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Long-term Organic Farming Impacts on Soil Fertility

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Abstract

Very few long-term organic farming studies exist, especially in the central Great Plains. Data was gathered from annual soil tests from Grant Family Farms (GFF), the largest organic mixed crop farm in Colorado, located in the Great Plains in Northern Colorado. The land that now makes up GFF was purchased in the early 1970s and sustainable agricultural practices were used until the mid-1980s when organic farming practices were implemented. GFF uses leguminous cover crops as green manures and dairy manure as their only fertility inputs. Crop rotations among over twenty different vegetable and other crops are standard practice.

Soil test data from twelve fields, 17 to 50 acres (7 to 20 hectares) in size, was compiled and analyzed for changes over time in soil chemical properties for ten soil fertility components: pH, electrical conductivity (EC), soil organic matter (SOM), nitrate (NO_3-N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). The number of years of data per field ranges from to 5 to12 over the period of 1985 to 2000.

Annual soil tests revealed a significant increase in P, K, SOM, Zn, Fe levels in ≥ 33% of the fields. Soil pH decreased significantly ($p<0.05$) in four fields. P reached a level that could be an environmental risk if soils are not managed carefully. NO_3-N and Cu did not change significantly over time in organic production in any of the observed fields. Overall, there was an observed increase in soil fertility components over time in organic production. Further studies should be done with multiple soil samples per year, to more accurately reflect changes over time.

Introduction

A common definition of organic agriculture is farming without synthetic pesticides and conventional fertilizers. Alternatively, the National Organic Standards Board defines organics as: "an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony (Organic Trade Association website. No date. http://www.northcoast.com/~startrak/ota/legislat.htm)."

Organic management practices including cover crops, green manures, crop rotation, and manure applications increase the fertility of the soil over time as opposed to conventional systems in which chemical fertilizers are used to maintain fertility (Clark et al., 1998; Petersen et al., 1999). Soil chemical, physical, and microbial properties all influence levels of fertility. A complex management system pays attention to all of these components. A few studies have been holistic in their approach, examining the effects of organic farming on two or more of these properties (Goh et al., 2001; Petersen et al., 1999; Reganold, 1988; Reganold et al., 1993; Scow et al., 1994; Swezey et al., 1998). In contrast, this study examines only the soil chemical data gathered from annual soil tests on a working organic farm. As such, it offers a limited perspective of the entire quality of the soil.

The objective of this research project is to assess the impact of the transition of what is currently named Grant Family Farms (GFF) from a conventional to an organic farm. The changes in the following fertility components over time in organic production have been evaluated: pH, electrical conductivity (EC), soil organic matter (SOM), nitrate (NO_3-N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). Only a few long-term studies examining soil fertility have been conducted on organic farming (Petersen et al., 1999; Reganold, 1988). Most organic farming research has been done on the U.S. West Coast, Pennsylvania, Europe, and some tropical areas; no formal research has been conducted in irrigated organic systems in the central Great Plains. This paper will address the effects of organic farming on soil fertility in the semi-arid climate of Northern Colorado over the periods of five to fifteen years.

Literature Review

Studies show that organic farming improves soil fertility over time (Clark et al., 1998; Drinkwater et al., 1995; Petersen et al., 1999). Some factors contributing to soil quality are microbial biomass and diversity, soil physical structure, water infiltration, carbon and nitrogen content and dynamics, and soil nutrient availability (Granatstein and Bezdicek, 1992). Organic farming can also have short-term negative effects on soil fertility. Nitrogen applied as a green manure can have a delayed effect (Jackson et al., 1995). The transition period between conventional and organic farming practices is often marked by a decrease in nitrogen (N) availability and in yields due to a shift in biological activity and N sources that are not immediately available for plant use (Petersen et al., 1999).

Soil Biological Properties

Among the benefits of organic farming is an increase in soil microbial activity and biological processes, which enhance the health of the soil (Fraser et al., 1988; Gunapala and Scow, 1998; Helwig, 1988; Linderman, 1988; Petersen et al., 1999; Scow et al., 1994; Werner, 1997). A decrease in disease and parasitic nematodes has also been observed (Scow et al., 1994). The Rodale Institute Farming Systems Trial (RIFST) evaluated microbial activity by measuring soil respiration rates and available or potentially available nitrogen levels. Of the three farming system treatments [animal-based (cover crops and animal manure only), legume-based (cover crop only), and conventional (N fertilizer)], the two organic systems had higher levels of microbial activity as well as a more diverse species composition than the conventional system (Wander et al., 1994). Werner (1997) found an earthworm population 2.5 times greater in organic plot tree rows than conventional ones (on one of the sample dates). In addition, vesicular-arbuscular mycorrhizal fungi, known to enhance P absorption by host roots (Linderman, 1988), also had significantly greater populations in the organic orchard plots than the conventional ones (Werner, 1997). An increase in soil microorganisms and earthworms helps improve the physical structure of the soil by enhancing soil aggregation and aeration (Reganold, 1988).

Soil Physical Properties

Organic fertility inputs like farmyard manure (FYM) and green manure (GM) improve soil physical properties by lowering bulk density, increasing water-holding capacity, and improving infiltration rates (Petersen et al., 1999; Tester, 1990; Werner, 1997). During conversion to organic orchard management, Werner (1997) found a significantly lower bulk density in the transitional organic plots than the conventional ones. Lower bulk density implies greater pore space and improved aeration, creating a choice environment for biological activity (Werner, 1997). Cover crops, specifically, influence several aspects of soil structure such as aggregation of soil particles, soil crusting, and soil compaction (Goldhamer et al., 1994; Hargrove et al., 1989; Knoblauch and Odlund, 1938). Soil structure is also preserved by prevention of erosion due to the covering of the soil. In the RIFST (Petersen et al., 1999), organic soils were looser and more porous with higher water-holding capacity. Tester (1990) also found that amending soil with compost significantly decreased bulk density and increased soil water content.

pH

Changes in soil pH over time occur by the displacement of cations or by additions of sources of acidity like hydrogen and aluminum ions (Tisdale et al., 1993). Chemical fertilizers are highly reactive and can cause extreme pH fluctuations in localized areas such as those near the fertilizer band. Inorganic ammonium fertilizers, especially ammonium sulfate, lacking a metallic cation, displace base elements from soil colloids and acidify the soil (Cooke, 1967). In contrast, organic manures can increase the buffering capacity of soils, preventing swings in pH, because of the additional organic matter (Arden-Clarke and Hodges, 1988). Comparison studies of conventional and organic agroecosystems revealed that organic systems sometimes have higher pH levels in mildly acidic soils than their conventional counterparts (Alvarez et al., 1993; Clark et al., 1998; Drinkwater et al., 1995; Reganold et al., 1993; Werner, 1997). This illustrates the important role organic manures and other organic matter inputs can have in buffering the soil (Arden-Clarke and Hodges, 1988; Stroo and Alexander, 1986). Alvarez et al. (1993) compared an organic pineapple production system, with compost as its only fertility input, with a conventional system using chemical nitrogen, phosphorus, and potassium fertilizer. They found that pH and available Ca and Mg were higher with the compost application.

Clark et al. (1998) conducted an eight-year study in the Sacramento Valley on changes in soil chemical properties resulting from organic and low-input farming practices. The four treatments were: (1) organic (animal manure and winter cover crops), (2) low-input (cover crop and manure for the first three years; cover crop and synthetic fertilizer for the last five years), (3) conventional-4 (synthetic fertilizer with a four year crop rotation), and (4) conventional-2 (synthetic fertilizer with a two year crop rotation). An increase in the pH levels of all four systems over a four-year period (all soils began at 6.8-6.9), most likely occurred because of the discontinuance of ammonium fertilizer applications in all treatments. Soil pH was significantly higher (in the top 30 cm) in the organic soils (0.2 units higher) that depended on winter cover crops and manure for fertility. During the last four years of this eight-year study, the pH of the conventional systems stabilized while the low-input and organic systems showed a consistent increase up to 7.3 in the top 30 cm of soil. The pH of the low-input system still increased even after manure applications ceased, indicating that cover crops may increase availability of additional cations. Conversely, Hargrove et al. (1989) found that hairy vetch caused a decrease in soil pH in an acidic soil, contributing to an increase in soil Mn availability to the point of plant toxicity.

Organic Matter and Soil Carbon Pools

There is documented evidence that organic and biodynamic farming practices increase SOM content (Alvarez et al., 1988; Clark et al., 1998; Drinkwater et al., 1995; Goh et al., 2001; Lockeretz et al., 1981; Petersen et al., 1999; Reganold, 1988; Reganold et al., 1993; Swezey et al., 1998). During the transition years from conventional to organic farming systems, soils show a very slow but important increase in soil organic matter (Clark et al., 1998; Kuo et al., 1997). The high organic matter content of manure contributes to soil tilth and nutrient-holding capacity (Tisdale et al., 1993).

Wander et al. (1994) proposed that the quantity of SOM may not show the whole picture, but a comparison of SOM quality reveals marked differences in farming systems that use cover crops and other organic inputs and those that do not. They conducted a ten-year comparison study (RIFST) of the effects of organic and conventional management on biologically active SOM pools. The animal-based system comprised the highest quality active SOM according to apparent rates of SOM turnover and biological activity (respiration). The legume-based system was the best net carbon sink of the three even though it had greater respiration rates and received the least total carbon inputs.

After four years, Clark et al. (1998) found that SOM levels in the 0-30 cm depth had increased in the organic and low-input treatments by 19%. The SOM in the Conventional-4 treatment increased by 10% because of the crop rotation (four year rotation of tomato, safflower, corn, wheat-bean), while no changes in SOM occurred in the Conventional-2 system. By the eighth year, the organic and low-input farming plots revealed small but important increases in SOM and larger pools of stored nutrients, which are critical for long-term soil fertility maintenance (Clark et al., 1998). Alvarez et al. (1988) found a positive correlation between soil organic matter content and available Ca, K, Mg, Na, and P.

N, P, K

Changes in soil nutrient contents, in addition to SOM and pH have also been documented. Generally, total soil N increases with the use of organic practices (Drinkwater et al., 1995; Reganold, 1988; Reganold et al., 1993; Wander et al., 1994). Soluble P, and exchangeable K can also be greater in organic systems (Alvarez et al., 1988; Clark et al., 1998; Petersen et al., 1999; Reganold, 1988; Reganold et al., 1993).

The RIFST examined, among other things, the effects of organic farming on soil nutrient levels (Petersen et al., 1999). Comparing three distinct farming systems, they found that total soil N increased in the manure-based system, remained the same in the legume-based system, and significantly decreased in the conventional system. Nitrogen supplied by legumes was retained in the soil better than N supplied by mineral fertilizers. When the two were compared, nearly twice as much N, derived from legumes, remained in the active fraction of the SOM a year after a cover crop was incorporated (Wander et al., 1994). In this same study, the available

P and K contents of all three treatments decreased over time. The manure-based system experienced a slower declining rate compared to the conventional and legume-based systems due to the nutrient content of the applied manure (Petersen et al., 1999). In the first four years of the eight-year Sacramento Valley study, Clark et al. (1998) observed an increase in both soluble P and exchangeable K in the organic and low-input systems. Ceasing manure applications in the low-input system resulted in declining levels of soluble P and exchangeable K.

