The Dirt on Organic:
Soil Fertility Differences between Organic and Conventional Farms in New England.

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Abstract:

With rising demand for organic food, interest in the impacts of organic agriculture on soil fertility has increased; yet it is not clear if differences between organic and conventionally managed soils result from varying soil amendment levels or other factors. The small scale of agriculture in New England enables farmers to use organic matter based amendments in both organic and conventional settings, providing a useful observational research framework. I investigated soil fertility differences between organic and conventional farms in southern New England with respect to the influence of soil amendments. I paired eight conventional farms with eight organic farms by size and soil texture, and assessed amendments based on the binary evaluation of five practices: cover crop, mulch, fertilizer, compost and manure. Using a stratified random sampling design, I gathered eight soil cores from the tomato field of each farm and analyzed bulk density, total soil carbon and nitrogen, and soil texture. Organic farms maintained higher average concentrations of carbon and nitrogen as a result of receiving more soil amendments. Carbon and nitrogen concentrations were directly associated with higher amendment ratings and influenced most significantly by compost addition. The one conventional farm that received more amendments than the organic farm with which it was paired had higher carbon and nitrogen concentrations. Bulk density was inversely associated with carbon rather than amendments. These findings suggest that the farmer's amendment choices outweigh the importance of the organic certification for soil fertility in New England.

Keywords: organic agriculture, organic amendments, soil organic carbon, soil fertility.

Introduction:

In recent years agriculture has been characterized by two seemingly opposing trends: small farms are giving way to corporate scale agri-business, while the National Organic Program grows in size and influence (Greene 2006). The National Organic Program (NOP) of the United States Department of Agriculture (USDA) defines certified organic produce as that grown without the assistance of genetic engineering, sewage sludge, synthetic fertilizers or synthetic pesticides. However, although the NOP requires candidates for certification to submit a plan for the development and maintenance of soil fertility, many farmers and organic enthusiasts believe that the NOP certification requirements do not do enough to satisfy the organic movement's founding principles of sustainability. (Agricultural Marketing Service 2002). The U.S. certified organic market currently constitutes an $11 billion dollar industry (Pollan 2006), and large mass-market retailers (e.g. Wal-Mart) have established certified organic brands in order to meet increasing demand from shoppers with diverse socio-demographic backgrounds. As the certified organic market merges with industrial agriculture, it is important to determine if certified organic agriculture supports the movement’s underlying philosophical goals of sustainability.

Box 1: Definitions (for this paper)

Certified Organic: An agricultural operation or product that has been certified by the National Organic Program (see: Agricultural Marketing Service 2002).

Organic: (1) *agriculture*- Although it may not be certified by the National Organic Program, organic agriculture refers to farms that do not use synthetic pesticides or synthetic fertilizers or genetically modified organisms and self-identify as using organic practices. (2) *matter*- A substance derived from plant or animal matter.

Conventional: Pertaining to agriculture that uses synthetic fertilizers and/or synthetic pesticides and/or genetically modified organisms.

There is a growing body of literature comparing the fertility of soils managed in accordance with the NOP standards for organic and those managed otherwise (conventionally) that almost universally concludes that organically managed soils have higher levels of soil organic matter (SOM) and soil organic carbon (SOC) than their conventional counterparts (Reganold et al 1993, Clark et. Al. 1998, Liebig and Doran 1999, Bulluck et al. 2002, Shepherd et al. 2002). As one of the most important contributors to soil fertility, organic matter beneficially influences the chemical, structural and biological properties of soil (Prasad and Power 1997, Reeves 1997). Organically managed soils not only have higher SOM levels in comparison to conventionally managed soils, but also show an associated increase in micro and macro nutrient concentrations and a higher cation exchange capacity (Reganold 1988, Drinkwater 1995, Clark 1998, Liebig and Doran 1999, Bulluck 2002). Higher levels of organic matter on organic farms also lead to higher aggregate stability, lower bulk density and increased water holding capacity (Prasad and Power 1997). In addition, organically managed soils enhance earthworm populations, biological activity and diversity, and strengthen fungal hyphae linkages. These characteristics are partially due to the lack of toxins from pesticides and to an increase in organic matter (Bulluck 2002, Shannon 2002, Scullion 2002, Shepherd 2002, Marinari 2005).

While abiotic factors such as temperature, precipitation and soil texture influence the level of organic matter in the soil, higher levels of SOM on organic farms are largely the result of farm management (Buckman and Brady 1969). Even the simple act of tilling, by stimulating microbial decomposition through aeration, can lead to a decrease in SOM and its associated benefits (Logan et al. 1991, Reeves 1997, Stockfisch et al. 1999, Liebig et. al. 2004). For example, the soil of the long term University of Illinois Morrow plots, established in 1876, has shown a continuous decline in organic matter, greatest in continuously cropped plots and those lacking the addition of fertilizer or manures

(Reeves 1997). Fertilizer addition, crop rotation and organic amendments (e.g. manures, compost, mulches and crop residues) increase SOM (Prasad and Power 1997). By increasing the amount of large particle, biologically active SOM (the light fraction), organic amendments have a stronger impact on soil fertility than synthetic fertilizers alone (Prasad and Power 1997, Liebig et al. 2002, Alvarez 2005, Liu et al. 2005).

