Soil quality and vegetable growth as affected by organic amendments to a tropical Oxisol during transition to organic farming

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Abstract
Changes in soil properties and vegetable growth were quantified during the transition from conventional to organic farming. Four treatments (2 composts, urea and control) were applied to an Oxisol in Hawaii. Two crops, Chinese cabbage and eggplant were grown sequentially as test crops. Hot-water soluble carbon, dehydrogenase activity and CEC were increased by compost amendments. CO_2 respiration rate did not correlate with the soil amendments. Nitrogen nutrition was the main factor that improved growth and carotenoid content in cabbage. The urea treatment promoted better growth of cabbage, while compost was effective for eggplant, suggesting N from organic inputs requires time to mineralize and to become available to crops.

Key Words
Compost, soil quality, hot-water soluble C, cabbage, eggplant

Introduction
During the transition from conventional to organic farming, N availability may decrease due to a shift in biological activities and N sources could not be immediately available for plant use (Petersen *et al*. 1999). Consequently, crop yields may be lower than those under conventional practices (Mäder *et al.* 2002). Predictably, total soil N would increase with organic amendments, but extractable P and exchangeable K often increased as well (Bhat and Sujatha 2006). Perhaps because of improved soil quality, organically grown crops often contain more vitamins (especially vitamin C), phenolic compounds, and carotenoids than conventionally grown crops (Adam 2001; Rembialkowska 2004). Being in the Tropics, Hawaii's soils are dominantly Oxisols and Ultisols, which are inherently low in plant nutrients. Furthermore, past sugarcane and pineapple cultural practices used large amounts of synthetic N fertilizers, which acidify the soil, decrease effective CEC and basic nutrients (Ca, Mg, K) (Hue *et al*. 2007; Hue 2008). Given such potentially poor growing conditions, tropical soils would be fittingly suitable for evaluating the effects, if any, of organic amendments on soil and crop responses. Thus, this study was conducted to quantify changes in properties of an Oxisol in Hawaii, where vegetables might be grown organically.

Methods
Site location, soil and amendment properties
The trial was conducted on an Oxisol (Rhodic Haplustox, clayey, kaolinitic, isohyperthermic, Wahiawa Series) located at the Poamoho Experiment Station (21°32'11" N – 157°56'24" W) of the University of Hawaii. The site receives approximately 1000 mm of annual mean precipitation, and is situated 265 m above sea level. The mean temperatures are: 27 °C in summer (May-September) and 21 °C in winter (October – April). In the unamended state, the soil has a bulk density of 1.12 Mg/m^3, a cation exchange capacity (CEC) of 11 cmol$_c$/kg as extracted with 1 *M* ammonium acetate, pH 7.0, a soil pH (1:1 in water) of 5.5, 2.2% total organic carbon and 0.2 % total N.

Four treatments were applied and incorporated into the soil to a depth of approximately 15 cm: (1) control (only plowing), (2) urea at 0.50 Mg/ha providing 140 mg N/kg, (3) a redwood- based commercial compost (Rwd compost) having 0.34% N fortified with a composted chicken manure (2.1% N) (total amount of the Rwd compost used was 17 Mg/ha), (4) a University of Hawaii compost (UH compost, 1.0% N) made of grass clippings and tree trimmings, lime and phosphate rock, fortified with the same composted chicken manure (total amount of the UH compost used was 13 Mg/ha). Both treatments (3) and (4) provided approximately 140 mg/kg total N. The plot size was 5 m x 10 m and drip irrigation was used. The experiment had a randomized complete block design with 3 replications per treatment.

Two weeks after treatment and irrigation applications, tomatoes (*Lycopersicon esculentum*) were planted. However, weeds, especially Guinea grass (*Panicum maximum*) became a serious problem, crowding out tomato seedlings, yielding poor stands. For this reason, the tomato crop was removed, and weeds were mechanically mowed. Subsequently, sunnhemp (*Crotalaria juncea* cv. Tropic Sun) was planted to all plots for 5 weeks, thereafter was plowed under as a green manure. A week later, black plastic sheets were placed on the surface of all plots to control weeds; and Bok Choi cabbage (*Brassica rapa* Chinensis group) were planted. Insects were controlled by periodically spraying with a commercial *Bacillus thuringiensis* (Bt)-derived biocide or with neem (*Azadirachta indica*) oil. The cabbage was harvested 6 weeks later. The soil was then idled for 4 weeks, before eggplant (*Solanum melongena*) was transplanted and grown for 7 weeks as a second crop.

