SOIL QUALITY IN ORGANIC AND CONVENTIONAL FARMS OF NEW MEXICO, USA

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Abstract

The goal of sustainable agriculture is to maintain a non-negative trend in productivity while maintaining soil quality. Our main objective was to determine the sustainability of organic cropping systems. Three of the selected farms were in organic production for three, six and nine years since certification, and a fourth in conventional production. We found significant relationships between some soil physical and chemical properties. Sand, transport and storage volumes together explained 92% of variability in biomass yield. A soil property-based rating index showed that the three-year organically managed field was the most sustainable whereas the conventional was the least sustainable system. The rating index was negatively correlated with biomass yield and increased with the duration of organic management, suggesting that an adjustment in management practices may improve soil properties and sustainability.

Keywords: biomass yield, bulk density, nitrate-N concentration, soil organic carbon, texture, sustainability

Introduction

The role of organic agriculture is to either enhance or sustain the overall quality and health of the soil ecosystem (Ekwue 1992). Organic agriculture is aimed at producing high quality food produce that is not only rich in nutrients but also contributes to health care and well-being of mankind. Since organic farming eliminates the use of most ‘conventional’ fertilizers, pesticides, animal drugs and food additives, it can improve soil, water and environmental quality and thus improve the overall quality of life.

Agricultural sustainability depends on productive soil. During the last several decades, much research has focused on increasing productivity and protecting environmental quality under different farming systems. These studies show that conventional farming’s use of chemical fertilizers and pesticides has increased crop yields and enhanced food security around the globe (Pang & Letey 2000). However, despite the high yields associated with it, conventional farming’s ability to sustain soil fertility and environmental quality has been called into question (Pang & Letey 2000). Conventional farming systems are reported to be associated with a decline in soil structure and soil aggregation, a decrease in water infiltration and an increase in soil bulk density, soil salinity, nitrogen leaching and ground water contamination (Logsdon et al. 1993, McGarry et al. 2000).

Tillage, climate, soil surface properties and biological activities reportedly influence the volume of transmission pores (VTP), pore structure and storage of water within the soil profile and can contribute to the spatial and temporal variability of the flow domain (Hagen et al. 2002). Some studies show that tillage disrupts pore continuity and decreases water storage and transport (Shukla et al. 2003), while others report no change (Lindstrom et al. 1981, Ankeny et al. 1990). Problems associated with tillage can be alleviated by implementing alternate tillage systems, such as conservation or minimum tillage that can improve soil structure, increase water storage and transmission, and enhance soil C and N content in the previously earlier plowed layer (Gantzer & Blake 1978).

In general, soil quality refers to the soil’s capacity to perform specific functions (SSSA 1987). In agriculture, it refers to the soil’s ability to sustain production (Lal 1994). Soil quality is also defined as the capacity of a soil to function within ecosystem and land-use boundaries, to sustain biological productivity,

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maintain environment quality, and promote plant and animal health (Doran & Parkin 1994) relative to human needs and purposes or to the requirements of one or more species (Johnson et al. 1997). Soil quality has a significant influence on health and productivity of a given ecosystem and the related environment. Important processes influenced by soil quality are water and nutrient movement and their redistribution and supply to plants; root growth and sustenance; maintenance of suitable biotic habitat; and responses to management treatments (Larson & Pierce 1994). High soil quality is associated with efficient use of water, nutrients and pesticides, improvement in water and air quality, mitigation of greenhouse gas emission, and increase in agronomic production (Lal 1994). Soil quality cannot be measured directly, but is inferred from static or dynamic soil quality indicators (SQIs) or measurable soil attributes generally influenced by land use and soil-management practices (Sanchez-Maranon et al. 2002, Seybold et al. 1997, Shukla et al. 2006).

Soil's physical and chemical properties can be used as indicators for making soil-quality assessments and for determining the sustainability of farming systems. Several minimum data sets have been proposed to quantitatively assess sustainability of a soil management practice (Larson & Pierce 1994). To determine a farming system's sustainability, criteria can be used that are based on the critical limits of key soil properties in relation to the threshold values beyond which productivity declines severely or environmental impact is drastic (Lal 1994, Shukla et al. 2004). It is important to establish critical SQI levels, assign a weighting factor, and relate them to productivity.

The USA, in general, and New Mexico in particular, are experiencing an increase in farm area under organic cultivation. This is largely due to the increasing awareness among farmers about the benefits of organic farming, availability of manure, and higher profitability. According to Scow et al. (1994), it takes about three to five years to stabilize soil properties following conversion from conventional to organic farming, and yields during the conversion period are often lower than those achieved later. Since tillage for weed control is an important component of organic farming in southern New Mexico, soil structure will play an important role in determining the soil quality and sustainability of the organic farming system. To determine a farming system's sustainability, an integrated assessment of physical and chemical soil properties on a field scale is essential. Therefore, there is a need to clearly understand the net effects of increased organic matter additions and tillage on soil quality on organic farms. The objectives of this study were to: (1) determine correlation among various soil physical and chemical properties, (2) predict biomass yield from measured soil properties and (3) assess the sustainability of land-use and management-systems using a soil property-based rating index.