EC

Electrical conductivity is a measure of total cations and anions in soil solution and is usually determined mainly by calcium and magnesium ions, depending on the soil type. The EC is tightly linked to NO_3-N concentration in the soil (Patriquin et al., 1993). Good organic management practices do not increase soil salinity (Clark et al., 1998). Werner (1997) observed relatively stable EC levels in the organic system, indicating that animal manure did not increase salinity. Manure has varying levels of salinity (Table 1) depending on the amount of salt present in animal feed.

Micronutrients

The majority of research has focused on SOM, soil nitrogen, potassium, and phosphorus. In comparison, very little research has evaluated on micronutrient impacts of organic farming practices (Pique, E. et al., 1996). Farmyard manure naturally provides micronutrients whereas chemical fertilizers usually only have nitrogen, phosphorus, and potassium (Table 1). Organic matter stores micronutrients in both stable and usable forms (Tisdale et al., 1993).

Table 1. Dairy manure EC, OM, and nutrient levels based on a wet weight basis*

	EC mmhos/cm	OM %	NO_3-N mg/kg	P %	K %	Fe %	Mn %	Cu %	Zn %
Ave	17.8	17.5	60.1	0.38	1.45	0.37	0.01	60	95
Min	1.5	10.1	0.1	0.11	0.19	0	0	0	0
Max	29.5	29.0	673.9	0.83	3.37	0.97	0.02	187	162
N	18	9	33	51	51	40	40	38	38

*Source: Jessica Davis, Colorado State University. Minimum, maximum, and average values for some dairy manure contents based on samples taken from various sources in Colorado.

In summary, the literature reveals marked differences between organic and conventional farming practices. Organic practices lead to an increase in SOM, available P, K, soil N levels, and have a neutralizing effect on soil pH. The EC is not significantly higher in organic plots compared with conventional ones. Very little evidence is available on the effects of organic farming methods on micronutrient soil levels and availability.

Materials and Methods

Study Site

Grant Family Farms is the largest vegetable and mixed crop organic farm in Colorado. It is located in the Great Plains just east of the foothills of the Rocky Mountains north of Fort Collins, Colorado. It has a semi-arid climate averaging about 13 inches (33 mm) of precipitation per year. The alkaline soil's texture varies from clay to clay loam and sandy clay loam.

Table 2. Description of Observed Fields[*]

ID #	Field Name	Size		Soil Texture
		Ac.	Ha.	
1	Pie 1 E	40	16	Clay loam
2	Pie 2 E	50	20	Sandy clay loam
3	Pie 2 NW	25	10	Sandy clay loam
4	Pie 2 SW	25	10	Clay
5	Pie 3 E	63	26	Sandy clay loam
6	Pie 3 W	63	26	Sandy clay loam
7	Pie 4 N	17	7	Clay
8	Pie 4 S	17	7	Clay
9	Black 1	27	11	Clay
10	Black 2	46	19	Clay
11	Black 3	30	12	Clay
12	Black 4	30	12	Clay

*Organic practices began in 1983 for Field 7 and 8 and 1985 for all other fields.

Farming System Description

From 1971 until the mid-1980s, some fields at GFF were farmed organically, and the others were farmed conventionally. Even during this period, practices that are now considered part of "sustainable agriculture" were employed on the conventional fields, but commercial fertilizers and chemical pesticides were also used in these conventional fields. Grant Family Farms employed these sustainable practices even before organic production began: crop rotation, crop cover to avoid wind and water erosion, green manures, dairy manure applications to reduce fertilizer needs, and contour planting on steeper sloping fields. By the mid-1980's, all fields were being farmed using fully organic farming practices. GFF has a goal of using a green manure, on average, two out of every three years and aims to apply dairy manure (usually in the Fall) once every three years. Occasionally, depending on the soil analysis, there is also a green manure grown in years receiving manure applications. Green manures are planted at one of three times depending on the crop rotation: spring (March-June), summer (July-October), or fall (October-March). Generally, a vetch/rye mix or Austrian pea/rye mix is used for over-wintered green manures, and oats or field peas are used for spring and summer. The tillage methods employed by GFF include plowing to turn under the cover crop or manure. Center pivots are installed in each field for irrigation.

Soil Sampling and Analysis

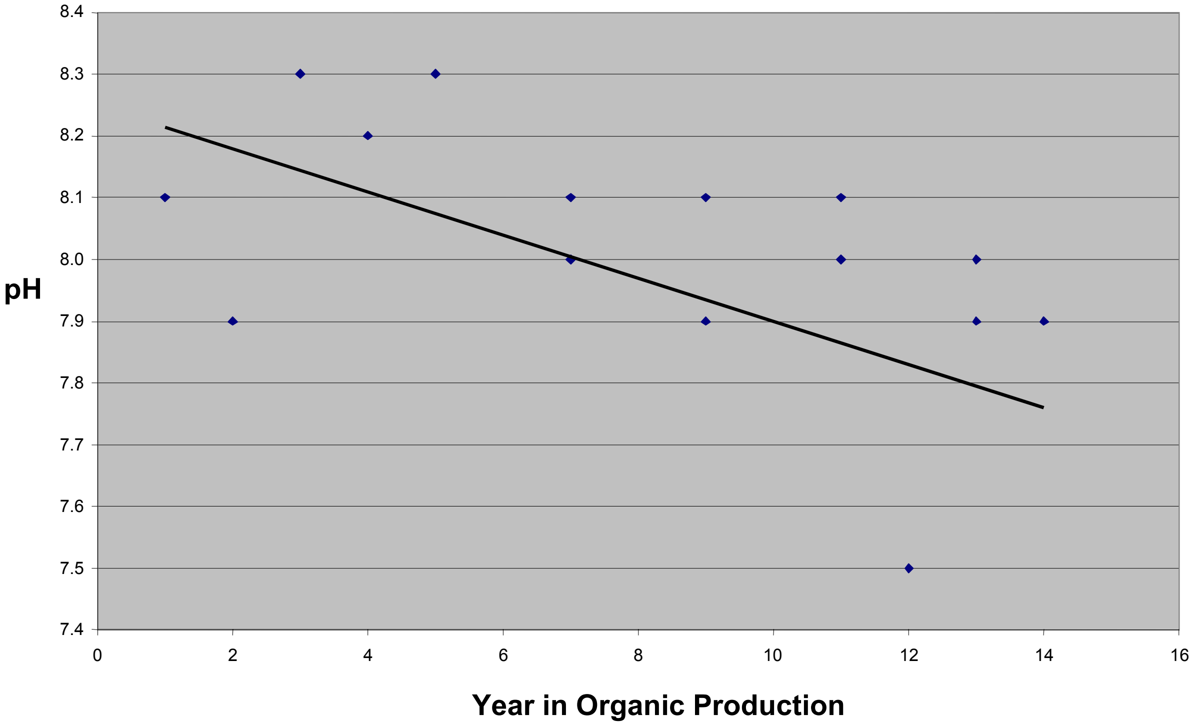
Generally, soil tests were taken in the fall after harvest and before any winter green manure plantings or dairy manure applications. Soil tests, conducted at Colorado State University (CSU) Soil, Water, and Forage Testing Laboratory were based on pint-sized soil samples taken by GFF. Soil probes were taken from each field, numbering 15-20 per 20 acres (8.1 ha.), or approximately 1 core per acre. The sub-samples, taken from the top 12 inches (30 cm) of soil, were collected and thoroughly mixed. The samples were then tested for these ten soil fertility components: pH, EC, SOM, NO_3-N, P, K, Zn, Fe, Mn, and Cu. Soil pH and EC were measured in a saturated paste, using a pH meter and a conductivity meter. The Walkley and Black (1934) method was used to determine percent SOM. Available NO_3-N, P, K, Zn, Fe, Mn, and Cu were extracted using ammonium bicarbonate-DTPA (Soltanpour and Schwab, 1977). The NO_3-N was then auto-analyzed using the zinc reduction method; the molybdate blue method was used to measure available P (Rodriguez et al., 1994; Murphy and Riley, 1962), and K, Zn, Fe, Mn, and Cu were analyzed using a spectrophotometer and inductively coupled plasma (Soltanpour, 1991).

Data Compilation and Analysis

Data was compiled from GFF archives of CSU soil analyses dating from 1985 to 2000 (Appendix D). There are multiple samples for some years, but not every year is represented in each field. The initial samples from the time (1970s) the Grants started farming the respective fields provide a point of comparison (Appendix B), but were not included in the data analysis. The number of samples (n) per field ranged from 5 to 20.

Soil fertility components were evaluated as a function of years in organic farming (YrsOrgFarming) using regression techniques in SAS (Fig. 1). The data for each of the twelve fields was analyzed (CSU Statistics Laboratory) using a linear model with linear and quadratic terms. The linear model included the quadratic term to first test for a departure from linearity. Data was then analyzed using the non-linear model: Component = a+b*(1-exp(-c*YrsOrgFarming)). Neither the model with a quadratic term nor the nonlinear models fit the data as well as the model with only the linear term due to a limited number of data points per field.

Figure 1. Linear regression of pH over time in organic production (Field 1).



Change in pH over time in organic production: (y=-0.0349x + 8.2492). R-square =0.2154. p=0.061

Results

Soil pH levels decreased significantly ($p<0.05$) with time in organic production in 33% of the fields (Table A-1). The slopes in these four fields ranged from –0.03 to –0.02 pH units per year. R-square values ranged from 0.35 to 0.67.

The EC increased significantly ($p<0.05$) in only two (17%) of the fields with slopes of 0.04 mmhos/cm per year in organic farming. These fields had the largest number of samples ($n=17$, 20). R-square values were 0.30 and 0.39 (Table A-2).

Soil organic matter percentages increased significantly ($p<0.05$) with time in organic production in four fields (33%) with slopes of 0.03 to 0.08 % per year (Table A-3). R-square values in these fields ranged from 0.26 to 0.48.

Available soil NO_3-N did not change significantly ($p<0.05$) over time in any of the test fields (Table A-4).

Every field but one (92%) showed significant increases ($p<0.05$) in available P over time in organic farming with slopes of 1.32 to 2.74 ppm per year. R-square values ranged from 0.55 to 0.93 in these eleven fields (Table A-5). The remaining field (#7), that did not show significant change over time, only had five samples ($n=5$) and only represented five years of data.

Available K increased significantly ($p<0.05$) with time in organic farming in 67 % of the fields with slopes of 8.61 to 20.04 ppm per year. R-square values in these eight fields ranged from 0.42 to 0.86 (Table A-6). The remaining four fields still had fairly low, but not significant p values (<0.20).

