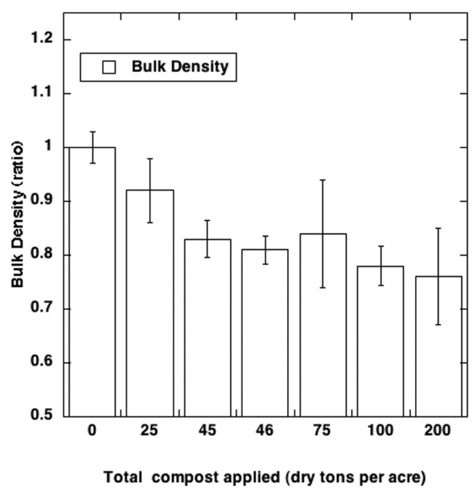

FIGURE 3. Soil bulk density in compost amended soils (ratio of observed values in amended soils in comparison to the control soils). Means and standard error are shown. Values <1 indicate reduced bulk density in comparison to the control soils.

Soil Respiration

Soil respiration significantly increased ($p<0.05$) in the soils that received total cumulative compost applications of 168 and 224 Mg ha (Figure 4). There was no significant increase in respiration at the lower cumulative loading rates. At the highest loading rate in this sampling, high variability resulted in the mean respiration being statistically similar to the control soil despite a mean value for respiration double the control. It would be expected that compost application would increase soil microbial activity as the organic matter in compost provides a food source for soil microorganisms. Other studies have shown increases in respiration rates following organic amendment addition (Brown *et al.* 2005; Flavel and Murphy 2006). Flavel and Murphy (2006) measured CO_2 production from compost-amended soils over a 150 day lab incubation. For most of the composts tested, the rate of CO_2 evolution decreased over time. The results from the current study may reflect the time elapsed between compost addition and sample collection. However, for the highest rates of compost application, there was a general trend towards increased microbial activity in comparison to the control soils.

Soil Water

The amount of water that is available to a plant will depend on two factors: the quantity of water that is able to infiltrate into the soil and the quantity of water that the soil is able to hold onto. For this study infiltration rate was used as a measure of soil permeability and gravimetric water content at 1 bar tension was used as a measure of the soil's ability to hold onto water. Soil texture is the primary factor affecting the quantity of water at each of these soil moisture tensions (Khaleel *et al.* 1981; Rawles *et al.* 2003). Clay soils, due to higher matric potential and smaller pore size will generally hold significantly more water by weight than sandy soils. The most pronounced increases in soil water holding capacity were in the sites that received 168 and 448 Mg ha cumulative application (Figure 5). These were also the soils with the coarsest texture of the soils sampled in the study. The soil texture for both of these soils was loamy sand whereas the texture for the site that had received 224 Mg ha was silty loam. The sites with lower application rates ranged in texture from sandy loam to silty loam.

A stepwise regression was carried out to determine the primary factors that affected water holding

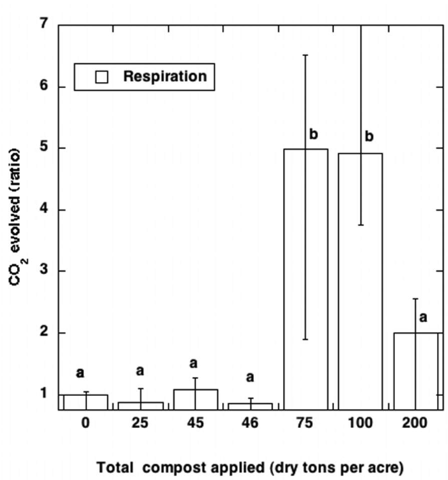

FIGURE 4. Soil respiration (CO_2 evolved) used as an indicator of soil microbial activity. The ratio of CO_2 in the compost-amended soils to that evolved in the control soil can be used as a measure of increase or decrease in microbial activity in relation to compost amendment.

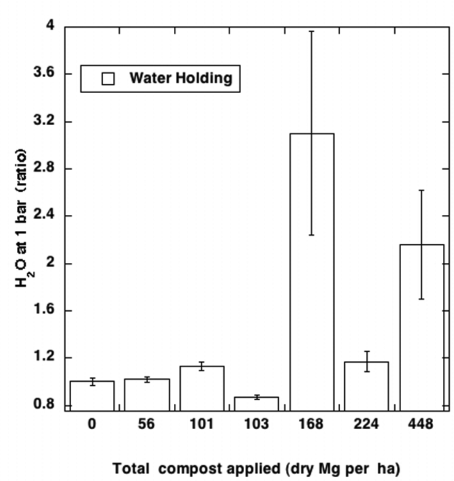

FIGURE 5. Water holding capacity in compost amended soils in comparison to the control soils. Quantity of soil water at 1 bar pressure was used to determine the water holding capacity. The ratio of water in comparison to the control soil is shown.

capacity for this study. This type of regression adds and removes variables from the analysis based on their ability to explain significant quantities of the variation in the data. For this analysis the probability was set for 0.05. The regression was carried out twice, once using the actual values for water content at a particular volume of soil and the second time using the ratio variable for water. The variables entered into the model for the initial run included soil texture, bulk density, total compost applied, and organic carbon content. For the second run of the model the variables included soil texture, the ratio variables for carbon and bulk density, and total compost applied. The ratio variable for water holding capacity was used as the dependent variable.