Materials and Methods

Experimental Site

We selected four farm fields located at about 1152 m above sea level in Anthony, located in Doña Ana County in southern New Mexico. Three fields (N 32° 01'58'', W 106° 38'15'') had been in organic production for three (OF3), six (OF6) and nine (OF9) years since certification, respectively, and the fourth field (N32° 03'13'', W106° 38'29'') selected as a reference, was conventionally farmed. Soil was identified as Harkey (coarse-silty, mixed, calcareous, thermic-typic Torrifluvents) and was deep, nearly level, well drained, and formed from alluvium on the flood plains and stream terraces along the Rio Grande Valley (Bulloch & Neher 1980). The area's climate is arid with mean annual temperatures ranging from 19-20^{o}C and mean annual precipitation from 180-230 mm.

Management Practices

Among organic farms, OF3 and OF9 were under a crop rotation of alfalfa (*Medicago sativa*) and Pima cotton (*Gossypium arboreum* L); OF6 was planted primarily in alfalfa, with occasional plantings of corn (*Zea mays*) and lettuce (*Lactuca sativa*) (Table 1). All three organic fields were moldboard plowed every year during the second week of January, followed by chisel tillage using a 35-cm-deep chisel plow. In all organic fields, 50 Mg ha^{-1} of dried cow manure was applied and incorporated into the soil. All organic fields were irrigated using furrow irrigation systems for all crops except alfalfa, which was flood irrigated. The reference conventional field was traditionally under a crop rotation of alfalfa and cotton (Ikemura et al. 2008). However, cotton had been planted since 2000. The conventional field was moldboard plowed every year during January (except in the year 2004) followed by 35-cm-deep chisel tillage. Liquid fertilizer (10-34-0) was applied at the pre-plant stage at a rate of 114 L ha^{-1}. Two applications of urea ammonium nitrate solution (URAN) (32-0-0) were made during May and July at the rate of 114 L ha^{-1}.

Table 1. Management history of farms under organic management for the past three (OF3), six (OF6) and nine (OF9) years, respectively, and the reference conventional farm

Field	Cropping history	Manure/Fertilizer	Tillage	Irrigation
OF3	Alfalfa in 2000, 2001, 2002; Pima cotton in 2003-05	50 Mg ha^{-1} dried cow manure and 0.18 Mg ha^{-1} dry chicken pellet for alfalfa	Annual moldboard followed by 35 cm chisel tillage	Furrow mostly, but flood with alfalfa
OF6	Corn in 2000; alfalfa in 2001-04; lettuce in 2005	50 Mg ha^{-1} dried cow manure and 0.18 Mg ha^{-1} dry chicken pellet for alfalfa	Annual moldboard followed by 35 cm chisel tillage	Furrow mostly, but flood with alfalfa
OF9	Alfalfa in 2000, 2003-05; Pima Cotton in 2001-02	50 Mg ha^{-1} dried cow manure and 0.18 Mg ha^{-1} dry chicken pellet for alfalfa	Annual moldboard followed by 35 cm chisel tillage	Furrow mostly, but flood with alfalfa
Conventional	Pima Cotton in 2001-05	30 gallons liquid fertilizer URAN (10-34-0; N-P-K) at pre-plant and two more (32-0-0; N-P-K)	Annual mold-board (except in 2004) followed by 35 cm chisel tillage	Furrow

Soil Sampling and Analyses

Core and bulk soil samples were collected in triplicate at 0-10, 10-20, and 20-30 cm depths from all four fields during September 2005. In each field at two soil sampling locations, a profile (60cmx60cmx60cm) was dug to a depth of 60 cm to determine the effective rooting depth (ERD) of the crops. Soil bulk density (ρ_b) was determined by the core method (Blake & Hartge 1986) and saturated hydraulic conductivity (K_s) by the constant head method (Klute & Dirksen 1986). Soil moisture (θ) characteristics were determined using a tension table (Leamer & Shaw 1941) and a pressure plate apparatus (Klute 1986). The θ value of 30 kpa was identified as field capacity (FC). The difference between θ at saturation and 30 kpa was computed to assess the effective porosity (θ_e) and between θ at 30 kpa and 1500 kpa to assess plant-available water capacity (AWC). Pore size distribution, obtained from soil moisture characteristic curves, was divided into two classes: (i) transmission pores (VTP) (> 50 μm) and (ii) storage pores (VSP) (0.5 and 50μm).

Bulk soil samples were air-dried and passed through a 2 mm sieve and particle size classification was determined by the hydrometer method (Gee & Bauder 1986). Soil pH and electrical conductivity (EC) were measured by a handheld pH and EC meter (OAKTON Instruments, Vernon Hills, IL). Ammonium N was determined in 2.0 *M* KCl extracts by the Technicon Autoanalyzer II (Technicon Autoanalyzer II) using the indophenol blue method and nitrate-N using the cadmium reduction method (Maynard and Kalra 1993). Total C and N were determined by the dry combustion method with a Thermo Electron CHNS-O analyzer, and inorganic C was determined by decomposing carbonates and measuring evolved CO_2 using gas chromatography (Loeppert & Suarez 1996). Soil organic C (SOC) was computed as the difference between total and inorganic C. Chloride was determined with 798 MPT Titrino titrator using 0.1 *M* silver nitrate solution.