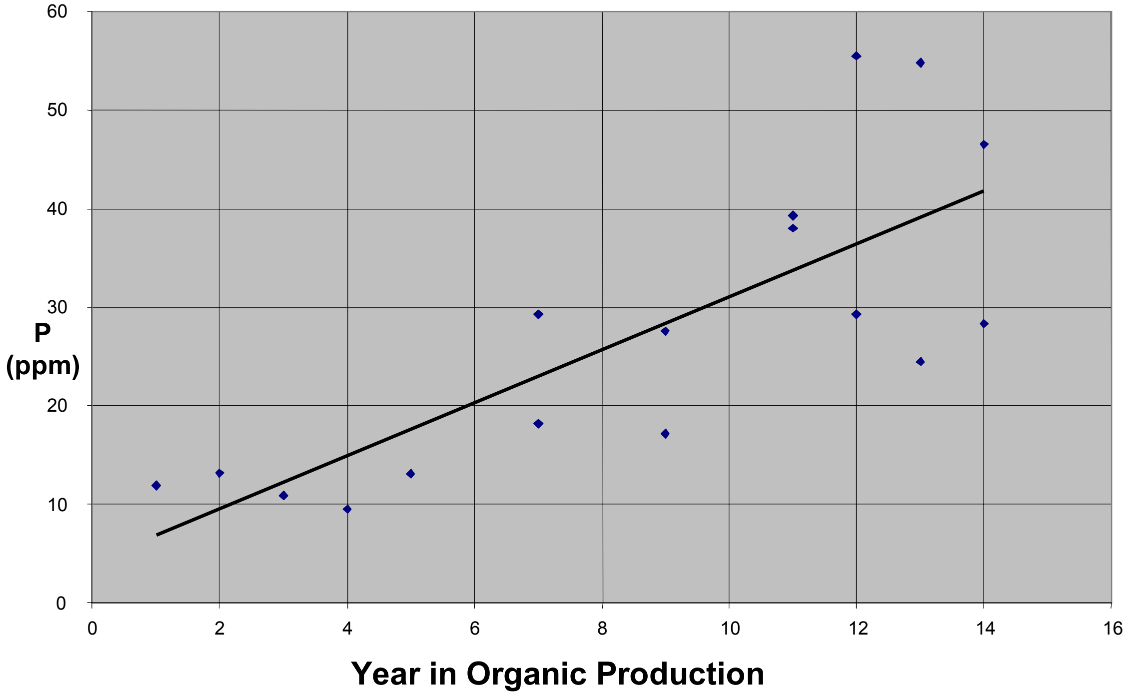
Available Zn increased significantly in 42% of the fields with slopes of 0.06 to 0.13 ppm per year in organic production. R-square values ranged from 0.40 to 0.82 in these five fields (Table A-7).

Available Fe increased significantly ($p<0.05$) in 5 fields or 42% of the fields. R-square values ranged from 0.34 to 0.60 in these fields. Slopes ranged from 0.39 to 0.93 ppm per year.

Two out of twelve fields (17%) showed a significant increase ($p<0.05$) in available Mn levels with slopes of 0.20 and 0.21 ppm per year in organic production. R-square values in these two fields were 0.60 and 0.70 (Table A-9).

Available soil Cu did not change significantly ($p<0.05$) over time in any of the test fields (Table A-10).

Figure 2. Linear regression of available P over time in organic production (Field 1).



Change in available P over time in organic production: ($y=2.6891x + 4.224$). R-square =0.6098. Available P increased significantly in Field 1 ($P=0.0002$).

Conclusions/Recommendations

Tisdale et al. (1993) identified four causes of soil acidification in crop production systems. The first is commercial fertilizers, "especially NH_4-N sources that produce H^+ during nitrification; secondly, crop removal of cations in exchange for H^+; thirdly, the leaching of these cations being replaced first by H^+ and subsequently by Al^{3+}; and fourthly, the decomposition of organic residues" (Tisdale et al., 1993). Four of the GFF fields showed a significant decrease in pH. Baseline pH levels before organic practices began ranged from 7.9-8.1; these numbers changed to 7.6-7.9 in the last year analyzed. The four fields that showed significant decreases ($p<0.05$) in pH also increased significantly in available P, K, and Fe.

EC significantly increased in two fields but still remained within the satisfactory levels for some field crops (Soltanpour and Follett, 2001), but reached detrimental levels in some years for sensitive vegetable crops like lettuce, onions, carrots, and beans, all of which GFF cultivates (Soltanpour and Follett, 1995). Manure applications did not cause a detrimental increase in soil salinity.

According to previous studies, SOM increases very slowly and may take several years to detect. Wander et al. (1994) recorded a very small increase (a few tenths of a percent) after ten years of organic farming. Werner (1997) found no difference in SOM levels after only two years in organic orchard management. For four of the fields, GFF soil testing revealed a very slight increase of SOM (<0.10 %) per year in organic production. The SOM levels remained in the medium category (1.5-3.0) with a few exceptions (Rodriguez, et al., 1994). For example, Field 1 had an exceptionally high (3.7, 3.6) The SOM content in years 12 and 13 (Table D-1); in years 13 and 14, Field 3 (Table D-3) also had unusually high SOM measurements (3.7, 4.0). These high percentages may be attributed to the timing of soil sampling, perhaps taken after a dairy manure application or green manure incorporation. The SOM levels fluctuate throughout the growing season, depending on precipitation, microbial processes, dairy manure and green manure incorporation. Multiple samples must be taken to accurately measure changes over time in SOM content.

Available P levels increased significantly over time 11 of the fields (Table A-5) to high (12-15 ppm) and very high levels (>15 ppm) for crop production (Soltanpour and Follett, 2001). In the 1970's, Fields 2-6 level ratings (Appendix B) were very low (0-3) to low (4-7 ppm) and increased to very high (>15 ppm) for crop production over time in organic production (Soltanpour and Follett, 2001). High levels of P in erodible soils (steeply sloping, uncovered) can be a serious environmental risk (Arden-Clarke and Hodges, 1988). The Colorado Phosphorus Index Risk Assessment (Sharkoff et al., 1999) identifies four factors that "can affect the potential for movement of P off-site". These are (1) runoff class, (2) soil test levels, (3) application rate, and (4) application method. Soils with steep slopes and low permeability rate high in the runoff class; soil test levels (AB-DTPA) of greater than 40 ppm are considered to be "very high"; and P_2O_5 application rates of >150 lbs/ac. (165 kg/ha.) are rated "very high" for environmental risk. Application methods should minimize the time in which the P application is exposed on the soil surface. Injection or subsurface applications rate the lowest for potential P losses while fall/winter surface applications with incorporation within two weeks rate high for risk of offsite P loss (Sharkoff et al., 2000). Grant Family Farms uses cover crops and contour planting for the steeper sloping fields to avoid soil erosion; however, most of the fields do not have steep slopes and all fields have good permeability rates.

As expected from the literature (Alvarez et al., 1988; Clark et al., 1998; Petersen et al., 1999; Reganold, 1988; and Reganold et al., 1993), levels of available K also increased significantly in eight fields. Clay soils in Colorado are not prone to K deficiencies, and additions of dairy manure and green manure to the soil replace K that is depleted by crop use (Miller and Donahue, 1995). The average K content of dairy manure (Table 1), according to analyses of 51 samples from different sources, is 1.45 %, with a range of 0.19% to 3.37%.

Many micronutrients are least available in basic soils. However, dairy manure can contain substantial amounts of these (Table 1). Zinc deficiencies occur mostly in basic soil, but solubility can increase 100-fold for each unit that pH is lowered (Miller and Donahue, 1995). The Zn content of the manure as well as the drop in pH are likely explanations for the significant available Zn increase in Fields 2, 5, 6, 8, and 9 (Table A-7). Four of the five fields in which Fe increased significantly ($p<0.05$) also decreased significantly in pH. Fields 3 and 4 increased from marginal levels to adequate levels of Fe (Table B-3, Table B-4) over time in organic production.

Nitrate levels fluctuate radically throughout a growing season and are highly dependent in the crop grown that season prior to the fall soil sample. As such, nitrate measurements do not accurately reflect N reserves in the soil. More complex measurements are needed to accurately reflect soil nitrogen dynamics (Petersen et al., 1999).

In summary, annual soil tests revealed a significant increase ($p<0.05$) in P, K, SOM, Zn, and Fe and decreased in pH levels in $\geq$ 33% of the fields. Available P reached a level that could be an environmental risk if soils are not managed carefully. Using cover crops and planting on the contour, as GFF practices, will help prevent loss of P from the site into water sources. Soil pH decreased significantly ($p<0.05$) in four fields. The drop in soil pH is due to an increase of H^+ and Al^{3+} ions in the soil solution and may partially explain the increase in available micronutrients (Zn, Fe, Mn). Manure also contributed to soil micronutrient levels and organic matter increased the buffering capacity of the soil, lowering pH. Mn increased significantly ($p<0.05$) in only two fields, while Cu and NO_3-N showed no significant changes over time in organic production. Salts measured by EC reached problematic levels for some vegetable crops in some years (Soltanpour and Follett, 1995). Based on the evidence provided by soil analyses, organic farming practices increased soil fertility levels over time in organic production. One constraint of this study is the limited number of data points per field. Sampling numerous times throughout the year would more accurately reflect soil nutrient levels. GFF will continue in organic production for years to come, providing data for more research. Organic farmers must take care with manure applications, as P levels may create an environmental risk (Sharkoff et al., 2000).

References

1. Alvarez, C.E., A.E. Carracedo, E. Iglesia, and M.C. Martinez. 1993. Pineapples cultivated by conventional and organic methods in a soil from a banana plantation. A comparative study of soil fertility, plant nutrition and yields. Biological Agriculture and Horticulture 9: 161-171.

2. Alvarez, C.E., C. Garcia, and A.E. Carracedo. 1988. Soil fertility and mineral nutrition of an organic banana plantation in Tenerife. Biological Agriculture and Horticulture 5: 313-323.

3. Arden-Clarke, C., and R.D. Hodges. 1988. The environmental effects of conventional and organic/biological farming systems. II. Soil ecology, soil fertility, and nutrient cycles. Biological Agriculture and Horticulture. 5:223-287.

4. Clark, M. Sean, W.R. Horwath, C. Shennan, K.M. Scow. 1998. Changes in soil chemical properties resulting form organic and low-input farming practices. Agronomy Journal 90: 662-671.

5. Cooke, G.W. 1967. The control of soil fertility. English Language Book Society and Crosby Lockwood Staples, London.

6. Drinkwater, L.E., D.K. Letourneau, F. Workneh, A.H.C. van Bruggen, C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecological Applications 5(4): 1098-1112.

7. Fraser, D.G., J.W. Doran, W.W. Sahs, and G.W. Lesoing. 1988. Soil microbial populations and activities under conventional and organic management. Journal of Environmental Quality 17:585-590.

8. Goh, K.M., D.R. Pearson, and M.J. Daly. 2001. Effects of apple orchard production systems on some important soil physical, chemical and biological quality parameters. Biological Agriculture and Horticulture 18: 269-292.

9. Goldhamer, D.A., D.W. Grimes, S.H. Gulick, D.S. Munk. 1994. Cover-cropped-enhanced water infiltration of a slowly permeable fine sandy loam. Soil Science Society of America Journal 58: 1539-1546.

10. Granatstein, D. and D.F. Bezdicek. 1992. The need for a soil quality index: Local and regional perspectives. American Journal of Alternative Agriculture 7(1/2): 5-16.

11. Gunapala, N., and K.M. Scow. 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. Soil Biology and Biochemistry 30:805-816.