Many organic farmers use crop rotation and organic amendments to substitute for synthetic fertilizers. Therefore, the majority of the literature utilizes experimental plots or comparisons between two to three farm pairs that almost universally feature organically managed soils receiving greater levels of organic matter based soil amendments than those managed conventionally (Clark 1998, Carpenter-Boggs 2000, Bulluck 2002, Scullion 2002, Shannon 2002, Liu 2005, Marinari 2006). This bias in the literature suggests that the observed disparity in soil fertility between organic and conventional farms may stem from higher organic matter inputs on organic farms, rather than the lack of synthetics (Shepherd et al. 2002, Clark et al. 1998). Few studies, however, have explicitly addressed the impact of the amendment differences on the soil fertility disparities between organic and conventional management.

Box 2: Definitions (for this paper)

Amendments: A substance the farmer deliberately adds to the soil to directly enhance nutrient content or organic matter. Lime was not considered an amendment in this sense.

Compost: Aerobically decomposed organic materials from both plant and animal sources.

Mulch: An organic soil cover placed between or on crop rows during the growing season. Includes both living mulches (a growing plant), and decomposing organic material (e.g. straw, leaves).

Cover Crop: A crop grown during the off-season for the purpose of maintaining soil fertility.

In New England, where small multi-crop farms compose the agricultural mainstream, conventional farmers often employ the intensive, amendment focused practices commonly associated with organic agriculture (Ayars 2002). This overlap between organic and conventional farming practices offers a unique opportunity to explore the drivers of the differences in soil fertility between organic and conventional farms. I investigated the questions: (1) Do soil properties differ between organic and conventional farms in New England, and (2) are the observed soil properties the result of soil amendments?

Methods:

Study Site:

All study farms were located in Rhode Island and Massachusetts (41° to 42° N, 70° to 72° W), with glacially derived inceptisols: fourteen farms had soil classified as mesic typic Dystrudepts (10 farms) or mesic aquic (4 farms) Dystrudepts, while an additional two farms had soil classified as mesic aeric Epiaquepts and mesic typic Udotherts subgroups respectively (NRCS Soils 2007) (Table 1). Annual precipitation in Rhode Island and Massachusetts averages 119 cm, 40% of which falls during the May to September growing season of most crops. Temperatures average -2ºC in the winter and 21ºC in the summer (NRCS 2000).

Sample Collection and Analysis:

Using a paired, stratified random design, I paired eight organic farms with eight conventional farms. Although not all organic farms were certified organic, I selected farms that consistent with the standards of the National Organic Program did not use genetically modified organisms, synthetic fertilizers or synthetic pesticides, and had been managed as such for at least three years. I paired farms with the same USDA soil texture classification and similar total farm size, which was assumed to be directly associated with the level of mechanization and, therefore, tillage and soil compaction. In seven pairs the farms did not differ in size by more than 12 hectares, while the eighth pair had a difference of 38 hectares. I only considered farms using conventional tillage to a depth of at least 10 cm. To minimize site specific variability, I did not include fields with > 8% slope or obviously poor soil drainage. Because most farmers in New England practice crop rotation, I only included current tomato (*Solanum lycopersicum*) fields of an area < 0.25 ha (measured by approximate pace length) in which a crop of a different family had been planted the previous year.

Defining amendments as substances added to the soil to deliberately enhance organic matter and/or nutrient concentrations, I assessed the level of amendment additions on each farm using a binary evaluation of five practices, with one point assigned for each amendment: cover cropping, fertilizer (organic or synthetic), organic mulch, compost and manure (either added separately or as part of the compost) (Box 2). I established two types of farm pairs: four in which amendments were less than two points different between the organic and conventional farm, and four in which the amendments rating on the organic farm exceeded that of its partner by over two points. On one conventional farm, I sampled two fields paired with the same organic farm: one field in which the farmer added compost, manure and a cover crop (pair E2), and one amended with only fertilizer and a cover crop (pair E1).

Table 1: Farm characteristics of 16 southern New England organic and conventional farms assessed for soil fertility. “Type” represents organic (org) or conventional (con). Soil subgroup and series were determined by the (NRCS Soils 2007): MTD = mesic typic Dystrudepts, MAD = mesic aquic Dystrudepts, MTU = mesic typic Udothernts and MAE = mesic aeric Epiaquepts. Amendment abbreviations are as follows: CC= cover crop, comp = compost, man = manure, fert = fertilizer.

Farm	Type	Location (County, State)	Farm Size (ha)	Field Size (ha)	Soil Texture	Soil Type	Soil Series	Amendments	Amend-ment Rating
Ao	org	Newport, RI	18	0.1	loam	MTD	Newport	living mulch; rye & oat CC; dehydrated poultry man. (4-3-3)	3
Ac	con	Middlesex, MA	58	0.2	sandy loam	MAE	Raynham	comp.; horse & poultry man.; rye & vetch CC; clover mulch; fert.	5
Bo	org	Newport, RI	1	0.09	loam	MAD	Pittstown	comp; horse man; saw dust, straw, wood chip mulch; buckwheat & oat CC	4
Bc	con	Washington, RI	1	0.08	sandy loam	MTD	Bridge-hampton	living mulch; rye & clover CC; fert. (20-10-20)	3
Co	org	Washington, RI	6	0.2	silt loam	MTD	Enfield	comp; horse man.; clover CC; fert.	4
Cc	con	Washington, RI	4	0.1	silt loam	MTD	Bridge-hampton	fert.	1
Do	org	Hampshire, MA	12	0.1	sandy loam	MTU	Hinckley	comp.; cow & horse man.; leaf mold; bone meal, blood meal, rock phosphate, lineseed; rye, oat or clover CC	4
Dc	con	Norfolk, MA	14	0.2	loam	MTD	Canton	rye & vetch CC; fert. (10-10-10, 13-13-13).	2
Eo	org	Newport, RI	40	0.2	loam	MAD	Pittstown	rye or vetch CC; fert.; comp.; man.	4
Ec1	con	Newport, RI	32	0.1	loam	MAD	Pittstown	fert. (10-10-10); oats CC	2
Ec2	con	Newport, RI	32	0.07	loam	MAD	Pittstown	oats CC; comp.; man.	3
Fo	org	Middlesex, MA	6	0.1	silt loam	MTD	Canton	comp.; clover or rye CC; fert. (7-4-4); man.; straw mulch	5
Fc	con	Bristol, RI	7	0.1	sandy loam	MTD	Canton	fert. (15-15-15)	1
Go	org	Kent, RI	5	0.09	silt loam	MTD	Narran-gansett	dehydrated poultry man. (4,3,3); fish emulsion (5-1-1); comp.; rye, oat or buckwheat CC	4
Gc	con	Providence, RI	8	0.07	loam	MTD	Narran-gansett	fert. (13-13-13); rye CC	2
Ho	org	Washington, RI	3	0.2	sandy loam	MAD	Rainbow	comp.; man.; fert. (5-3-4, 6-2-4); straw mulch; rye or vetch CC	5
Hc	con	Kent, RI	3	0.03	loam	MTD	Bridge-hampton	fert. (14-14-14); wheat or rye CC	2