Biomass Yield Measurement

Crops were cut manually from an area one-meter long and two rows wide (1 m x 1.6 m) at all soil sampling sites. This was done so that local soil physical and chemical properties can be compared to local biomass yield. Biomass moisture content was measured by the difference of field moist vs. oven dried samples kept at 60^0 C for four days. Biomass yields were calculated on an oven-dry basis.

Critical Limits and Indices of Sustainability

Critical limits proposed by Lal (1994) for soil physical and chemical properties for the tropical ecosystem were assumed to be applicable to the arid study area and were used in this study. Although these sustainability categories may be regarded as arbitrary, still this rating system was used because it provides a broad-stroke approach to sustainability. Soils of the study area have high pH mainly because of the inorganic C; therefore, limitations proposed by Lal (1994) for soil pH, were modified and are presented in Table 3. Critical levels were assigned on the basis of limitations to crop production and ranged from none to extreme on a scale of one to five for the relative weighting factor (Table 2). The lower limit of one (or none) for a soil property indicated no limitation, and the upper limit of five reflected a severe constraint. The sustainability index was obtained by adding critical levels for each soil physical and chemical property within a depth, separately for each field. Cumulative ratings (CR) for various fields can range from sustainable (CR < 20) to unsustainable (CR > 40) (Lal, 1994) (Table 3).

Table 2. Relative weighting factors (RWF) and critical levels for some soil physical and chemical properties (Lal 1994)

Limitation	RWF	ρ_b Mg m^{-3}	θ_e cm^3cm^{-3}	WP cm^3cm^{-3}	AWC cm	Ks cm h^{-1}	SOC %	Texture
None	1	<1.3	>0.20	>0.15	>30	>2	5-10	loam
Slight	2	1.3-1.4	0.18-0.20	0.15-0.18	20-30	0.2-2	3-5	SiL, SiCL
Moderate	3	1.4-1.5	0.15-0.18	0.18-0.20	8-20	0.02-0.2	1-3	CL, SL
Severe	4	1.5-1.6	0.10-0.15	0.20-0.25	2-8	0.002-0.02	0.5-1	SiC, LS
Extreme	5	>1.6	<0.10	<0.25	<2	>0.002	<0.5	C, S

Limitation	RWF	CFF %	ERD m	EC ds m^{-1}	pH*
None	1	< 10	1.5	<3	7-8
Slight	2	10-20	1.0-1.5	3-5	6-7 or 8-9
Moderate	3	20-40	0.5-1.0	5-7	5.5-6 or 9-9.5
Severe	4	40-60	0.25-0.5	7-10	5.0-5.4 or >9.5
Extreme	5	>60	<0.25	>10	<5 and >9.5

ρ_b is bulk density; θ_e is effective porosity; WP is the wilting point moisture content at 15 bars; AWC is available water capacity for 20 cm slice; K_s is saturated hydraulic conductivity; SOC is soil organic carbon; CFF is coarse fragment fraction (>2 mm); ERD is effective rooting depth; EC is electrical conductivity; L is loam; SiL is silt loam; SiCL is silty clay loam; CL is clay loam; SL is sandy loam; SiC is silty clay; LS is loamy sand; C is clay; S is sand; *pH ratings were modified from Lal (1994)

Table 3. Sustainability of a land-use and management system in relation to the cumulative ratings (CR) based on above 11 indicators

Sustainability	RWF	CR
Highly sustainable	1	<20
Sustainable	2	20-25
Sustainable with high input	3	25-30
Sustainable with another land use	4	30-40
Unsustainable	5	>40

RWF- Relative weighting factors

Statistical Analysis

In order to describe the variability of a soil property a classification suggested by Wilding (1985) was used. To identify significant relationships among soil properties and to reject or keep a given property for assessing sustainability based on soil property rating index, correlation analyses were performed on 17 measured soil attributes, separately at each depth, using the Statistical Analysis System 9.1.3 (SAS Institute 2003). Attributes used for the correlation analysis were: ρ_b, sand, silt and clay content, θ_e, FC and WP, K_s, AWC, VTP, VSP, EC, pH, SOC, nitrate-N, ammonium-N and chloride. Since measured soil properties and biomass had different dimensions, correlation analysis was performed on standardized data with zero mean and unit variance. Among highly correlated variables, a variable was retained for the sustainability analysis if it had an important specific function or was easier to determine. To derive relationships between biomass yield and all 17 soil properties, both simple and multiple linear regression analyses were performed using standardized biomass as the dependent variable, and measured standardized soil attributes as independent variables (SAS Institute, 2003). For the two-parameter model, the total number of pairs selected was $^nC_{2,}$ and for the three-parameter model they were $^nC_3$, where n is the number of independent variables. A program in SAS was written to determine all possible two-parameter and three-parameter combinations, and multiple linear regression analysis was performed on all the pairs. The regression analysis was also performed on standardized biomass yield as the dependent variable and soil properties rating factors as independent variables. To find out whether a higher order linear equation was a statistically better predictor of the biomass yield, an F-test based on the sum of squared deviations and degrees of freedom was conducted. All statistical analyses were performed for a significance level of $P \leq 0.05$.