12. Hargrove, W.L., K.A. McVay, and D.E. Radcliffe. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Science Society of America Journal 53: 1856-1862.

13. Helweg, A. 1988. Microbial activities in soil from orchards regularly treated with pesticides compared to the activity in soils without pesticides (organically cultivated). Pedobiologia. 32:273-281.

14. Jackson, L.E., K.F. Schulback, L.J. Wyland. 1995. Soil plant nitrogen dynamics following incorporation of a mature rye cover crop in a lettuce production system. Journal of Agricultural Science. Cambridge. 124:17-25.

15. Knoblauch, H.C. and T.E. Odlund. 1938. The value of cover crops in continuous corn culture. Journal of the American Society of Agronomy 30(1): 22-29.

16. Kuo, S., U.M. Sainju, E.J. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. Soil Science Society of America Journal 61(1):145-152.

17. Linderman, R.G. 1988. VA (vesicular-arbuscular) mycorrhizal symbiosis. ISI Atlas Anim. Plant Sci., 1(2): 183-188.

18. Lockeretz, W., G. Shearer, and D.H. Kohl. 1981. Organic farming in the corn belt. Science 211: 540-547.

19. Miller, R.W. and Donahue, R.L. 1995. Soils in our environment (7th Edition). Prentice Hall, Englewood Cliffs, New Jersey. 649 pp.

20. Murphy, J., and J.P. Riley. 1962. A modified single solution method for determination of phosphates in natural waters. Anal. Chim. Acta 27:31-36.
21. Patriquin, D.G., H. Blaikie, M.J. Patriquin, C. Yang. 1993. On-farm measurements of pH, electrical conductivity and nitrate in soil extracts for monitoring coupling and decoupling of nutrient cycles. Biological Agriculture and Horticulture 9(3): 231-272.
22. Petersen, C., L.E. Drinkwater, and P. Wagoner. 1999. The Rodale Institute Farming Systems Trial: The first fifteen years. Kutztown, PA: The Rodale Institute.
23. Pique, E., C.E. Alvarez, and M. Fernandez. 1996. Micronutrients in soils and plants from organic farms of Tenerife (Canary Islands). Biological Agriculture and Horticulture 13: 113-122.
24. Reganold, J.P. 1988. Comparison of soil properties as influenced by organic and conventional farming systems. American Journal of Alternative Agriculture 3(4): 144-154.
25. Reganold, J.P., A.S. Palmer, J.C. Lockhart, and A.N. Macgregor. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. Science 260:344-349.
26. Rodriguez, J.B., J.R. Self, and P.N. Soltanpour. 1994. Optimal conditions for phosphorus analysis by the ascorbic acid molybdenum blue method. Soil Science Society of America Journal 58:866-870.
27. Scow, K.M., O. Somasco, H. Ferris, N. Gunapala, S. Lau, R. Venette, R. Miller, C. Shennan. 1994. Transition from conventional to low-input agriculture changes soil fertility and biology. California Agriculture 48(5): 20-26.
28. Sharkoff, J.L., R.M. Waskom, and J.G. Davis. 2000. Colorado phosphorus index risk assessment. USDA-NRCS Agronomy Technical Note No. 95.
29. Soltanpour, P.N. and A.P. Schwab. 1977. A new soil test for simultaneous extraction of macro and micronutrients in alkaline soils. Comun. Soil Sci. Plant Anal. 8:195-207.
30. Soltanpour, P.N. and R.H. Follett. 1995. Crop tolerance to soil salinity. Colorado State University Cooperative Extension Fact Sheet No. 0.505.
31. Soltanpour, P.N., and R.H. Follett. 2001. Soil Test Explanation. Colorado State University Cooperative Extension Fact Sheet No. 0.502.
32. Stroo, H.F., and M. Alexander. 1986. Role of soil organic matter in the effect of acid rain on nitrogen mineralisation. Soil Science Society of America Journal 50:1219-1223.

33. Swezey, S.L., M.R.Werner, M. Buchanan, and J. Allison. 1998. Comparison of conventional and organic apple production systems during three years of conversions to organic management in Coastal California. American Journal of Alternative Agriculture 13(4):162-180.

34. Tester, C.F. 1990. Organic amendment effects on physical and chemical properties of a sandy soil. Soil Science Society of America Journal 54(3):827-831.

35. Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L. Havlin. 1993. Soil fertility and fertilizers. 5th ed. Macmillan Publ. Co., New York. 634 pp.

36. Walkley, A. and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chronic acid titration method. Soil Science 37:29-38.

37. Wander, M.M., S.J. Traina, B.R. Stinner, S.E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Science Society of America Journal 58: 1130-1139.

38. Werner, M.R. 1997. Soil quality characteristics during conversion to organic orchard management. Applied Soil Ecology 5: 151-167.

Appendix A-Statistical parameters from regression of soil fertility components.

Table A-1. Statistical parameters from regression of soil pH as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.22	0.061	-0.04	8.25
2	12	20	0.67	<0.0001	-0.03	8.25
3	12	12	0.51	0.009	-0.02	8.23
4	10	10	0.65	0.005	-0.03	8.28
5	9	12	0.35	0.040	-0.02	8.13
6	10	11	0.03	0.640	-0.006	8.07
7	5	5	0.03	0.780	0.02	7.88
8	8	8	0.23	0.229	-0.12	8.07
9	8	13	0.13	0.230	-0.01	8.01
10	5	9	0.25	0.206	-0.02	8.12
11	7	7	0.06	0.590	-0.01	7.96
12	6	13	0.22	0.111	-0.02	8.03

PH decreased significantly ($p<0.05$) in four fields

Table A-2. Statistical parameters from regression of soil EC as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.30	0.023	0.04	0.51
2	12	20	0.39	0.003	0.04	0.46
3	12	12	0.29	0.07	0.03	0.50
4	10	10	0.21	0.184	0.02	0.54
5	9	12	0.25	0.099	0.04	0.54
6	10	11	0.09	0.368	0.03	0.62
7	5	5	0.22	0.426	0.11	0.21
8	8	8	0.004	0.880	0.007	1.00
9	8	13	0.15	0.191	0.03	0.52
10	5	9	0.35	0.120	0.04	0.46
11	7	7	0.05	0.640	0.01	0.58
12	6	13	0.29	0.0588	0.04	0.36

EC increased significantly ($p<0.05$) in two fields over time in organic production.

Table A-3. Statistical parameters from regression of SOM as a function of time in organic production.

Field ID #	# Years Represented	n (# samples)	R^2	p	Slope	Intercept
1	11	17	0.27	0.033	0.05	2.34
2	12	20	0.26	0.020	0.03	2.24
3	12	12	0.48	0.013	0.08	2.01
4	10	10	0.07	0.460	0.02	2.24
5	9	12	0.33	0.049	0.07	2.42
6	10	11	0.17	0.215	0.03	2.58
7	5	5	0.04	0.740	0.03	2.19
8	8	8	0.005	0.870	-0.002	2.43
9	8	13	0.0002	0.959	-0.002	2.78
10	5	9	0.07	0.538	0.01	2.17
11	7	7	0.20	0.320	0.02	1.99
12	6	13	0.10	0.287	0.03	2.27

SOM increased significantly ($p<0.05$) in four fields over time in organic production.

Table A-4. Statistical parameters from regression of soil NO_3-N as a function of time in organic production.

Field ID #	# Years Represented	n (# samples)	R^2	p	Slope	Intercept
1	11	17	0.02	0.611	0.41	25.86
2	12	20	0.13	0.120	0.87	20.40
3	12	12	0.05	0.484	-0.49	29.70
4	10	10	0.01	0.775	0.35	29.54
5	9	12	0.32	0.056	1.11	13.76
6	10	11	0.09	0.350	0.53	15.52
7	5	5	0.14	0.543	5.30	3.50
8	8	8	0.13	0.390	1.45	18.70
9	8	13	0.23	0.099	2.33	7.22
10	5	9	0.19	0.287	-0.79	25.85
11	7	7	0.001	0.937	0.15	19.65
12	6	13	0.005	0.821	-0.14	22.82

NO_3-N did not show significant changes over time in organic production in any field.

Table A-5. Statistical parameters from regression of available soil P as a function of time in organic production.

Field ID #	# Years Represented	n (# samples)	R^2	p	Slope	Intercept
1	11	17	0.61	0.0002	2.69	4.22
2	12	20	0.75	<0.0001	2.04	-0.16
3	12	12	0.70	0.0007	2.74	-1.62
4	10	10	0.90	<0.0001	2.30	-1.2
5	9	12	0.93	<0.0001	2.14	1.16
6	10	11	0.92	<0.0001	1.86	2.84
7	5	5	0.06	0.700	0.39	8.40
8	8	8	0.84	0.001	1.32	2.07
9	8	13	0.57	0.003	2.34	-1.75
10	5	9	0.80	0.003	1.46	5.25
11	7	7	0.77	0.0098	1.56	6.38
12	6	13	0.55	0.004	1.95	5.81

P increased significantly ($p<0.05$) in eleven fields over time in organic production.

Table A-6. Statistical parameters from regression of available soil K as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.54	0.0008	14.30	318.71
2	12	20	0.42	0.002	14.24	229.45
3	12	12	0.75	0.0003	19.49	205.07
4	10	10	0.65	0.005	15.75	228.59
5	9	12	0.65	0.0014	20.04	337.54
6	10	11	0.44	0.026	9.17	361.61
7	5	5	0.63	0.111	32.20	106.80
8	8	8	0.86	0.001	8.61	200.30
9	8	13	0.22	0.105	13.61	165.93
10	5	9	0.49	0.055	9.86	170.78
11	7	7	0.44	0.105	12.85	173.14
12	6	13	0.43	0.015	10.61	229.36

K increased significantly ($p<0.05$) in eight fields over time in organic production.

Table A-7. Statistical parameters from regression of available soil Zn as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.0006	0.924	-0.02	3.75
2	12	20	0.54	0.0002	0.12	0.69
3	12	12	0.03	0.578	0.11	1.20
4	10	10	0.02	0.679	0.12	2.04
5	9	12	0.78	0.0001	0.11	1.12
6	10	11	0.82	0.0001	0.13	1.10
7	5	5	0.06	0.693	0.03	1.41
8	8	8	0.76	0.005	0.06	1.20
9	8	13	0.40	0.021	0.12	1.15
10	5	9	0.001	0.937	-0.03	4.57
11	7	7	0.01	0.818	-0.09	4.11
12	6	13	0.007	0.794	-0.05	3.11

Zn increased significantly ($p<0.05$) in five fields over time in organic production.

Table A-8. Statistical parameters from regression of available soil Fe as a function of time in organic production.

Field ID #	# Years Represented	N (#samples)	R^2	p	Slope	Intercept
1	11	17	0.44	0.004	0.93	6.82
2	12	20	0.34	0.006	0.39	6.73
3	12	12	0.59	0.004	0.93	4.69
4	10	10	0.60	0.009	0.40	6.27
5	9	12	0.48	0.013	0.58	9.02
6	10	11	0.27	0.100	0.38	8.92
7	5	5	0.02	0.810	0.35	11.97
8	8	8	0.005	0.863	0.04	13.18
9	8	13	0.132	0.223	0.35	9.02
10	5	9	0.109	0.424	0.21	9.96
11	7	7	0.26	0.245	0.38	6.86
12	6	13	0.19	0.136	0.31	7.91

Fe increased significantly ($p<0.05$) in four fields over time in organic production.