Sampling and chemical analysis

The soil samples were collected after cabbage harvest from all 12 plots by mixing 3 or 4 small cores (1-15 cm depth) taken within each plot. The samples were air dried and screened to pass a 2-mm sieve. Soil pH was measure in 1:1 (soil: water by weight). Mehlich-3 extractable nutrients were measured with an inductively couple plasma spectrometer (AtomScan-16 ICP, Thermo Jarrell-Ash/Fisher Scientific,Waltham, MA), (Mehlich, 1982). Total C and N in soil samples and N in plant samples were measured by dry combustion using a LECO CN-2000 analyzer (Leco Corp., St. Joseph, MI). Other nutrients in plant samples were measured using ICP (Hue *et al*. 2000). Cation exchange capacity was measured as proposed by Sumner and Miller (1996); dehydrogenase activity was measured as proposed by Tabatabai (1982); hot-water soluble carbon was measured by the Mn-pyrophosphate complex method proposed by Bartlett and Ross (1988); total carotenoids in leaves were measured as proposed by Gross, 1991; and soil CO_2 measurement was measured by incubation as described by Zibilske (1994).

All samples were analyzed in triplicate and standard errors were determined. Analysis of Variance was performed to establish the significance ($P < 0.05$) and LSD was used to compare treatment means. Statistical software used was either SAS 9.1 or WinStat (an add-in to MS Excel).

Results

Amendment effects on soil properties

Adding compost or urea to this Oxisol certainly altered many soil properties, especially those representing soil biological and chemical characteristics (Table 1).

Table 1. Soil quality as measured by hot-water soluble C, dehydrogenase activity, CO_2 production, total C, N, and C/N ratio as affected by the additions of urea or composts to an Oxisol of Hawaii.

Treatment	Hot-water C mg/kg	Dehydrogenase mg TPF/kg	CEC $cmol_c$/kg	Total C %	Total N	C/N	CO_2 mg/g/day
Control	180 b	146 b	12.6 b	2.29 b	0.22 b	10.4	0.89 a
Urea	211 b	139 b	11.9 b	2.38 b	0.27 a	8.8	0.93 a
Rwd compost	385 a	192 a	13.7 a	2.82 a	0.26 a	10.8	0.90 a
UH compost	371 a	172 ab	13.9 a	2.27 b	0.22 b	10.3	0.72 b
LSD	129	34	0.84	0.36	0.038	---	0.14

LSD = least significant difference; different letters following numbers within a column indicate differences ($P < 0.05$).

For example, hot-water soluble carbon, increased from 180 mg C/kg in the control to 385 mg C/kg in the Rwd compost. Concentrations of dehydrogenase enzyme activity also increased significantly with the compost treatments and correlated positively with soluble C (Table 2). In contrast, CO_2 production, which ranged from 0.72 to 0.93 mg/g soil/day did not correlate well with any treatments (i.e., compost vs. urea) nor with biological activities. Total organic carbon, ranging from 2.27% to 2.82%, also was not a good indicator of the soil amendments: only the Rwd compost showed a slight increase (Table 1). Total C/N ratio also did not change with the organic inputs, averaging 10.5, but dropped slightly to 8.8 with the addition of urea. Cation exchange capacity (CEC), increased significantly with the additions of compost, being the highest (13.9 $cmol_c$/kg) in the UH compost and lowest in the urea treatment. Regarding soil nutrients that may affect plant growth in the short term, soil test data show that the UH compost significantly increased pH, P, Ca and K (Table 3). Such nutritional enhancements, however, were probably due to the quality of the amendment because the UH compost had lime ($CaCO_3$) and phosphate rock added during its preparation. The addition of the Rwd compost also slightly increased extractable P, K and Fe relative to the control (Table 3). In general, the soil seemed to be marginal (pH 5.5, 30 mg/kg P and 1280 mg/kg Ca as extracted by the Mehlich-3 solution) for crop production, especially vegetables, based on the interpretations for Hawaii soils (Yost *et al*. 2000; Hue and Fox 2009).

Table 2. Correlation among soil-quality indicators after additions of urea or composts to an Oxisol of Hawaii.

Treatment	Hot-water C	Dehydrogenase	CO_2	Total C	CEC
Hot-water C	1	0.93*	-0.54 ns	0.53 ns	0.90*
Dehydrogenase activity	0.93*	1	-0.33 ns	0.71 ns	0.89*
CO_2	-0.54 ns	-0.33 ns	1	0.41 ns	0.70 ns
Total C	0.53 ns	0.71 ns	0.41 ns	1	0.33 ns
CEC	0.90*	0.89*	-0.70 ns	0.33 ns	1

* Significant at $P < 0.05$; ns = non significant.