Results

According to the USDA classification (refer to p.43 of Lal & Shukla, 2004), soil texture at all depths was silt loam for the conventional field and loam for organic fields OF6, and OF9. In OF3, soil texture varied from loam at the 0-10 cm depth to silt loam at the 10-20 and 20-30 cm depths. Soil properties having a coefficient of variation (CV) > 35% were K_s, ammonium-N and nitrate-N content; those having a CV < 35% were pH, FC and WP water content, and sand, silt and clay content across fields and depths. The CV for biomass yield was always < 35%.

Correlation among Soil Properties

At 0-10 cm depth, FC water content was strongly correlated with WP water content ($r = 0.87$; $P < 0.001$; Table 4). WP and AWC were used to assess sustainability using soil-property based rating index. The K_s was positively correlated with VSP ($r = 0.62$), and EC ($r = 0.58$), and VTP was positively correlated to θ_e ($r = 0.73$). While increasing clay content is usually reported to increase the total porosity of the soil, we found that clay content across fields was inversely related to VTP ($r = -0.76$) and θ_e ($r = -0.84$) indicating decrease in macroporosity with increasing clay content. This was further supported by a direct relationship between clay content and WP water content ($r = 0.76$). The θ_e was inversely related to FC and VTP and positively with VSP. θ_e was retained in place of FC, VTP and VSP. Soil EC was also directly correlated with nitrate-N ($r = 0.97$) and chloride ($r = 0.88$) and nitrate-N was correlated with chloride ($r = 0.88$; $P < 0.001$); therefore, we retained EC in place of chloride, and since nitrate-N is an important plant nutrient though variable due to the variations in the cropping systems, we retained EC for sustainability analysis.

Table 4. The correlation coefficient among soil physical and chemical properties using standardized data with zero mean and unit variance for 0-10 cm depth (Note: data not shown for P > 0.05)

Property	FC	WP	K_s	Sand	Clay	VTP	VSP	θ_e	EC	pH	Nitrate-N
WP	0.87**										
Sand	-0.79***	-0.67*									
Silt	0.65*										
Clay	0.84**	0.76***									
VTP											
VSP		-0.75***	0.62*		-0.76***						
θ_e	-0.64*		0.59*		-0.84**	0.73***	61*				
EC			0.58*								
Ammonium-N							-0.63*			-0.59*	
Nitrate-N			0.70*		-0.61*		0.62*	0.63*	0.97**		
Chloride									0.88**		0.88**

* is p-value 0.05-0.01; ** is p-value 0.01-0.001; *** is p-value <0.001; FC is water content at 30kpa; WP is water content at 1500kpa; K_s is saturated hydraulic conductivity; VTP is volume of transmission pores; VSP is volume of storage pores; θ_e is effective porosity; EC is electrical conductivity

At 10-20 cm depth, VSP was positively correlated to AWC (r= 0.88), VTP (r = 0.59) and VTP to θ_e (r = 0.97) (Table 5). Clay content showed a significant positive correlation with WP water content (r = 0.88). The FC and WP water contents were also correlated (r = 0.77; P< 0.001), and WP and AWC was retained for assessing sustainability, similarly among θ_e, FC, VTP and VSP; θ_e was retained. High positive correlations also were obtained among K_s and VTP (r = 0.59), K_s and θ_e (r = 0.66), and EC and nitrate-N (r = 0.91). EC was retained.

Table 5. The correlation coefficient among soil physical and chemical properties using standardized data with zero mean and unit variance for 10-20 cm depth (Note: data not shown for P > 0.05)

Property	FC	WP	K_s	Sand	AWC	VTP	VSP	EC
WP	0.77***							
Sand		-0.61*						
Silt								
Clay		0.88**						
VTP		-0.64*	0.59*					
VSP					0.88**	0.59*		
θ_e	-0.67*	-0.62*	0.66*			0.97**	0.67*	
EC	-0.74***							
pH				-0.59*	-0.60*			
Ammonium-N	0.59*							
Nitrate-N	-0.83**	-0.68*				0.59*		0.91**

* is p-value 0.05-0.01; ** is p-value 0.01-0.001; *** is p-value <0.001; FC is water content at 30kpa; WP is water content at 1500kpa; K_s is saturated hydraulic conductivity; AWC is available water capacity; VTP is volume of transmission pores; VSP is volume of storage pores; θ_e is effective porosity; EC is electrical conductivity

At the 20-30 cm depth, clay content showed a positive correlation with FC (r = 0.84) and WP water content (r = 0.87) and FC with WP water content (r = 0.77; P< 0.001) (Table 6). The WP and AWC were retained for further analysis. The θ_e was inversely related to FC and VTP and positively with VSP, and θ_e

was retained. K_s was positively correlated with VTP (r = 0.68), nitrate-N (r = 0.90) and chloride (r = 0.73), and chloride with nitrate-N (r = 0.58). Nitrate-N was positively correlated with EC (r = 0.91) and EC was retained for assessing sustainability.