Sampling throughout July and August 2006, I divided each field into four equally sized strata based on slope and drainage, and collected two randomly located cores (3.8 cm diameter) of the Ap horizon from each stratum using a PVC corer. I sampled only in crop rows approximately 20 cm from the plant stems, and rejected cores in which there was ≥ 10% compaction. Samples were refrigerated for 12 to 24 hours, put through a 2 mm sieve, and air dried. After recording the mass of the soil (< 2 mm) and course fragments (>2 mm), I homogenized the soil and extracted a 10 g sub-sample to be oven dried for 48 hours at 105ºC. All results are reported on an oven dried basis. Bulk density was calculated as soil mass divided by a core volume corrected for the volume of coarse fragments which were assumed to have a density of 2.65 g/cm^3. I analyzed soil texture with the hydrometer method as described by Bouyoucos (1962) using a 40 second measurement to represent silt and clay particles in solution, and a two hour measurements to represent the suspended clay particles.

Total soil carbon and total soil nitrogen were measured using the modified Dumas technique (Nelson and Sommers 1996). After pulverizing oven dried sub-samples for 3.5 minutes in a Spex 5300 Mixer Mill, I analyzed 10 to 15 mg sub-samples in randomized order in a Thermo Quest NC2100 Elemental Analyzer running Eager 200 software. Every seventh sample was run in triplicate, and after every 12 samples, I ran two references of the same substances used to calibrate (Acetanelide, Mag, Montana Soil 2271, Pine, and Cyclohexanone). Average percent carbon and nitrogen error (100 times the difference in the observed and expected concentrations divided by the expected concentration) across all references and runs was 1.3% and 6.2%, respectively. Montana Soil 2271, the reference most closely approximating the samples, had the highest percent error (carbon = 5.7% and nitrogen = 22%), but the lowest difference in carbon and nitrogen between the observed and expected values (nitrogen = 4.4 μg and carbon = 17 μg); close to the precision of the instrument. A comparison of triplicate samples and Montana soil references between Runs 1 and 3, shows that neither carbon nor nitrogen values vary significantly between runs ($p=0.97$ for carbon and $p=0.45$ for nitrogen). Because I used total soil carbon as a proxy for soil organic carbon, I measured inorganic carbon concentrations on a subset of samples of both farms that applied lime and those that did not. I used standard coulometric methods to measure the $CO_{2(g)}$ evolved from acidifying each sample with a UIC Inc. CM240 Total Inorganic Carbon Analyzer. Inorganic carbon values were below the detection limits of the Elemental Analyzer for all samples analyzed, thus I assumed that all carbon measured was organic.

Statistical Analysis:

The strength of the farm pairs could be reduced to amendment, soil texture and farm size variables, therefore, except for paired two-tailed T-tests to determine overall differences between organic and conventional farms, the majority of the statistical analysis ignored the farm pairings. I excluded pair E2 from analyses between pairs. In order to account for inherent farm variability, I used STATA version 9.0 software to perform a multi-predictor linear regression random effects model with robust standard errors to assess the impact and importance of each amendment practice, farm size, and sand and silt concentrations. Organic classification and manure addition were not included in the analysis because they were associated with compost; and cover cropping was excluded because all but one farm grew cover crops. Unimportant variables were removed from the final model by performing a sensitivity analysis. I used STATA to perform a one way Analysis of Variance, ANOVA, of all samples to evaluate the association between amendment rating and each parameter, while I assessed association between parameters with simple linear regression of farm means using the Microsoft Excel statistical analysis package. I used two tailed unpaired t-Tests assuming unequal variance preformed in Microsoft Excel to determine differences within pairs. All means are reported with 95% confidence intervals.

Results:

Carbon and Nitrogen

Carbon and nitrogen concentrations were higher on organic farms than on conventional farms ($p < 0.01$ and $p=0.04$ respectively). Organic farms had a mean soil carbon concentration of 2.4 ± 0.24% (95% CI) in comparison to 2.01 ± 0.18% on conventional farms. Mean total nitrogen concentration was 0.19 ± 0.02% on organic farms, but only 0.16 ± 0.02% on conventional farms. Amendment ratings ranged from 3 to 5 on organic farms, but 1 to 5 with an average of 2 on conventional farms. In all but 3 pairs (C, D and H), the farm with a higher amendment rating had a higher mean total carbon and nitrogen concentration regardless of organic or conventional management (Figures 1 and 2). Within pair E, the carbon and nitrogen concentrations did not differ from the organic farm on the field receiving a cover crop, compost and manure (p=0.61 and p=0.62, respectively), but were significantly lower than the organic farm on the field receiving only a cover crop and fertilizer (p<0.01 for both).