Table A-9. Statistical parameters from regression of available soil Mn as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.18	0.089	0.09	2.02
2	12	20	0.14	0.105	0.08	2.33
3	12	12	0.32	0.054	0.14	1.88
4	10	10	0.02	0.694	0.02	2.40
5	9	12	0.60	0.003	0.20	1.52
6	10	11	0.23	0.135	0.11	1.76
7	5	5	0.11	0.583	0.18	1.14
8	8	8	0.16	0.320	0.055	1.78
9	8	13	0.09	0.330	0.16	1.91
10	5	9	0.70	0.0098	0.21	1.25
11	7	7	0.08	0.527	0.04	1.80
12	6	13	0.14	0.215	0.07	1.89

Mn increased significantly ($p<0.05$) in two fields over time in organic production.

Table A-10. Statistical parameters from regression of available soil Cu as a function of time in organic production.

Field ID #	# Years Represented	n (#samples)	R^2	p	Slope	Intercept
1	11	17	0.01	0.682	0.01	2.74
2	12	20	0.03	0.473	0.01	2.57
3	12	12	0.26	0.094	0.07	2.46
4	10	10	0.0007	0.9426	-0.002	2.78
5	9	12	0.002	0.886	-0.01	3.26
6	10	11	0.01	0.738	0.02	3.19
7	5	5	0.06	0.694	0.04	2.24
8	8	8	0.04	0.642	0.01	2.40
9	8	13	0.04	0.487	-0.065	4.02
10	5	9	0.001	0.940	-0.001	2.53
11	7	7	0.005	0.876	-0.003	2.50
12	6	13	0.008	0.776	0.008	2.38

Cu did not change significantly ($p<0.05$) over time in organic production in any field.

Appendix B-Comparisons of soil fertility levels from pre-organic years, the first year of organic, and the last year sampled*

Table B-1. Comparison of nutrient levels under conventional and organic practices in Field 1

	Conventional	Organic	
	1972*	1985	1988
pH	8.1	8.1	7.9
EC	1.0	0.6	1.3
OM	1.8	2.3	2.6
NO_3-N	3.0	36.0	31.8
P	20.0 vh	11.9 h	37.4 vh
K	+500 vh	288.0 vh	493.0 vh
Zn	0.80 l	1.9 a	2.7 a
Fe	13.0 a	8.4 a	20.2 a
Mn	--	1.3	3.4
Cu	--	2.4	2.7

*Average of samples from SE and SW field sections

Table B-2 Comparison of nutrient levels under conventional and organic practices in Field 2

	Conventional		Organic	
	1972*	1979**	1985	2000
pH	8.1	8.3	8.2	7.9
EC	0.6	0.8	0.5	1.3
OM	2.6	1.5	2.3	3.0
NO_3-N	5.0	3.0	17.5	33.6
P	1.0 vl	1.0 vl	4.7 l	31.9 vh
K	226.0 vh	154.0 h	237.0 vh	357.5 vh
Zn	1.3 mg	0.8 l	1.0 mg	2.3 a
Fe	4.3	5.5	8.0	14.0
Mn	0.8	0.6	1.9	3.6
Cu	2.4	0.10	2.6	2.9

*N section of Field 2, **South section of Field 2

Table B-3. Comparison of nutrient levels under conventional and organic practices in Field 3

	Conventional	Organic	
	1979	1985	1988
pH	8.1	8.3	7.8
EC	0.6	0.5	1.2
OM	2.6	2.4	3.0
NO_3-N	5.0	20.0	9.2
P	1.0 vl	4.2 l	28.0 vh
K	226.0 vh	232.0 vh	364.0 vh
Zn	1.3 mg	0.9 l	2.7 a
Fe	4.9 mg	6.0 a	20.1 a
Mn	0.8	1.1	3.2
Cu	2.4 a	2.5 a	3.5 a

Table B-4. Comparison of nutrient levels under conventional and organic practices in Field 4

	Conventional	Organic	
	1979	1985	1999
pH	8.1	8.3	7.9
EC	0.6	0.5	0.6
OM	2.6	2.4	2.3
NO_3-N	5.0	20.0	25.0
P	1.0 vl	4.2 l	27.3 vh
K	226.0 vh	232.0 vh	426.0 vh
Zn	1.3 mg	0.9 l	2.5 a
Fe	4.9 mg	6.0 a	13.0 a
Mn	0.8	1.1	2.6
Cu	2.4 a	2.5 a	3.1 a

Table B-5. Comparison of nutrient levels under conventional and organic practices in Field 5

	Conventional	Organic	
	1978	1985	1997
pH	7.9	8.0	7.7
EC	1.4	0.6	1.5
OM	2.6	2.3	3.1
NO_3-N	14.0	18.0	27.0
P	5.0 l	6.0 l	31.0 vh
K	437.0 vh	361.0 vh	592.0 vh
Zn	2.1 a	1.4 mg	2.8 a
Fe	8.4 a	10.5 a	17.9 a
Mn	--	1.7	5.4
Cu	--	3.1	3.8

Table B-6. Comparison of nutrient levels under conventional and organic practices in Field 6

	Conventional	Organic	
	1978	1985	1998
pH	8.0	8.0	7.9
EC	1.6	0.6	1.2
OM	2.1	2.3	2.8
NO_3-N	12.0	18.0	23.6
P	6.0 l	6.0 l	34.5 vh
K	423.0 vh	361.0 vh	518.0 vh
Zn	1.1 mg	1.4 mg	2.8 a
Fe	5.7 a	10.5 a	17.5 a
Mn	--	1.7	3.5
Cu	--	3.1	3.2

*vl=very low, l=low, m=medium, h=high, vh=very high, a=adequate, mg=marginal (Soltanpour and Follett, 2001)

Appendix C-Graphs of linear regressions for Field 5

Figure C-1. Change in pH over time in organic production (Field 5)

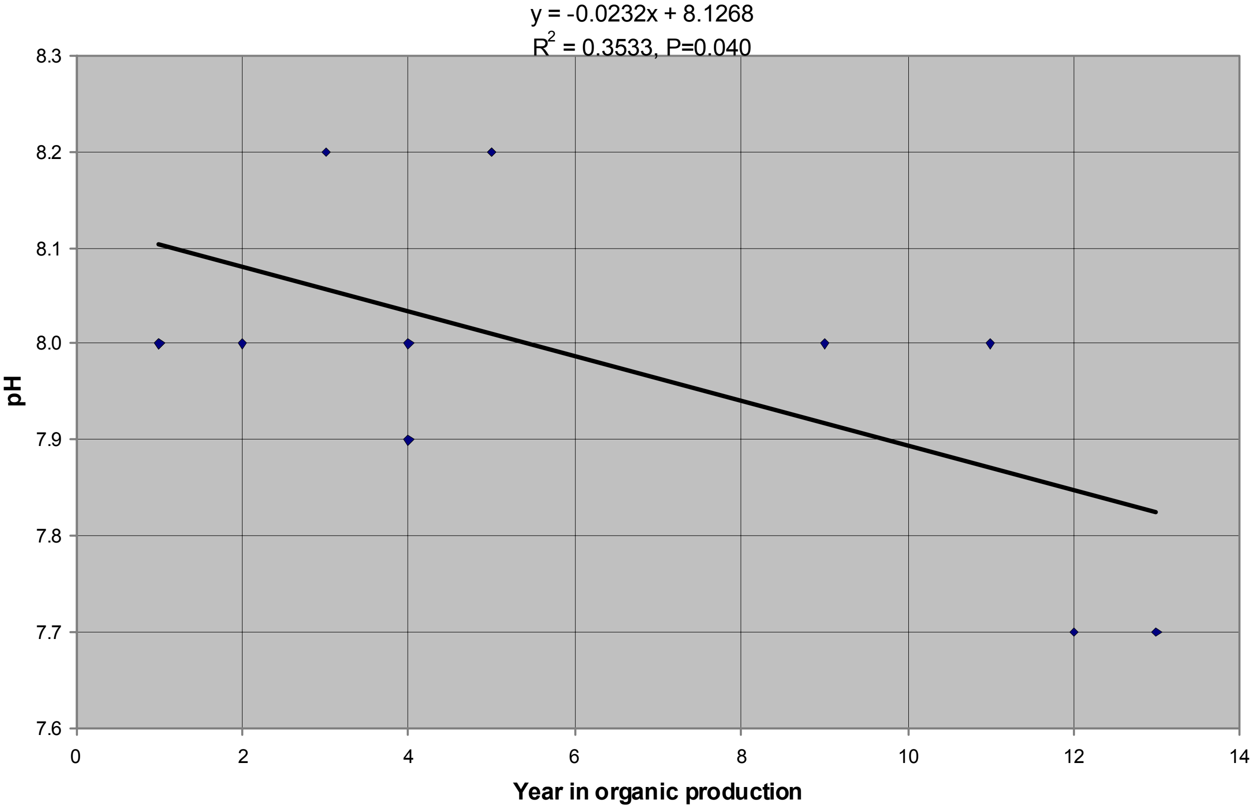


Figure C-2. Change in EC over time in organic production (Field 5)

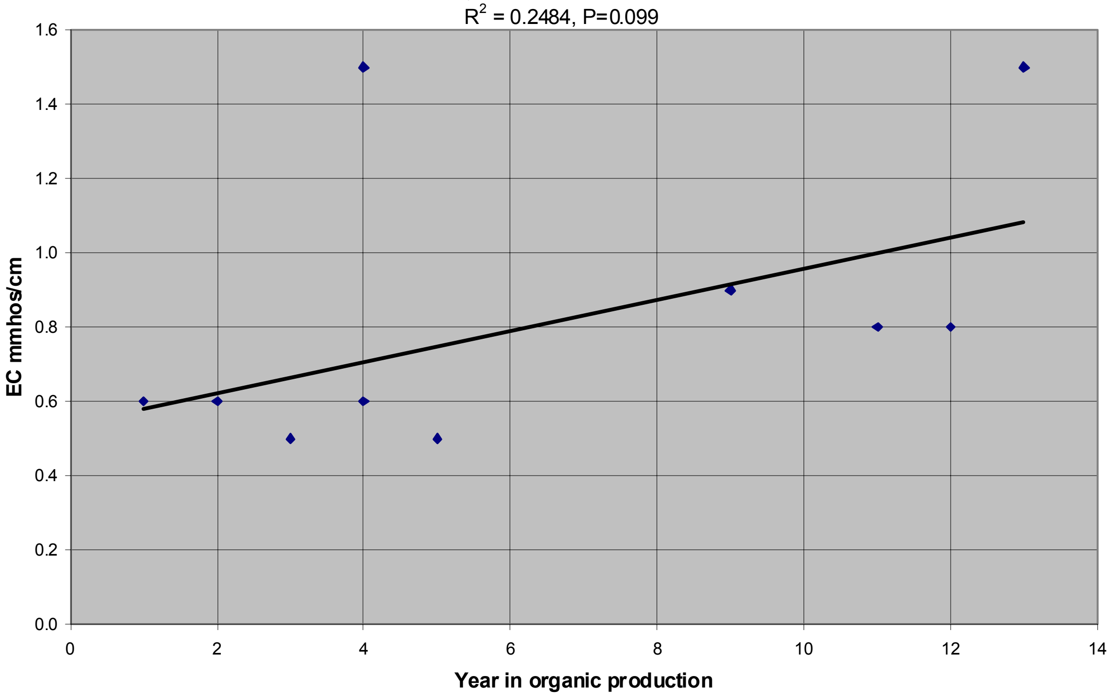


Figure C-3- Change in SOM over time in organic production (Field 5)