Table 6. The correlation coefficient among soil physical and chemical properties using standardized data with zero mean and unit variance for 20-30 cm depth (Note: data not shown for P > 0.05)

Property	ρ_b	FC	WP	K_s	Sand	Clay	AWC	VTP	VSP	θ_e	Nitrate-N
WP		0.85**									
Sand		-0.68*	-0.66*								
Silt											
Clay		0.84**	0.87**								
AWC		0.86**									
VTP		-0.72***	-0.70*	0.68*							
θ_e		-0.83**	-0.67*			-0.58*	-0.74***	0.73***	0.70*		
EC											
Ammonium-N		0.59*	0.76***					-0.73***		-0.59*	
Nitrate-N				0.90**				0.62*			
Chloride	-0.67*			0.73***				0.58*			0.58*

* is p-value 0.05-0.01; ** is p-value 0.01-0.001; *** is p-value <0.001; ρ_b is bulk density; FC is water content at 30kpa; WP is water content at 1500kpa; K_s is saturated hydraulic conductivity; AWC is available water capacity; VSP is volume of storage pores; θ_e is effective porosity; EC is electrical conductivity

Effect of Measured Soil Properties on Biomass Yield

The standardization of data effectively took care of the differences caused by the differences in units of measurement for various properties. At first, we related biomass yield as the dependent variable to each individual measured soil property as independent variable and found that silt content alone explained 47% of the variability of biomass yield (P<0.01). The VTP explained 44% (P<0.02), and sand content 27%, of variability of biomass yield, respectively (P<0.09) (Fig. 1; Table 7). The positive coefficient of silt content attested to the effect of the silt's smaller pore, which can increase the porosity and total water retention in the soil. The positive coefficient on the independent variable VTP indicated a direct relationship between biomass yield and VTP. Soil VTP increases the macroporosity and total infiltration of water into the soil. These pores also drain very quickly and are replenished with air relatively quickly. Thus, reduction of air-to-water ratio caused by rainfall or irrigation is quickly reversed. The negative value of the coefficient associated with sand content indicated the reduction in total porosity and water retention with increases in sand content. No other individual soil property provided a significant correlation.

The coefficient of determination increased from 0.44 to 0.83 for two parameter models (Table 7). Soil property pairs of AWC and VTP explained the greatest variability (83%) of biomass yield (P<0.0003). Silt content and θ_e, and sand content and $\theta_{e,}$ explained 79% and 77% variability of biomass yield, respectively (P<0.001). Some other pairs of soil properties, such as silt content and nitrate-N, silt content and K_s, VSP and sand content, bulk density and silt content, and silt content and ammonium-N, also were significantly correlated to biomass yield with R^2 ranging from 70% to 57% (P<0.02). In all the above mentioned pairs of independent variables, the coefficients for silt content, θ_e, nitrate-N, K_s and VSP were positive, and indicated that increasing values for these coefficients increased the biomass yield. On the other hand, coefficients for sand content, bulk density and ammonium-N content were negative and showed an inverse relationship to biomass yield.

The three-parameter linear model further improved the biomass yield vs. soil property relationship, and accounted for up to 93% of variability in biomass yield (Table 7). Three-parameter linear regression models of biomass yield, as the dependent variable, vs. sand content, AWC and θ_e; sand content, VTP and VSP; and silt content, AWC and VTP, as independent variables, respectively, explained about 92% of variability of biomass yield (P<0.0001). The coefficients for sand content were negative, whereas the coefficients for silt content, AWC, θ_e, VSP and VTP were positive. VTP, VSP and EC also explained 91% of variability in biomass yield ($P<0.0002$).

Only 47% of variability in total biomass yield from all four fields was attributed to differences in silt content, and 44% to differences in VTP. There were three significant one-parameter linear relationships that could be used to predict the biomass yield. The F-test results showed that there were four two-parameter linear relationships that showed significant improvement over the one-parameter linear model ($F>13$) (Table 7). There were five three-parameter linear relationships that showed significant improvement over the two-parameter model ($F>22$). Therefore, a total of 12 significant relationships were identified for predicting biomass yield variability by soil properties.