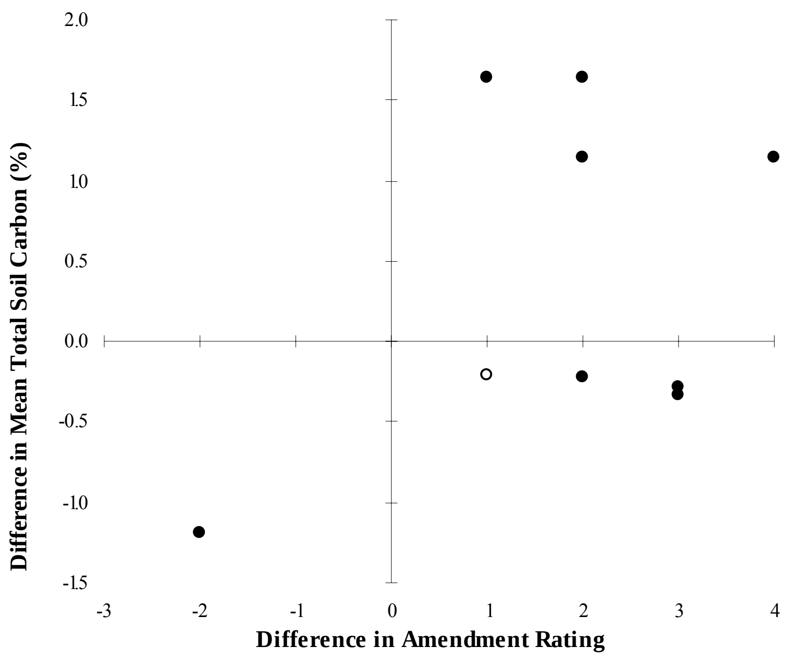

Figure 1: Differences in mean total soil carbon concentration in the Ap horizon of 8 southern New England organic and conventional farm pairs relative to amendment additions. Each point represents the organic farm mean minus that of the conventional farm. The open circle represents pair E2.

One way ANOVAs demonstrated that amendment ratings 4 and 5 were directly proportional to carbon and nitrogen concentration. In both cases the increase in carbon and nitrogen concentrations between those farms receiving an amendment rating of 4 or 5 were significantly higher than those farms receiving a rating of 1 ($p<0.05$, Figure 3). The linear regression random effects model revealed that compost ($p=0.01$) and fertilizer ($p=0.07$) both significantly influenced total soil carbon concentration, while compost ($p=0.09$) and mulch ($p=0.10$) significantly influenced soil nitrogen concentrations.

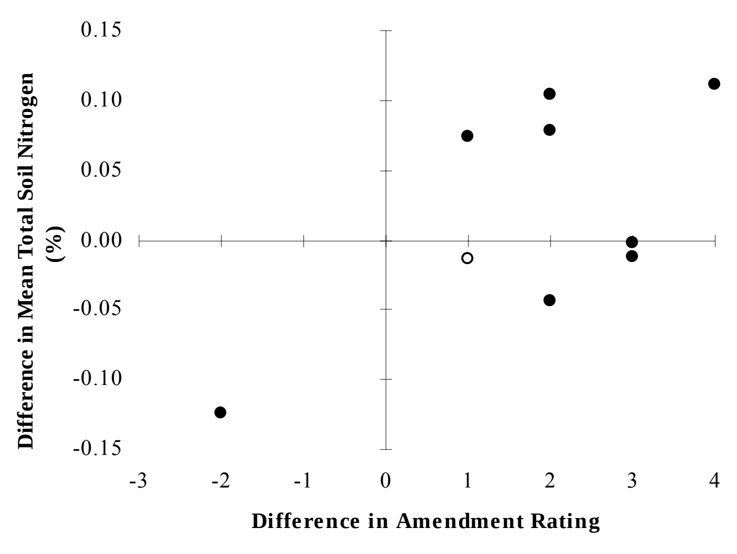

Figure 2: Differences in mean total soil nitrogen concentration in the Ap horizon of 8 southern New England organic and conventional farm pairs relative to amendment additions. Each point represents the organic farm mean minus that of the conventional farm. The open circle represents pair E2.

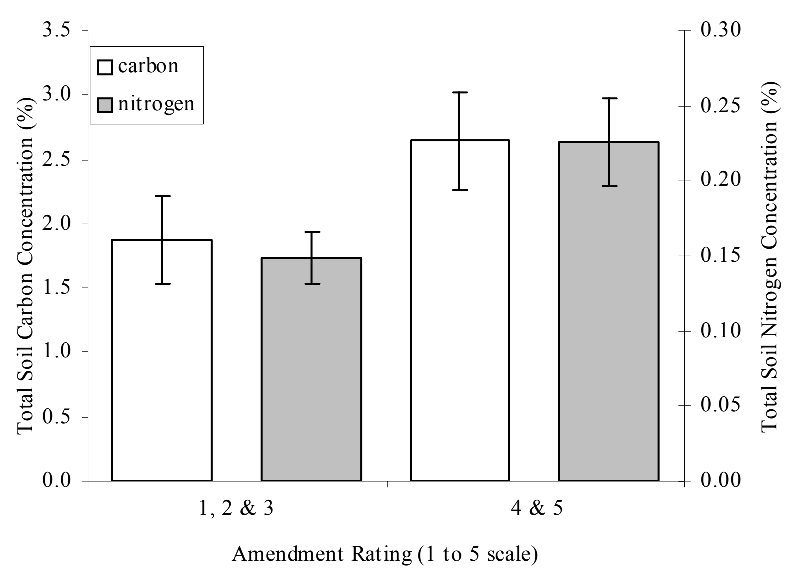

Figure 3: Mean soil carbon and nitrogen concentrations in the Ap horizon of 16 organic and conventional southern New England farms at different levels of amendment additions. Amendment rating is a qualitative 5 point scale (1= lowest, 5 = highest). Error bars represent 90% confidence