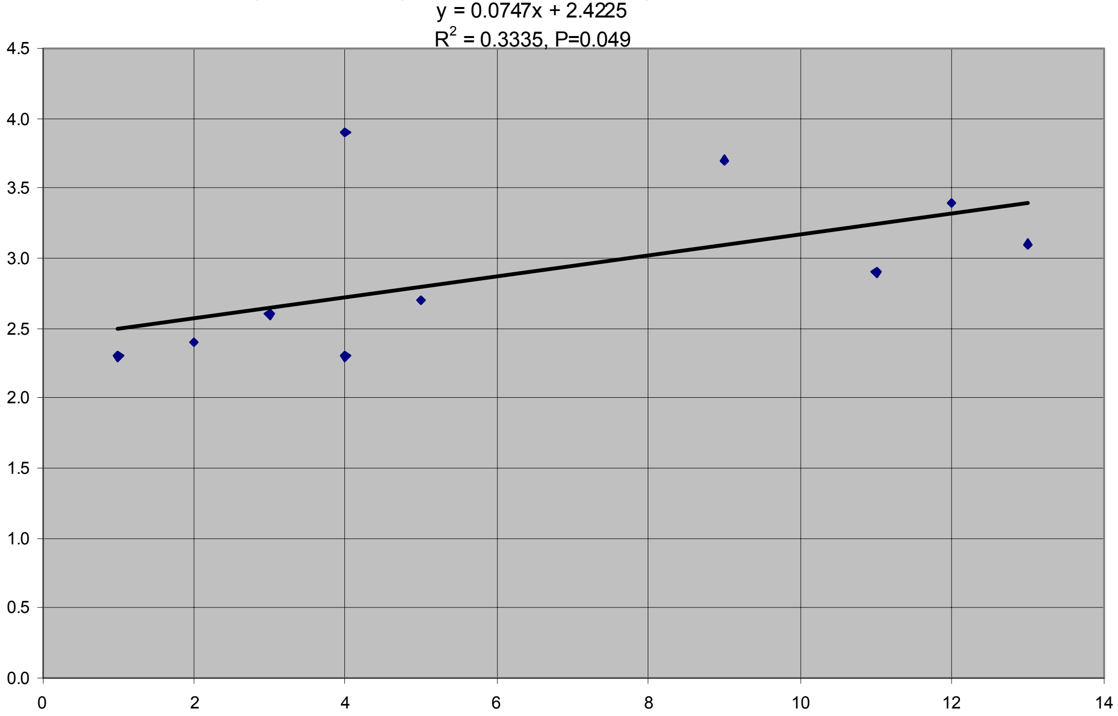


Figure C-4- Change in NO3-N over time in organic production (Field 5)

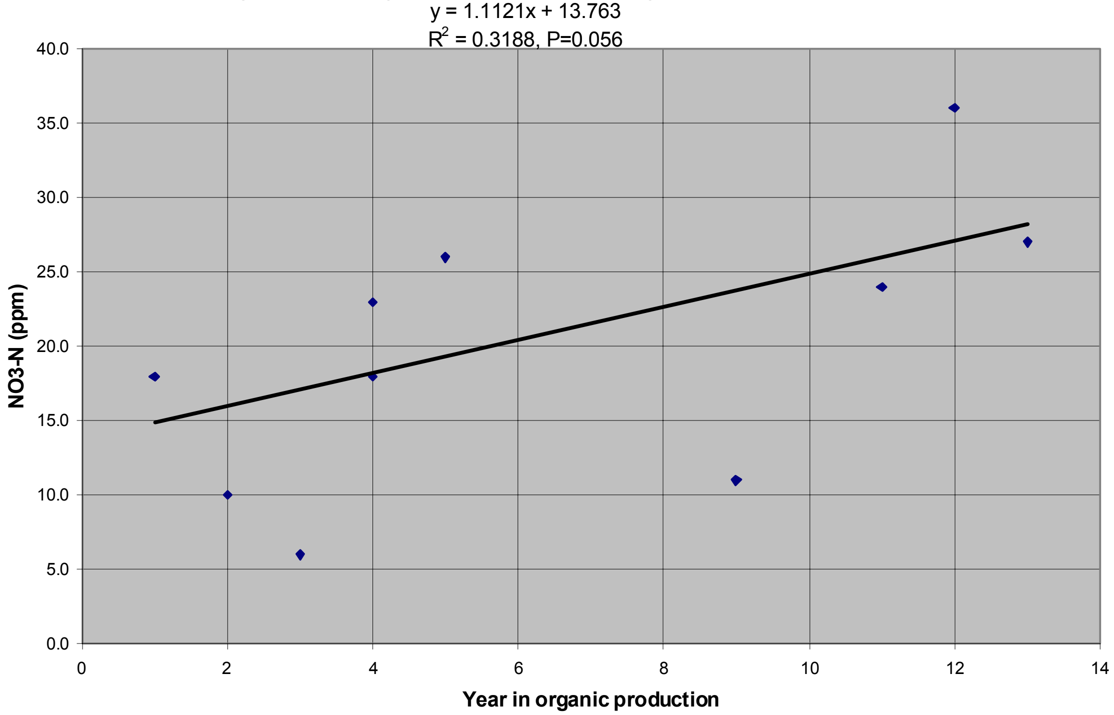


Figure C-5. Change in available soil P over time in organic production (Field 5)

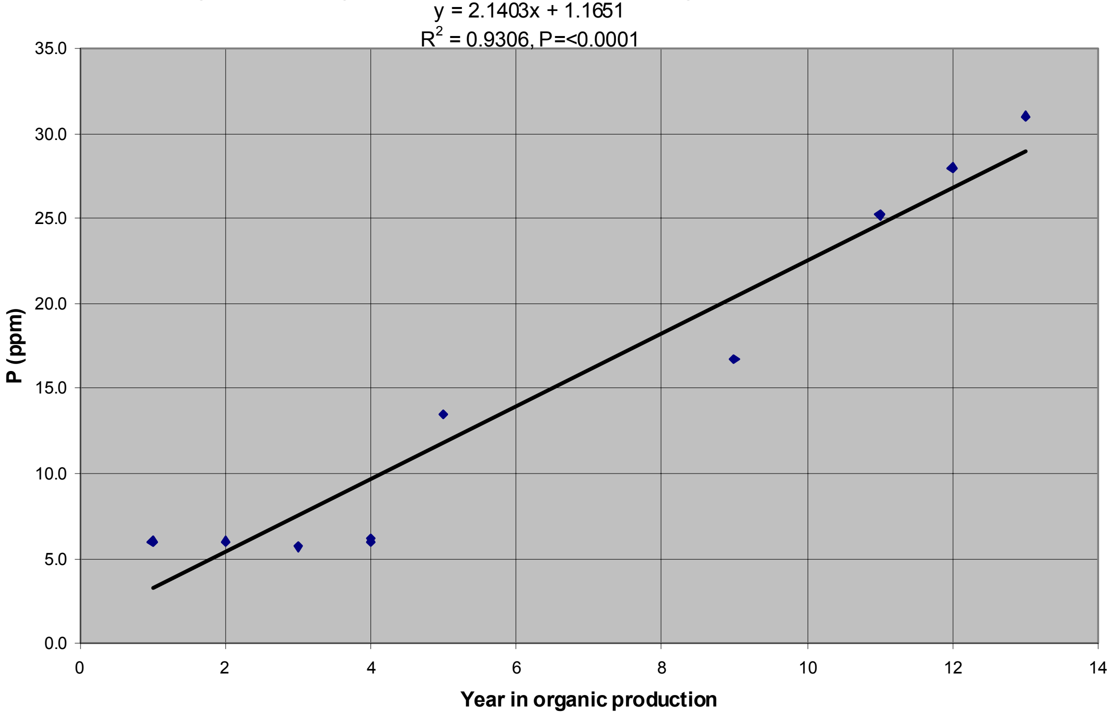


Figure C-5-Change in available K over time in organic production (Field 5)

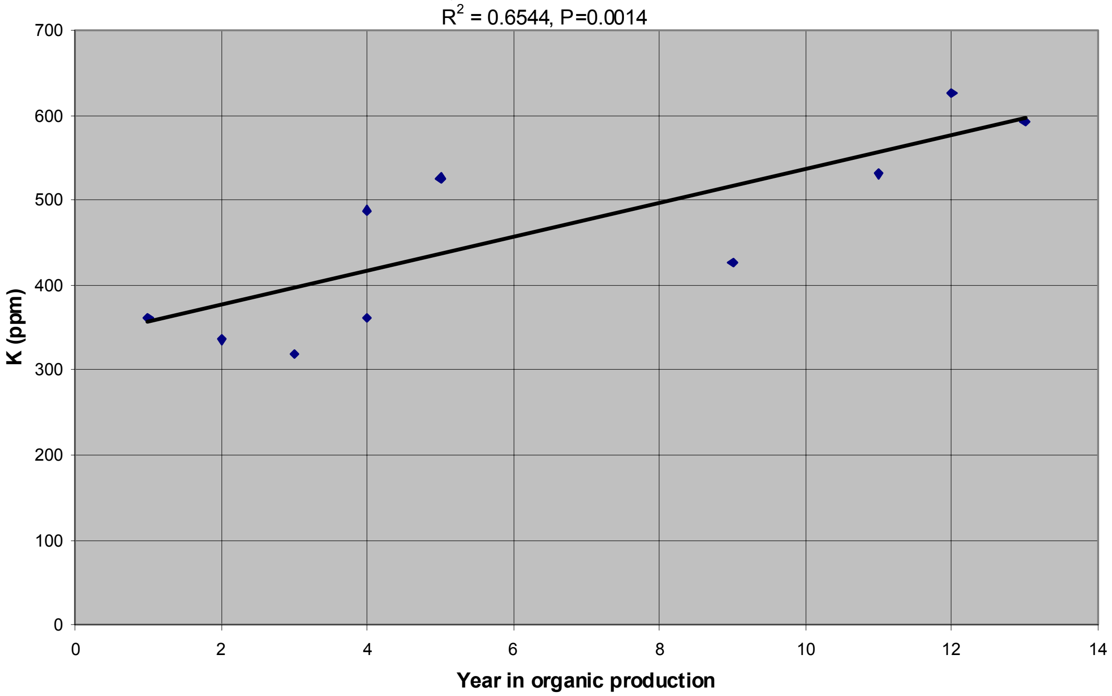


Figure C-7--Change in Zn over time in organic production (Field 5)