Table 7. Linear regression analysis for normalized biomass (Y) as the dependent variable, and measured and normalized soil properties as dependent variables

Model	P-value	R^2	SS	F-value	F-table
One parameter					
Y=-0.001+0.683*Silt	0.01	0.47	5.85		
Y=-7.39E-17+0.662*VTP	0.02	0.44	5.82		
Two parameters				F2-1	4.94
Y=0.001+0.669*AWC+0.901*VTP	0.0003	0.83	1.79	22.66	
Y=-0.001+0.809*Silt+0.580*θ_e	0.001	0.79	2.30	15.44	
Y=-9.13E-17+0.790*θ_e-0.868*Sand	0.001	0.77	2.52	13.27	
Y=-0.001+0.936*Silt+0.541*Nitrate-N	0.005	0.70	3.32	7.62	
Three parameters				F3-2	4.24
Y=0.001+0.330*Silt+0.542*AWC+0.756*VTP	0.0001	0.92	0.94	8.16	
Y=-4.26E-17-0.803*Sand+0.573*VTP+0.659*VSP	<.0001	0.92	0.94	8.07	
Y=0.001-0.816*Sand+0.412*AWC+0.884*θ_e	<.0001	0.92	0.96	7.82	
Y=-0.001+0.739*Silt+0.456*VTP+0.497*VSP	0.0002	0.90	1.09	5.74	
Y=0.001-0.266*Sand+0.585*AWC+0.834*VTP	0.0003	0.89	1.09	5.86	
Y=-9.59E-06+0.745*Silt+0.367*AWC+0.671*θ_e	0.0002	0.91	1.16	4.89	

SS is sums of squares; VTP is volume of transmission pores; AWC is available water capacity; θ_e is effective porosity; VSP is volume of storage pores; F value 2-1 is when SS from two parameter models compared to the SS from best-fit one-parameter model; F value 3-2 is when SS from three parameter models compared to the SS from best-fit two-parameter model

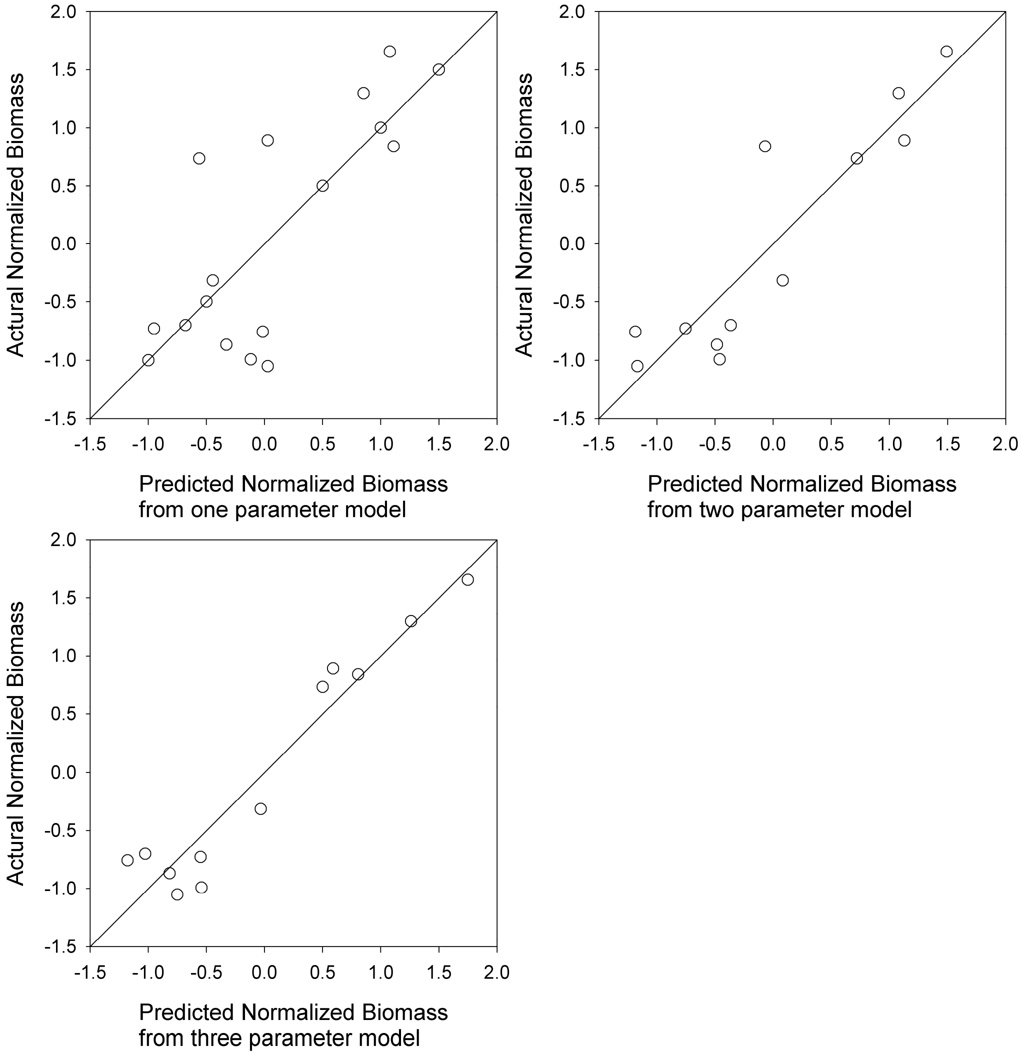

Fig. 1. Relationship between actual normalized biomass and predicted normalized biomass using one- two and three soil parameters models

Among soil physical and chemical properties, VTP was a factor in 6 of 12 one-, two-, or three-soil property vs. biomass yield relationships. The AWC was a factor in five, silt and sand content in four, θ_e in three, nitrate-N in two, and VSP and EC in one. Coefficients for VTP and AWC were always positive in all equations, which indicated that biomass yield increases with increasing available water content or porosity. The coefficient also was positive for silt and nitrate-N content. The coefficient on sand content and EC was negative indicating an inverse relationship with biomass yield. Reduction in biomass yield with increasing sand content is likely to be related to the reduction in the AWC.