Carbon and nitrogen mass per unit area closely parallel the concentration data patterns. Organic farms had a mean of 7.3 ± 0.59 kg carbon/ m^2 and 560 ± 45 g nitrogen/ m^2, while conventional farms had a mean of 6.3 ± 4.4 kg carbon/m^2 and 520 ± 45 g nitrogen/m^2.

Carbon/ Nitrogen Ratio

Although organic farms had a C/N ratio of 13 compared to 12 on conventional farms ($p < 0.01$), all farms retained a relatively constant C/N ratio within the expected range for agricultural soils (10 to 15). The C/N ratios did not display a consistent association with amendment rating; however, the random effects regression model reveals that compost (p=0.05), mulch (p=0.06) and fertilizer ($p < 0.01$) significantly influenced C/N ratio. Although compost is directly proportional to C/N ratio (coefficient = 0.95), fertilizer and mulch show an inverse relationship with C/N ratio (coefficients = -2.1 and -1.1 respectively).

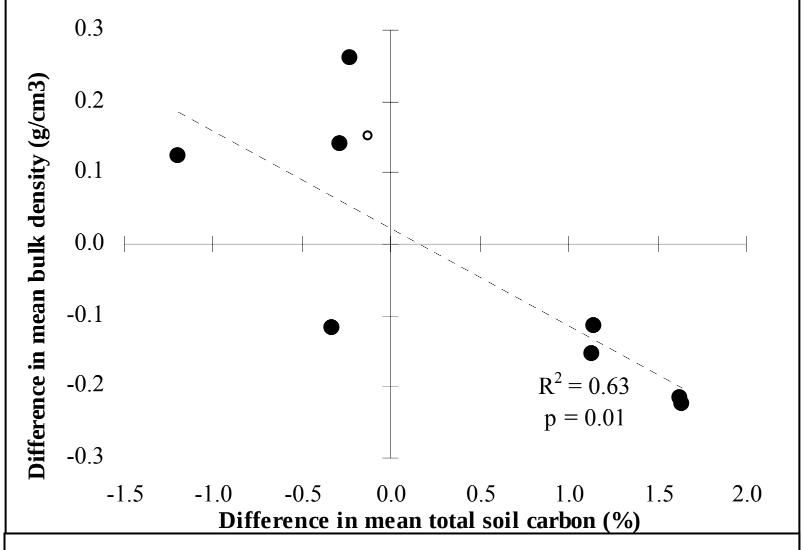

Figure 4: Differences in mean soil bulk density in the Ap horizon of 8 southern New England organic and conventional farm pairs relative to differences in total soil carbon. Each point represents the organic farm mean minus that of the conventional farm. The open circle, not included in the regression, represents pair E2.

Bulk Density

Bulk density did not vary with amendments nor differ between organic and conventional farms. However, all farms with higher soil carbon concentrations than their partners displayed lower bulk density (Figure 4). Simple linear regression shows bulk density to be inversely and linearly related to total soil carbon on organic farms ($p < 0.01$, Figure 5), but not on conventional ($p = 0.29$). This trend is also observed using a multi-predictor linear regression random effects model to examine the association between bulk density and soil carbon, while controlling for potential confounding from farm size, soil texture, and inherent variability between farms. The random effects model shows carbon to be inversely associated with bulk density when all farms are examined together (coefficient = -0.04, $p < 0.01$) and when organic farms are analyzed alone (coefficient = -0.06, $p < 0.01$), but when conventional farms are examined individually, the relationship between carbon and bulk density is not significant (coefficient = 0.06, p= 0.40).