Soil amendment effects on vegetable growth and leaf nutrients

As a consequence of insect damage, we had to combine all 3 replications of cabbage together to obtain some estimated yields, which ranged from 3.50 Mg/ha in the UH compost treatment to 8.50 Mg/ha in the Rwd compost treatment, with an overall average of 5.68 Mg/ha. On the other hand, nutrient analysis of cabbage leaves shows differences among the treatments (Table 4). Cabbage grown in the two compost treatments had 3.01 and 3.20% N. Interestingly, total carotenoids in cabbage leaves were highest in the urea treatment (125 µg/g), followed by the UH compost (90 µg/g) and lowest in the control (62 µg/g). Perhaps, good N nutrition yielded good growth, which in turn provided higher levels of carotenoids.

Table 3. Soil properties as measured by pH, EC, Mehlich-3 extractable nutrients as affected by additions of urea or composts to an Oxisol of Hawaii.

Treatment	pH	EC	P	Ca	Mg	K	Fe	Mn	Zn
		dS/m	←-----	-----	-----	-----mg/kg	-----	-----	-----→
Control	5.51	0.23	37	1278	221	190	53	596	18
Std. Err.	0.06	0.02	13	51	30	33	6	40	1.3
Urea	5.74	0.94	30	1806	303	213	44	637	20
Std. Err.	0.11	0.14	10	340	27	28	4	24	5.0
Rwd compost	5.80	0.29	53	1434	264	279	60	593	18
Std. Err.	0.05	0.05	18	245	24	38	6	58	2.1
UH compost	6.23	0.68	200	3718	410	518	44	565	25
Std. Err.	0.19	0.00	19	123	41	75	4	26	3.3

pH and electrical conductivity (EC) were measured in 1:1 soil:water.

Table 4. Total carotenoids and leaf nutrients in Chinese cabbage (*Brassica rapa*, Chinensis group) grown on an Oxisol amended with urea or composts.

	Carotenoids	N	P	K	Ca	Mg	Fe	Mn	Zn
Treatment	µg/g	<-----	-----	-----%-----	-----	----->	< -----	-----µg/g-----	----->
Control	62 b	2.80	0.43	5.99	3.19	0.61	109	139	98
Std. Err.		0.47	0.06	0.14	0.32	0.01	4	7	34
Urea	125 a	3.64	0.40	6.01	3.05	0.61	84	175	75
Std. Err.		0.30	0.02	0.32	0.39	0.01	4	28	15
Rwd compost	73 b	3.01	0.43	5.75	3.52	0.62	99	159	73
Std. Err.		0.16	0.04	0.07	0.34	0.02	6	11	7
UH compost	90 ab	3.20	0.43	6.17	2.78	0.56	112	166	69
Std. Err.	LSD = 34	0.20	0.02	0.08	0.33	0.06	19	17	6

LSD = least significant difference; different letters following numbers within a column indicate differences ($P < 0.05$).

After crops were changed from cabbage to eggplant, and leaf insects were controlled by biocides, yields of the second crop were reliably obtained (Table 5). Eggplant yields were highest in the UH compost treatment (5013 kg/ha) followed by the urea, Rwd compost and control, respectively. These fruit fresh weights seemed to correspond well with N nutrition, which was highest in the UH compost treatment (3.80% N), suggesting that N mineralization in this treatment has approached or reached its optimal potential (approximately 6 months after application).

Table 5. Fruit fresh yield and leaf nutrients in eggplant (*Solanum melongena*) grown on an Oxisol amended with urea or composts.

	Fruit yield	N	P	K	Ca	Mg	Fe	Mn	Zn
Treatment	Kg/ha	<-----------------	%		---------------------->		< ---------	µg/g	------->
Control	3013 b	3.00	0.37	2.52	2.40	0.43	61	147	28
Std. Err.		0.18	0.03	0.36	0.48	0.04	16	23	2.6
Urea	3626 ab	3.48	0.34	2.77	2.86	0.47	86	140	26
Std. Err.		0.21	0.02	0.10	0.21	0.02	31	33	3.5
Rwd compost	2333 b	3.22	0.41	2.79	2.32	0.39	69	143	33
Std. Err.		0.16	0.02	0.16	0.06	0.01	25	16	4.8
UH compost	5013 a	3.80	0.38	2.60	2.51	0.44	143	195	29
Std. Err.	LSD = 1811	0.21	0.03	0.05	0.19	0.05	47	34	2.5

LSD = least significant difference; different letters following numbers within a column indicate difference ($P < 0.05$).

Conclusion

Switching from conventional to organic farming provide opportunities as well as challenges in getting good crop yields and making profits. These challenges include weeds, insects, and plant nutrient requirements. On the other hand, soil quality as measured by such parameters as hot-water soluble C, dehydrogenase activity, and CEC, was improved by adding organic amendments, especially to low-fertility soils of the Tropics.

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