Critical Levels of Measured Soil Properties

Critical levels were obtained for EC, pH, AWC, θ_e, ρ_b, WP, Ks, CFF, SOC, ERD and soil texture using Table 2. These critical levels were added up for each location, and the cumulative ratings (CR) were obtained for each field and depth, separately. The reference conventional site had consistently high CR and ranged from 27 ± 2.7 at the 0-10 cm depth to 28 ± 2.2 at the 20-30 cm depth. The lowest CR was obtained for the OF3 (CR= 22 ± 1.5) at the 0-10 cm depth. Overall CR for the 0-30 cm depth can be described as follows: OF3 (24 ± 2.3) < OF6 (25 ± 1.9) = OF9 (26 ± 1.2) < conventional (28 ± 2.3). Based upon the sustainability index (Lal, 1994); the conventional farming system ratings ranged from sustainable only with high input to sustainable with another land use. For 0-10 cm depth, the variation in cumulative rating can be described as OF3< OF6< OF9< conventional. For each field, the highest value of cumulative rating was obtained for the 10-20 cm depth. Increases in the cumulative rating with increasing duration of organic farming probably indicate the undercutting of benefits of organic matter additions to the soil due to the adverse impact of tillage that exposes the organic matter to rapid oxidation under the climatic conditions of arid New Mexico. Therefore, effects of manure additions in the organic farm seem to diminish, rendering the organic fields no different over time than the conventional one with respect to soil structure and related soil-plant-water-relations.

Soil Properties Rating Factor Effects on Biomass Yields

At first, we related biomass yield as a dependent variable to ratings of individual soil properties as independent variables and found that texture alone explained 58% of biomass yield variability ($P<0.01$). Inclusion of the ratings for two parameters in the regression as independent variables improved the coefficient of determination from 0.58 to 0.75 (Table 8). The rating for texture and θ_e together explained the greatest variability (89%) of biomass yield ($P<0.002$). The CR also showed a significant relationship with biomass yield among organic farms ($R^2 = 0.42$; $P<0.06$) with biomass yield decreasing as CR increased (Fig. 2).

Table 8. Linear regression analysis for normalized biomass (Y) as the dependent variable and ratings for soil properties as dependent variables. The table value of F2-1 = 4.96

Model	P<	R^2	SS	F-value	F-table
One parameter					4.96
Y=-1.263+0.842*Texture	0.004	0.58	4.60		
Two parameters					
Y=-0.334-0.266*θ_e +0.886*Texture	0.002	0.75	2.77	6.61	

SS is sums of squares; θ_e is effective porosity

Discussion

The VTP and silt content were predominant in explaining biomass variability. The variability expressed by the CV was 43% for VTP and only 18% for silt content across all four fields. The VTP is strongly influenced by tillage due to initial soil loosening and subsequent compaction, which causes changes in soil bulk density over the growing season (Franzluebbers 2002). Similarly AWC, which was also important in explaining biomass yield, is influenced by the changes in texture and bulk density. A slight increase in finer particles, organic matter or decrease in soil bulk density can increase the soil AWC (Harris & Megharaj 2001). In an arid environment, AWC increases may be important for maintaining available water supply to plants and moderating soil temperature. Therefore, among physical soil properties, VTP and AWC can vary during the growing season and can be treated as dynamic indicators of biomass productivity or dynamic soil quality indicators. EC and nitrate-N concentration, among the soil chemical properties best correlate with biomass productivity .Drinkwater et al. (1995) documented higher pH, soil organic C and N, and N mineralization potential in organic fields as compared with conventionally managed fields. For organic farming systems, nutrient cycling and retentive ability of the soil for nutrients can be high (Reganold 1988); at the same time, manure may contain elevated levels of salts. Soil EC and soil nitrate-N concentrations can vary during the growing season; therefore, these can be treated as dynamic indicators of biomass productivity.