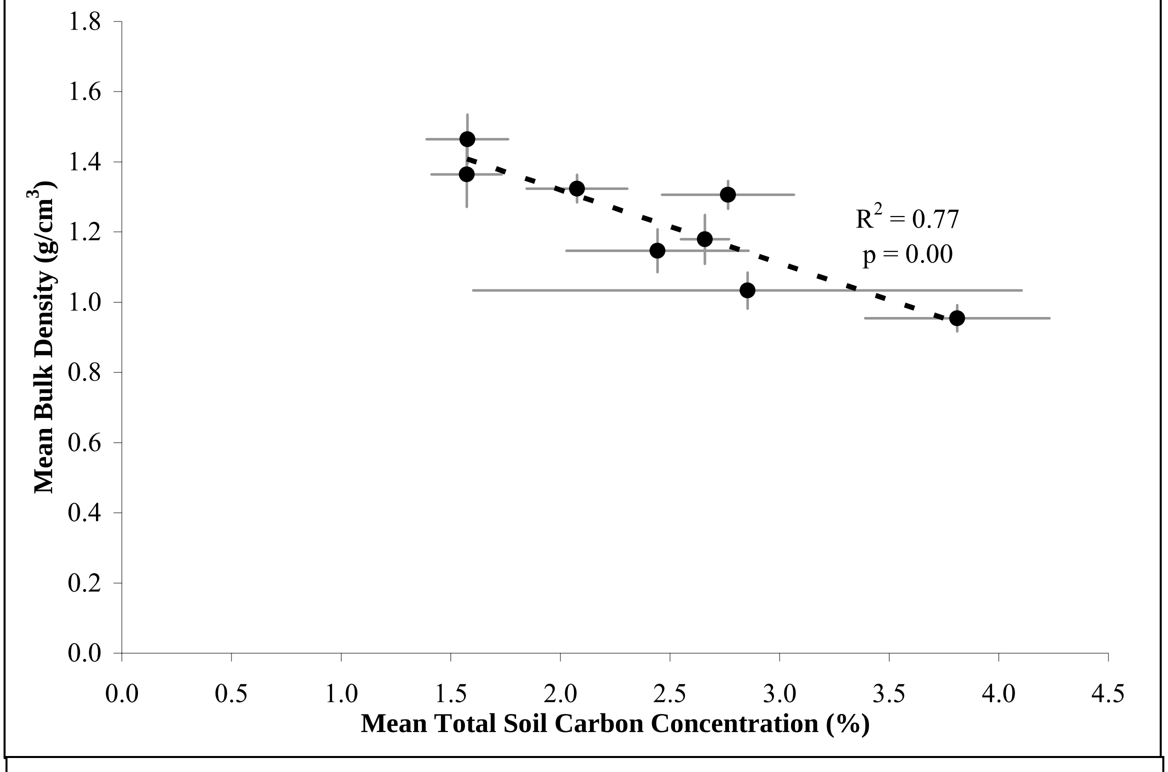

Figure 5: Mean soil carbon concentration in relation to mean bulk density from the Ap horizon of 8 southern New England organic farms. Each point represents the mean of 8 samples per farm. The error bars represent 95% confidence intervals for the mean bulk density (y) and total soil carbon concentration (x).

Discussion:

Consistent with what others have reported (Shepherd 2002, Stockdale 2002), mean carbon and nitrogen concentrations were higher on organic farms than on conventional farms, but directly dependant on both the amount and type of amendments added. For example, the only conventional farm that had amendment levels exceeding those of the organic partner also maintained higher concentrations of carbon and nitrogen ($p < 0.01$ for both). Moreover, the within farm comparison offered by pair E, suggests that the higher total carbon and nitrogen concentrations on the field receiving compost and manure relative to the field lacking these additions resulted from the increase in organic amendments. These observations reveal, albeit anecdotally, that the level of organic amendments plays a greater role in determining soil fertility than the use of synthetics. In other words, conventional farms using organic amendments can achieve concentrations of nitrogen and organic carbon equivalent to those of organic farms.

The results of the one way ANOVAs further support this finding, and reveal that more diverse amendment regimes, represented by ratings 4 and 5, can lead to higher organic matter and nutrient concentrations. Not surprisingly, specific amendments varied in the strength of their impact on soil fertility. Compost and mulch appeared to have the greatest impact on nitrogen concentrations, while compost alone was the driving factor behind carbon concentrations. The lack of a fertilizer association with nitrogen suggests, as expected, that inorganic fertilizer introduces a more transient source of soil nitrogen than organic matter (Prasad and Power 1997, Alvarez 2005).

For both carbon and nitrogen, however, three pairs do not follow the amendment determined trend: pairs C, D, and H. In these pairs the conventional farm, despite lower amendment estimations, had carbon and nitrogen concentrations greater than or equal to those of the organic farm. The discrepancy appears to result from unaccounted amendments. In pairs C and D, the organic farms left bare soil between the crop rows, while the conventional farms supported a thick growth of weeds. In addition to competing with crops for soil nutrients, weeds impact soil fertility. Many farmers leave weed residues on their fields in the hopes that their decomposition will augment SOM concentrations (Vazquez et al. 2003), but the presence of living legume or broadleaf weeds between crop rows has been demonstrated to accelerate net release of mineral nitrogen and produce higher crop yields than weed-less plots (Sakonnakhon et al. 2006). Moreover, root residues from either weeds or crops are directly related to aggregate formation and levels of particulate organic matter in the soil (Gale 2000). Weeds would function in much the same way as mulch; thus, the significant impact of mulch on C/N ratio and nitrogen concentration supports the hypothesis that weeds may have been a confounding factor. More importantly, however, the conventional farm in pair D was a dairy farm until the 1960s. Concentrated cow manure additions could leave a lasting legacy of elevated carbon and nitrogen concentrations in the soil even 100 years later (Compton 2000).

Shifts in C/N ratios appear to depend more on the type of amendment than the quantity as reflected by the rating scale, with compost, mulch and fertilizer all significant drivers of C/N ratio. The higher C/N ratio on organic farms can be explained by the higher level of carbon rich amendments, particularly compost whose high C/N ratio (approximately 25:1) probably resulted in the direct relationship between compost and C/N ratio. By contrast, the negative association between mulch and C/N ratio suggests that living mulches (e.g. clovers) may add more nitrogen to the soil in relation to carbon than other amendments. Although the inverse association between soil carbon and bulk density on organic farms shown using the simple linear regression was expected and well documented in the literature (Buckman and Brady 1969), the breakdown of this relationship on conventional farms was not, and cannot be satisfactorily explained given these data.

This reported work allowed for the type of observational comparison of organic and conventional farms not well represented in the scientific literature, but it carried with it some potential sources of error. I choose to sample only active tomato fields in order to reduce variation in nutrient uptake; however, this limited my sampling to a small proportion of each farm (between 0.2 to 9%). Secondly, I was not able to assess the absolute quantity of each amendment, thus reducing the robustness of my analysis.