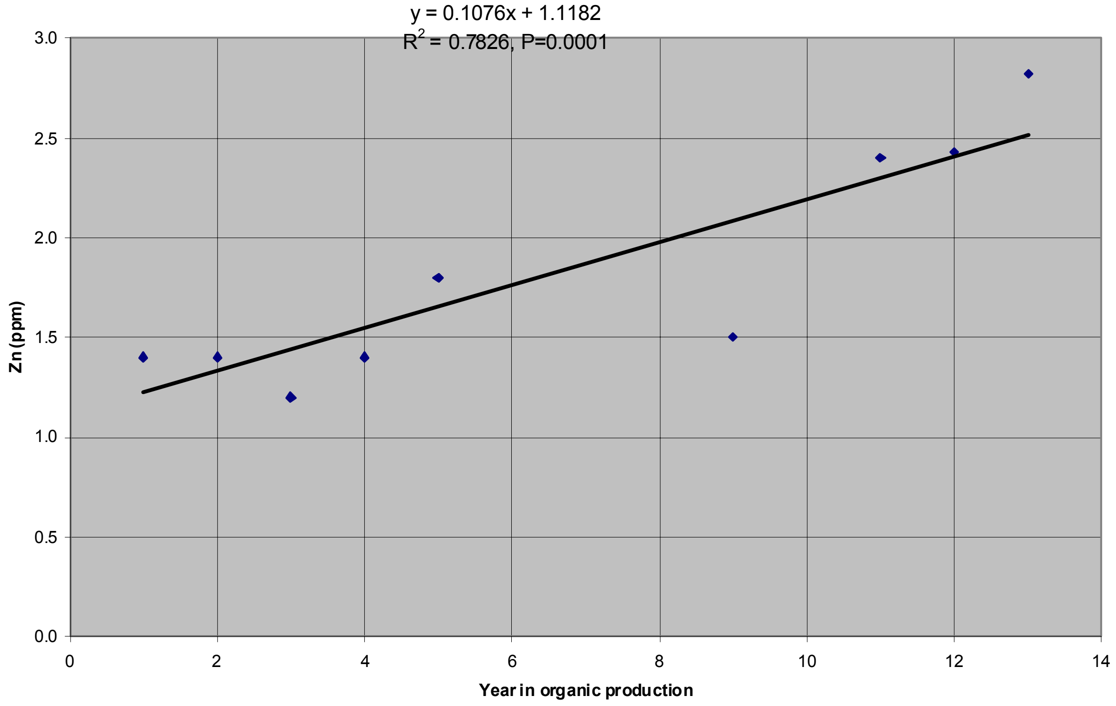


Figure C-8- Change in Fe over time in organic production (Field 5)

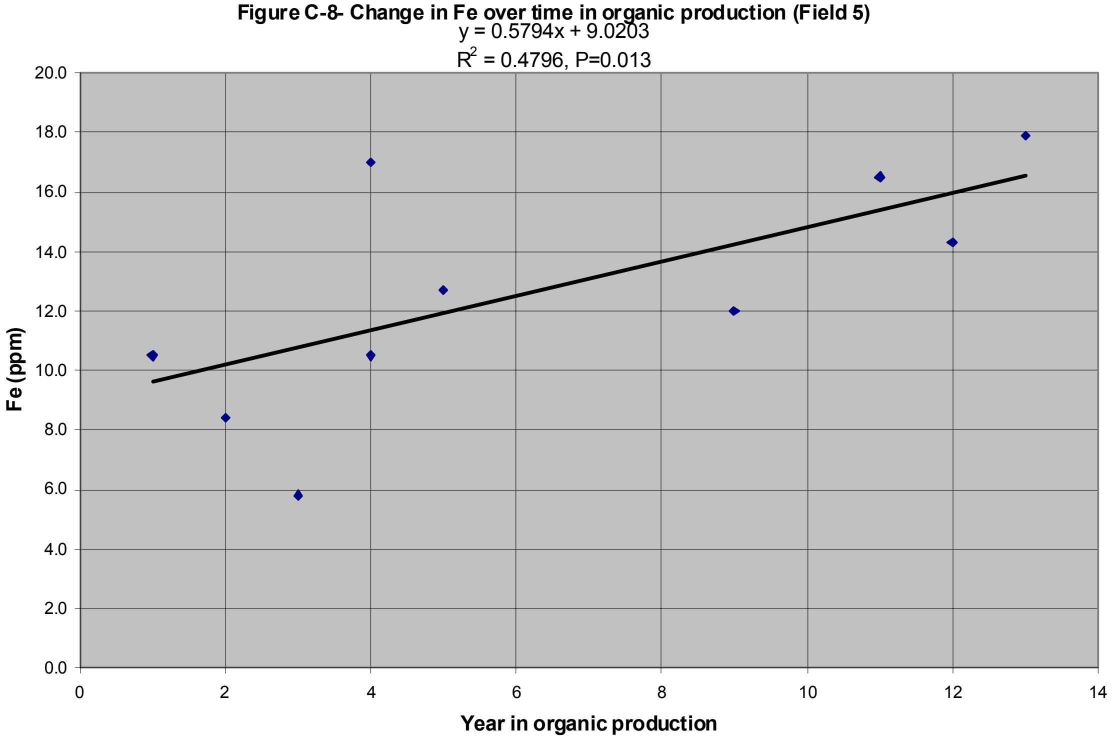


Figure C-9. Change in Mn over time in organic production (Field 5)

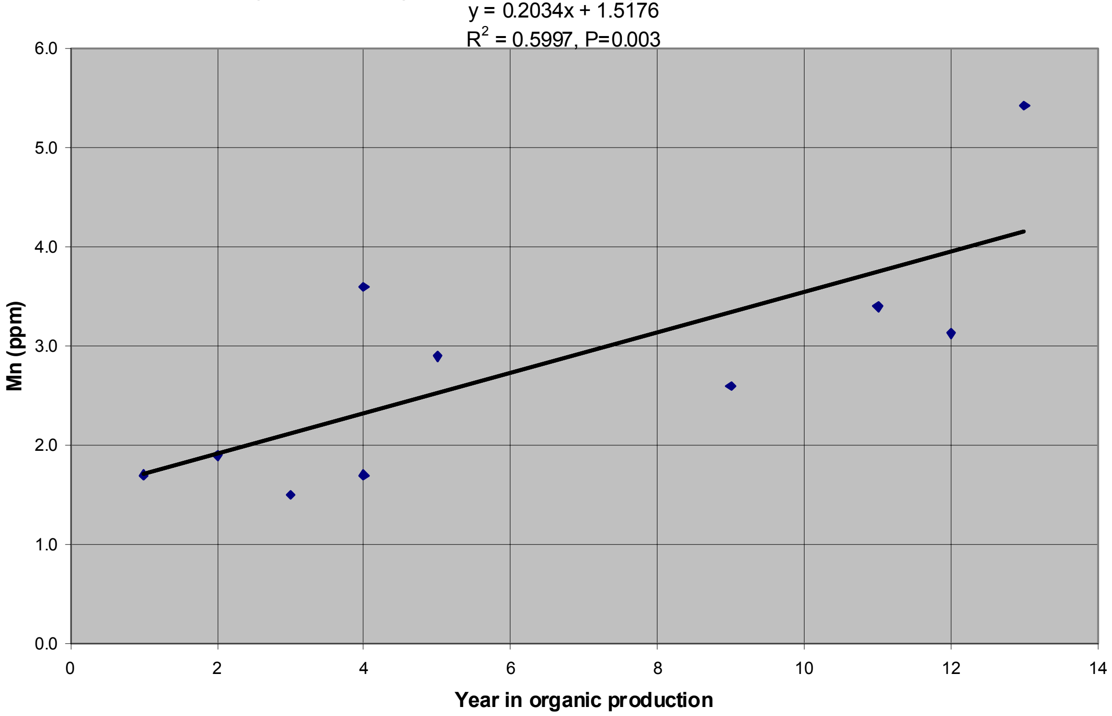
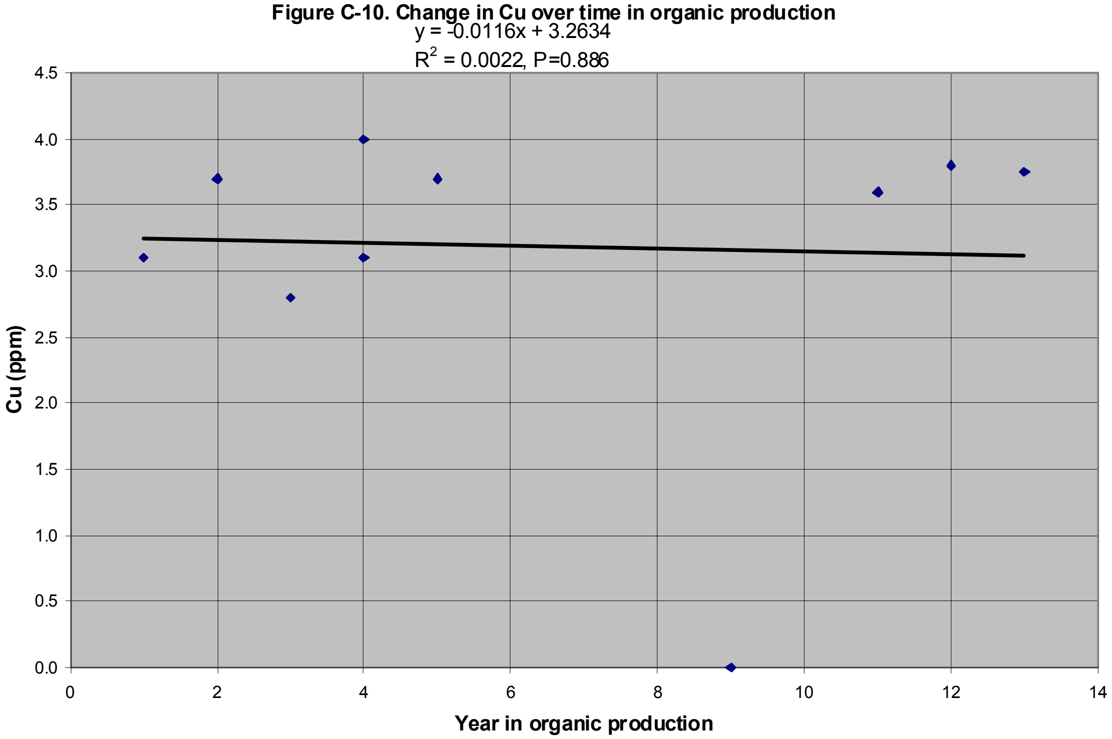