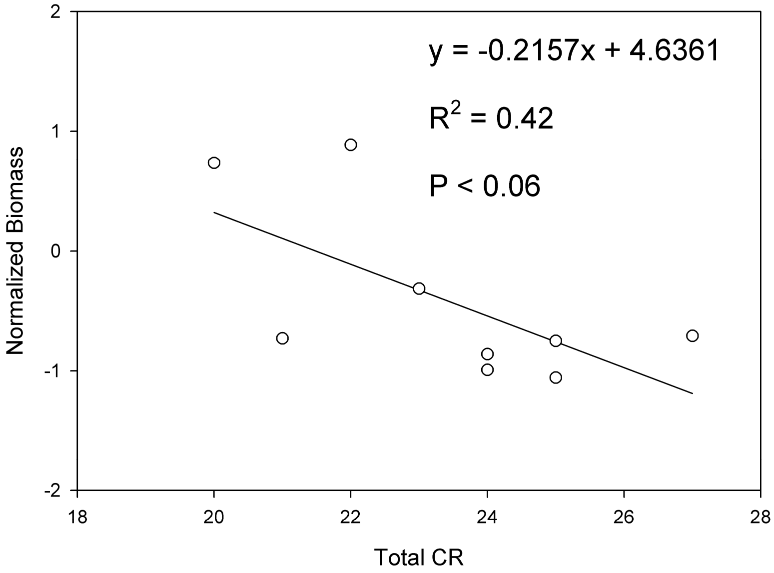

Fig.2. Relationship between total cumulative rating and normalized actual biomass yield from three organic fields.

Two-parameter models of sand content and θ_e, and silt content and θ_e are essentially very similar because of the strong negative correlation (r = -0.96) between sand and silt contents (Table 7). Similarly, three-parameter models of silt content-AWC-VTP and sand content-AWC-VTP are similar, and sand content-AWC-θ_e and silt content-AWC-θ_e are also similar (Table 7). Therefore, the total number of significant two-parameter relationships is reduced to three, and three-parameter relationships to four. Among the variables, VTP and AWC were present in most of the significant biomass vs. soil property relationships. Both these factors are important soil structure components. Since the current study area is located in an arid ecosystem, water availability is limited. Therefore, land use and management systems should be directed toward improving soil structure and soil water retention capacities.

There exists a strong correlation between sustainable land use and soil quality (Lal 1994). Thus, measured soil properties need to be interpreted in terms of the potential and constraints of the land use and management systems (Lal 1994). Several studies report improvement of soil structure and water transmission properties through manure application (Haynes & Naidu 1998, Harris & Megharaj 2001). However, the results of this study somewhat contradict those results by showing increased CR with increasing years of organic cultivation and lowering of soil quality in organic fields. The CR was highest for conventional field, which also had the lowest soil structural, water retention and transmission properties. A change in management practice can improve soil structure and water storage and transport properties, and make conventional farming more sustainable. Since the conventional field was planted to cotton for the past five years, one of the strategies to improve soil quality could be to follow crop rotations, which have been reported to improve soil quality (Mrabet et al. 2001).

The SOC is reported to be significantly related to biomass yields (Shukla et al. 2004). However, in this study, SOC was not found to be an important factor in one-, two- or three-parameter soil properties vs. biomass yield relationships. Tillage was the common management factor across experimental fields, and no significant relationship between SOC content and biomass yield pointed to the likely adverse impact of tillage on organic matter. Nitrogen deficiency and weed competition were identified as two primary problems with organic system in California (Sean et al. 1999). Nitrogen deficiency was overcome through legume cover crop management and weed competition by tillage (Pimentel et al. 2005). We did not find any nitrogen deficiency in the organic fields; however, alternate weed control other than conventional tillage is needed to improve the soil quality.

All organic fields were managed by the same farmer, and farm implements used on organic farms and the reference site were similar. All fields were managed conventionally for several years before being converted to organic management. Except for 2004, tillage practices and intensities were similar across experimental fields. Some of the limitations of this study were that replicated fields were not available and no consistent crop rotations existed in the experimental area. Still, this study showed that a change in farming systems from conventional to organic (refer the newest site, OF3) initially improved soil structural and water retention properties. Higher soil quality was likely due to the increased incorporation of residues in the form of manures in OF3. However, as time under organic farming increased, soil quality started to decline, indicating that conventional tillage is likely undercutting some of the advantages of increased manure application (Wander et al. 1994). Overall, the OF3 was more sustainable than the conventional system; yet there is a need to address the impact of tillage on soil quality in the organically farmed field. It is recommended that options like reduced tillage, more frequent crop rotations and cover cropping should be practiced in organic farms, as these have been shown to be beneficial for soil quality enhancement (Pimentel et al. 2005).

Conclusions

Acreage under organic production is continuously increasing in the state of New Mexico, USA. The major objective of this research was to look at the long-term sustainability of the organic cultivation system based on soil quality. The correlation analysis showed that significant relationships exist between soil properties. The multiple regression analysis with biomass yield as the dependent variable and measured soil attributes, or their ratings as independent variables showed that the pairs of VTP, AWC and silt or sand content explained the largest variability in biomass yield. Other important variables for explaining biomass yield variability were θ_e, nitrate-N and EC. A technique based on the limitations of soil was tested in this report, and ratings were obtained for the key soil properties. The CR for different farms suggested that OF3 was sustainable, OF6 and OF9 were sustainable with high input, and the conventional field ranged from sustainable with high input to sustainable with another land use. Among all experimental farms, the conventional was found to be the least sustainable. However, because CR increased with increasing amount of time under organic cultivation, a decline in soil quality is indicated, and there is a need to make adjustments to the existing organic management system for making it sustainable.

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