The individual management practices of each farm appear to be far more important for maintaining soil fertility than compliance with the National Organic Program. Conventional farms that added compost and manure had higher carbon and nitrogen concentrations than organic farms without such robust amendment techniques, indicating that these conventional farms displayed greater sustainability of soil fertility. Unlike previous experimental studies on this subject, this study is one of the few to observe a variety of small farms. The observational component of this work reveals that small scale conventional farms often practice rigorous soil management, an observation that is not generally accounted for in much of the literature assessing organic and conventional agriculture. In New England, cover cropping and crop rotation practices are the standard among small-scale, vegetable growers, while most farmers add additional organic amendments. Such observations reveal the need to investigate the relationship between farm size and soil conserving practices. The work can also be extended by examining the relative importance of different amendments, their interactions and potential synergies. Based on my data, a sustainability rating scale that assigns points for various practices may be more appropriate for determining environmental impact than organic certification. A graduated rating scale, analogous to the Leadership in Energy and Environmental Design (LEED) rating system for green buildings, may be more appropriate than a binary certification, and would discourage overly simplistic conclusions as to the merit of different agricultural systems. Such a system could assign points to farms that use site appropriate techniques to promote sustainability and preserve human health, such as the addition of organic matter to the soil, the elimination of harmful fertilizers and pesticides, or the use of diversified plantings and regular crop rotations.

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Appendix 1: Results of total soil carbon and nitrogen concentration, bulk density, and texture analysis on 16 New England farms. The capital letter in sample ID represents the pair, the lower case letter represents organic (o) or conventional (c) management, the number represents the sample number.

Sample	% Total N	% Total C	C/N	Bulk Density (g/cm^3)	% Silt	% Sand	% Clay
Ac1-1	0.20	2.4	12	1.2	39	57	5
Ac1-2	0.21	2.4	11	1.3	39	57	5
Ac2-1	0.29	3.5	12	1.2	39	57	5
Ac2-2	0.20	2.5	12	1.3	39	57	5
Ac3-1	0.24	2.9	12	1.2	39	57	5
Ac3-2	0.27	3.2	12	1.3	39	57	5
Ac4-1	0.20	2.4	12	1.2	39	57	5
Ac4-2	0.25	3.0	12	1.2	39	57	5
Ao1-1	0.11	1.4	13	1.6	40	48	11
Ao1-2	0.10	1.4	14	1.2	40	48	11
Ao2-1	0.09	1.4	15	1.1	40	48	11
Ao2-2	0.13	1.9	14	1.3	40	48	11
Ao3-1	0.12	2.0	17	1.4	40	48	11
Ao3-2	0.12	1.6	14	1.5	40	48	11
Ao4-1	0.10	1.3	13	1.4	40	48	11
Ao4-2	0.10	1.5	15	1.4	40	48	11
Bc1-1	0.23	2.8	12	1.1	37	58	5
Bc1-2	0.16	1.9	12	1.2	37	58	5
Bc2-1	0.24	2.0	8	1.0	37	58	5
Bc2-2	0.15	1.6	11	1.3	37	58	5
Bc3-1	0.25	2.0	8	1.3	37	58	5
Bc3-2	0.21	2.4	12	1.2	37	58	5
Bc4-1	0.20	2.3	12	1.2	37	58	5
Bc4-2	0.20	2.4	12	1.2	37	58	5
Bo1-1	0.29	4.0	14	1.0	45	43	12
Bo1-2	0.35	4.9	14	0.89	45	43	12
Bo2-1	0.28	3.8	14	0.88	45	43	12
Bo2-2	0.24	3.1	13	1.0	45	43	12
Bo3-1	0.29	4.0	14	1.1	45	43	12
Bo3-2	0.23	3.0	13	0.93	45	43	12
Bo4-1	0.30	4.0	13	0.95	45	43	12
Bo4-2	0.26	3.5	14	1.0	45	43	12
Cc1-1	0.16	2.2	13	0.94	59	33	8
Cc1-2	0.18	2.5	14	1.2	59	33	8
Cc2-1	0.14	2.0	14	1.2	59	33	8
Cc2-2	0.12	1.8	14	1.1	59	33	8
Cc3-1	0.16	2.2	14	1.1	59	33	8
Cc3-2	0.17	2.3	14	1.2	59	33	8
Cc4-1	0.20	3.0	15	1.4	59	33	8
Cc4-2	0.20	2.9	14	1.3	59	33	8
Co1-1	0.18	2.3	12	1.2	56	36	7
Co1-2	0.15	1.9	12	1.4	56	36	7
Co2-1	0.14	2.0	14	1.4	56	36	7
Co2-2	0.12	1.5	13	1.4	56	36	7
Co3-1	0.19	2.7	14	1.2	56	36	7
Co3-2	0.14	2.0	14	1.3	56	36	7
Co4-1	0.16	2.1	14	1.3	56	36	7
Co4-2	0.16	2.2	13	1.4	56	36	7