For the first run, the significant factors in determining water holding capacity were soil texture (model R^2= 0.36), bulk density (model R^2= 0.556) and organic carbon (model R^2= 0.59). The values in the parenthesis represent the cumulative adjusted R^2 value of the model. For the second run of the model using the ratio variables in an attempt to normalize the data across sites, the significant factors were total compost applied (model R^2= 0.26) and bulk density (model R^2= 0.34) with a model R^2 of 0.34. These results indicate that while overall, texture is the primary factor affecting water holding capacity, increasing organic carbon is a significant factor for improving soil water holding capacity. Using the ratio variables to eliminate the influence of variation as a result of soil texture, compost loading rate was the most significant factor effecting water holding capacity. These results suggest that compost application will have the greatest effect on soil water holding capacity on coarser textured soils with smaller to no change in water holding capacity on finer textured soils.

Water infiltration rate was also measured. Across all soils, compost addition increased water infiltration rate compared to the control soil (Figure 6). Increased infiltration is another indication of increased efficiency in water use as a higher fraction of irrigation or rainfall is likely to enter soils with higher infiltration rates. More rapid infiltration is associated with reduced runoff, better aeration, and improved irrigation efficiency. As with water holding capacity, soil texture will have a significant effect on infiltration rate. However, unlike water holding capacity, the largest improvements would be expected in fine textured soils that tend to be poorly drained. Because of this, soil texture is a significant factor in infiltration rate. In this study, the largest improvements in water holding capacity were seen in the coarse textured or sandy soils. The largest improvements in water infiltration rate were observed in the finer textured soils. For example,

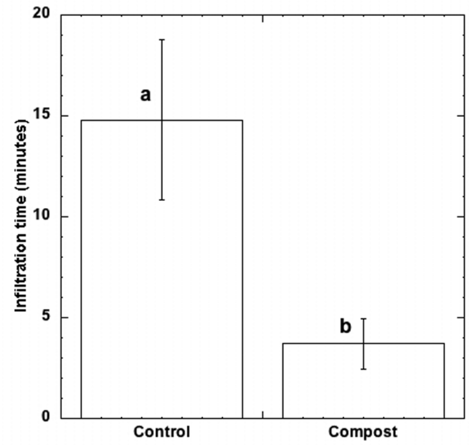

Figure 6. Water infiltration (minutes) for all compost amended and control soils with the same soil series. Means and standard errors are presented. Different letters above each mean indicate that the values are significantly different ($p < 0.05$).

at the site in Monterey County, infiltration rate in the control averaged 17.5 minutes. In the compost-amended soils, this time was reduced to < 1 minute. This site was tilled, discounting the potential for work row compaction to be a factor. Texture in this soil was a silty loam. However, in the coarser textured soils there were no significant differences in infiltration rates as a result of compost amendment.

Conclusions

In our limited field sampling we saw a range of improvements in soil quality as a result of compost application. Using a response variable to normalize across sites, improvements were seen in total carbon, reduced bulk density, increased microbial activity, total nitrogen (in comparison to control soils), water holding capacity, and water infiltration rate. Plant available nutrients in compost amended soils were generally similar to conventionally managed soils. Looking at the effect of compost application rate, the largest response to compost amendment were seen at the sites that received the highest cumulative loading rates. Sites with lower loading rates generally showed no significant response to measured variables. It is possible that the lack of significant response at the lower loading rates was a result of analyzing the top 15 cm of soil. For the majority of sites included in this sampling, compost was surface applied. Significant differences may have been observed at the lower loading rates if the surface soil had been further divided into 7.5 cm increments.

Due to the variety of soils, topography, rainfall frequency and intensity, and types of compost use, response per dry ton of compost applied will vary across the state. However, our study showed consistently better responses with increased compost applications over time. The results from our sampling suggest that consistent use of compost over time will improve soil health. Water savings are also most likely to be observed in coarser textured, well-drained soils. In addition to agricultural use, which was the focus of our survey, similar benefits would be expected for compost use in landscaping, restoration, urban areas, and on greenscapes adjoining roads (McDonald 2005).

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