Sample	% Total N	% Total C	C/N	Bulk Density (g/cm3)	% Silt	% Sand	% Clay
Dc1-1	0.19	2.2	11	1.2	42	48	10
Dc1-2	0.19	2.1	11	1.0	42	48	10
Dc2-1	0.15	1.7	11	1.2	42	48	10
Dc2-2-2	0.14	1.7	12	1.2	42	48	10
Dc3-1	0.15	1.8	12	1.3	42	48	10
Dc3-2	0.15	1.6	11	1.1	42	48	10
Dc4-1	0.14	1.5	11	1.0	42	48	10
Dc4-2	0.18	2.0	11	1.3	24	71	10
Do1-1-2	0.11	1.5	14	1.6	24	71	5
Do1-2	0.12	1.5	12	1.5	24	71	5
Do2-1	0.08	1.2	16	1.5	24	71	5
Do2-2	0.10	1.5	14	1.5	24	71	5
Do3-1	0.14	1.8	13	1.3	24	71	5
Do3-2	0.10	1.4	13	1.5	24	71	5
Do4-1	0.12	1.6	14	1.3	24	71	5
Do4-2	0.11	1.6	14	1.5	24	71	5
Ec1-1	0.10	1.4	14	1.3	42	46	12
Ec1-2	0.11	1.4	13	1.4	42	46	12
Ec2-1	0.14	1.6	12	1.3	42	46	12
Ec2-2	0.12	1.4	12	1.4	42	46	12
Ec3-1-2	0.09	1.1	12	1.2	42	46	12
Ec3-2	0.11	1.3	12	1.2	42	46	12
Ec4-1	0.12	1.2	10	1.3	42	46	12
Ec4-2	0.09	1.1	11	1.2	42	46	12
Ecf21-1	0.15	1.8	12	1.3	45	46	10
Ecf21-2	0.25	2.9	11	1.0	45	46	10
Ecf22-1	0.33	4.7	14	0.84	45	46	10
Ecf22-2	0.24	3.1	13	1.1	45	46	10
Ecf23-1	0.18	2.2	12	1.1	45	46	10
Ecf23-2	0.18	2.5	14	0.15	45	46	10
Ecf24-1	0.14	1.7	12	1.3	45	46	10
Ecf24-2	0.16	2.4	15	0.72	45	46	10
Eo1-1	0.22	2.6	12	1.2	45	44	11
Eo1-2	0.21	2.4	11	1.3	45	44	11
Eo2-1	0.22	2.9	13	1.0	45	44	11
Eo2-2	0.24	3.6	15	1.1	45	44	11
Eo3-1	0.14	1.8	13	1.2	45	44	11
Eo3-2	0.14	1.8	13	1.2	45	44	11
Eo4-1	0.17	2.1	12	1.1	45	44	11
Eo4-2	0.17	2.3	14	1.1	45	44	11
Fc1-1	0.13	1.6	13	1.4	23	71	6
Fc1-2	0.14	1.8	13	1.4	23	71	6
Fc2-1	0.11	1.3	12	1.2	23	71	6
Fc2-2	0.11	1.4	13	1.2	23	71	6
Fc3-1	0.14	1.8	13	1.3	23	71	6
Fc3-2	0.11	1.2	11	1.4	23	71	6
Fc4-1	0.14	1.5	11	1.2	23	71	6
Fc4-2	0.11	1.4	13	1.3	23	71	6
Fo1-1	0.23	3.0	13	1.2	52	40	8

Sample	% Total N	% Total C	C/N	bulk density (g/cm^3)	% Silt	% Sand	% Clay
Fo1-2	0.19	2.7	14	1.2	52	40	8
Fo2-1	0.36	2.7	7	1.1	52	40	8
Fo2-2	0.22	2.7	12	1.1	52	40	8
Fo3-1	0.22	2.6	12	1.2	52	40	8
Fo3-2	0.21	2.5	12	1.1	52	40	8
Fo4-1	0.23	2.6	11	1.4	52	40	8
Fo4-2	0.22	2.5	12	1.1	52	40	8
Gc1-1	0.10	1.2	11	1.2	44	45	10
Gc1-2	0.07	1.0	14	1.4	44	45	10
Gc2-1	0.13	1.6	12	1.4	44	45	10
Gc2-2	0.10	1.3	13	1.2	44	45	10
Gc3-1	0.14	1.7	12	1.2	44	45	10
Gc3-2	0.08	1.0	12	1.3	44	45	10
Gc4-1	0.09	1.0	11	1.2	44	45	10
Gc4-2	0.09	1.1	12	1.3	44	45	10
Go1-1	0.15	2.1	14	1.0	62	32	6
Go1-2	0.50	7.1	14	0.9	62	32	6
Go2-1	0.12	2.1	17	1.1	62	32	6
Go2-2	0.14	1.8	13	1.1	62	32	6
Go3-1	0.26	3.2	12	1.0	62	32	6
Go3-2	0.22	3.0	14	1.0	62	32	6
Go4-1	0.13	1.7	14	1.1	62	32	6
Go4-2	0.13	1.8	14	1.0	62	32	6
Hc1-1	0.24	3.2	14	1.4	43	49	9
Hc1-2	0.23	3.0	13	1.3	43	49	9
Hc2-1	0.15	2.1	14	1.4	43	49	9
Hc2-2	0.23	3.2	14	0.9	43	49	9
Hc3-1	0.23	3.2	14	1.5	43	49	9
Hc3-2	0.19	2.8	15	1.6	43	49	9
Hc4-1	0.23	3.4	15	1.8	43	49	9
Hc4-2	0.17	2.5	14	1.5	43	49	9
Ho1-1	0.15	2.2	15	1.4	36	58	6
Ho1-2	0.17	2.1	12	1.3	36	58	6
Ho2-1	0.26	3.3	13	1.3	36	58	6
Ho2-2-2	0.22	2.4	11	1.4	36	58	6
Ho3-1	0.22	2.7	12	1.3	36	58	6
Ho3-2	0.22	3.1	14	1.3	36	58	6
Ho4-1	0.22	3.2	14	1.2	36	58	6
Ho4-2	0.22	3.2	15	1.4	36	58	6