Figure C-10. Change in Cu over time in organic production



Appendix D-Raw soil data

Table D-1 Raw soil test data for Field 1 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC mmhos/ cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 1	E	1985	1	8.1	0.6	2.3	36.0	11.9	288	1.9	8.4	1.3	2.4
Pie 1	E	1986	2	7.9	0.6	2.5	42.0	13.2	356	2.4	10.3	2.8	2.8
Pie 1	E	1987	3	8.3	0.4	2.5	10.0	10.9	304	1.7	5.6	1.2	2.1
Pie 1	E	1988	4	8.2	0.6	2.2	15.0	9.5	400	2.1	14.4	3.2	3.1
Pie 1	E	1989	5	8.3	0.5	2.5	11.0	13.1	401	2.4	15.0	3.9	3.6
Pie 1	SE	1991	7	8.1	0.8	2.7	29.0	18.2	455	11.3	16.0	2.9	3.5
Pie 1	NE	1991	7	8.0	1.3	2.9	50.0	29.3	553	12.0	9.1	3.3	3.0
Pie 1	SE	1993	9	8.1	1.2	2.9	21.0	17.2	362	2.0	15.0	2.2	2.4
Pie 1	NE	1993	9	7.9	1.3	3.1	32.0	27.6	449	1.7	7.6	1.3	2.4
Pie 1	SE	1995	11	8.0	0.9	2.8	54.0	38.0	513	3.5	19.4	3.1	2.6
Pie 1	NE	1995	11	8.1	0.5	2.6	17.0	39.3	475	2.9	8.9	1.8	2.5
Pie 1	SE	1996	12	6.9	0.5	2.7	22.0	29.3	443	2.8	16.2	3.0	2.8
Pie 1	NE	1996	12	7.5	0.8	3.7	47.0	55.5	444	2.5	23.1	3.4	3.3
Pie 1	SE	1997	13	8.0	1.1	2.9	20.0	24.5	505	2.6	25.6	3.4	3.3
Pie 1	NE	1997	13	7.9	1.1	3.6	30.0	54.8	586	3.9	17.3	3.8	3.2
Pie 1	SE	1998	14	7.9	1.3	2.3	33.4	28.3	437	2.4	25.5	2.9	2.7
Pie 1	NE	1998	14	7.9	1.2	2.8	30.1	46.5	549	3.1	14.8	3.8	2.6

Table D-2. Raw soil test data for Field 2 from GFF archives

Field Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmho s/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 2 E	1985	1	8.3	0.5	2.4	20.0	4.2	232	0.9	6.0	1.1	2.5
Pie 2 NE	1985	1	8.1	0.4	2.2	15.0	5.2	242	1.0	10.0	2.6	2.6
Pie 2 E	1986	2	8.1	0.6	2.4	39.0	6.0	255	0.9	6.5	3.4	2.8
Pie 2 E	1987	3	8.3	0.4	2.3	12.0	4.2	222	0.7	6.4	1.6	2.2
Pie 2 E	1988	4	8.2	0.6	2.0	15.0	3.8	274	0.8	10.7	3.8	2.8
Pie 2 NE	1988	4	8.1	0.8	2.1	31.0	11.1	401	1.9	11.6	3.6	3.2
Pie 2 E	1989	5	8.3	0.6	2.6	27.0	10.3	302	1.3	8.7	2.9	2.8
Pie 2 NE	1993	9	7.9	1.3	2.7	34.0	13.5	310	1.0	6.8	1.9	2.0
Pie 2 SE	1993	9	8.0	1.3	3.2	41.0	17.2	315	1.1	8.9	2.1	1.8
Pie 2 SE	1995	11	7.9	0.7	2.3	29.0	21.2	344	2.0	8.3	1.5	2.4
Pie 2 NE	1996	12	7.9	0.7	2.7	42.0	34.9	492	2.1	8.5	3.3	2.7
Pie 2 SE	1996	12	7.8	0.5	2.7	6.0	18.0	555	3.9	11.2	4.2	2.7
Pie 2 NE	1997	13	7.9	1.0	2.7	20.0	35.0	491	3.3	17.6	4.1	3.4
Pie 2 SE	1997	13	8.1	1.1	3.0	33.0	25.5	495	2.4	14.4	5.5	3.2
Pie 2 NE	1998	14	7.9	0.9	2.5	20.5	35.3	454	2.5	12.6	3.0	2.8
Pie 2 SE	1998	14	7.9	1.5	2.2	38.7	23.4	449	1.9	10.4	2.6	2.2
Pie 2 SE	1999	15	7.9	0.7	2.4	55.0	36.8	514	2.4	14.2	2.9	2.7
Pie 2 NE	2000	16	7.8	1.4	2.9	44.3	35.2	393	2.5	15.3	3.4	3.2
Pie 2 SE	2000	16	7.9	1.1	3.0	22.8	28.5	322	2.1	12.7	3.7	2.6

Table D-3. Raw soil test data for Field 3

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 2	NW	1985	1	8.3	0.5	2.4	20.0	4.2	232.0	0.9	6.0	1.1	2.5
Pie 2	NW	1986	2	8.1	0.7	2.0	48.0	4.5	243.0	0.9	6.6	3.1	3.0
Pie 2	NW	1987	3	8.3	0.4	2.3	12.0	4.2	222.0	0.7	6.4	1.6	2.2
Pie 2	NW	1988	4	8.2	0.6	2.0	15.0	3.8	274.0	0.8	10.7	3.8	2.8
Pie 2	NW	1989	5	7.9	0.6	2.5	44.0	9.5	288.0	1.5	10.6	2.6	3.3
Pie 2	NW	1991	7	7.9	1.2	2.3	32.0	13.1	366.0	13.4	6.4	2.0	2.5
Pie 2	NW	1995	11	8.1	0.5	2.4	20.0	26.5	399.0	2.2	8.7	1.8	2.4
Pie 2	NW	1996	12	8.0	0.5	3.7	25.0	57.7	507.0	4.0	26.6	4.6	3.3
Pie 2	NW	1997	13	8.1	1.1	4.0	21.0	42.4	552.0	3.3	17.9	5.9	5.0
Pie 2	NW	1998	14	7.9	1.2	2.8	28.9	35.1	471.0	2.5	14.9	4.0	2.6
Pie 2	NW	1999	15	7.8	0.7	2.9	31.0	34.0	550.0	2.6	16.8	3.7	3.7
Pie 2	NW	2000	16	7.8	1.2	3.0	9.2	28.0	364.0	2.7	20.1	3.2	3.5

Table D-4. Raw soil test data for Field 4

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 2	SW	1985	1	8.3	0.5	2.4	20.0	4.2	232.0	0.9	6.0	1.1	2.5
Pie 2	SW	1986	2	8.1	0.7	2.0	48.0	4.5	243.0	0.9	6.6	3.1	3.0
Pie 2	SW	1987	3	8.3	0.4	2.3	12.0	4.2	222.0	0.7	6.4	1.6	2.2
Pie 2	SW	1988	4	8.2	0.6	2.0	15.0	3.8	274.0	0.8	10.7	3.8	2.8
Pie 2	SW	1989	5	8.2	0.6	2.6	57.0	9.5	331.0	1.4	9.6	3.2	3.0
Pie 2	SW	1991	7	7.9	1.1	2.6	33.0	13.5	473.0	14.9	8.5	2.8	3.7
Pie 2	SW	1995	11	8.1	0.5	2.1	25.0	23.7	338.0	2.2	7.2	1.5	2.4
Pie 2	SW	1996	12	7.8	1.0	3.1	62.0	34.9	484.0	2.8	11.3	3.4	2.6
Pie 2	SW	1998	14	7.9	1.1	2.3	24.4	32.6	428.0	2.4	12.8	2.7	2.3
Pie 2	SW	1999	15	7.9	0.6	2.3	25.0	27.3	426.0	2.5	13.0	2.6	3.1

Table D-5 Raw soil test data for Field 5 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 3	NE	1985	1	8.0	0.6	2.3	18.0	6.0	361	1.4	10.5	1.7	3.1
Pie 3	SE	1985	1	8.0	0.6	2.3	18.0	6.0	361.0	1.4	10.5	1.7	3.1
Pie 3	NE	1986	2	8.0	0.6	2.4	10.0	6.0	336	1.4	8.4	1.9	3.7
Pie 3	NE	1987	3	8.2	0.5	2.6	6.0	5.7	319	1.2	5.8	1.5	2.8
Pie 3	NE	1988	4	8.0	0.6	2.3	18.0	6.0	361	1.4	10.5	1.7	3.1
Pie 3	SE	1988	4	7.9	1.5	3.9	23.0	6.2	488.0	1.4	17.0	3.6	4.0
Pie 3	NE	1989	5	8.2	0.5	2.7	26.0	13.5	526	1.8	12.7	2.9	3.7
Pie 3	SE	1989	5	8.2	0.5	2.7	26.0	13.5	526.0	1.8	12.7	2.9	3.7
Pie 3	SE	1993	9	8.0	0.9	3.7	11.0	16.7	426.0	1.5	12.0	2.6	0.0
Pie 3	SE	1995	11	8.0	0.8	2.9	24.0	25.2	531.0	2.4	16.5	3.4	3.6
Pie 3	SE	1996	12	7.7	0.8	3.4	36.0	28.0	626.0	2.4	14.3	3.1	3.8
Pie 3	SE	1997	13	7.7	1.5	3.1	27.0	31.0	592.0	2.8	17.9	5.4	3.8

Table D-6 Raw soil test data for Field 6 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 3	W	1985	1	8.0	0.6	2.3	18.0	6.0	361	1.4	10.5	1.7	3.1
Pie 3	W	1986	2	7.9	0.5	2.5	8.0	7.0	395	1.5	8.6	2.0	3.7
Pie 3	W	1987	3	8.2	0.5	2.6	6.0	5.7	319	1.2	5.8	1.5	2.8
Pie 3	W	1988	4	7.9	1.5	3.1	26.0	12.3	506	1.7	16.0	3.5	3.4
Pie 3	W	1989	5	8.3	0.6	2.9	32.0	12.3	402	1.8	11.8	2.4	3.8
Pie 3	SW	1993	9	7.9	1.2	3.4	26.0	19.2	401	2.0	10.4	2.7	2.4
Pie 3	SW	1995	11	8.2	0.5	2.7	15.0	23.4	398	3.3	13.8	1.8	2.8
Pie 3	NW	1995	11	8.3	0.5	2.5	14.0	23.0	485	2.6	11.5	2.1	3.5
Pie 3	SW	1996	12	7.9	0.5	2.8	23.0	20.5	483	2.5	9.2	2.1	2.8
Pie 3	SW	1997	13	7.8	1.6	3.3	24.0	25.6	489	3.3	15.6	5.0	5.0
Pie 3	NW	1998	14	7.9	1.2	2.8	23.6	34.5	518	2.8	17.5	3.5	3.2

Table D-7. Raw soil test data for Field 7 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 4	N	1985	3	8.0	0.5	2.1	13.0	12.7	241	1.7	14.9	1.6	2.4
Pie 4	N	1986	4	7.8	0.7	2.6	53.0	7.2	224	1.4	14.1	2.8	2.6
Pie 4	N	1987	5	8.2	0.5	2.4	8.0	8.4	206	1.3	7.4	0.8	2.0
Pie 4	N	1988	6	7.8	1.4	2.1	20.0	10.3	308	1.7	17.0	2.2	2.6
Pie 4	N	1989	7	8.1	0.7	2.5	56.0	13.1	360	1.7	15.2	2.8	2.6

Table D-8. Raw soil test data for Field 8 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Pie 4	S	1985	3	8.0	0.6	2.2	12.0	10.1	229	1.6	16.2	1.7	2.4
Pie 4	S	1986	4	7.8	1.2	2.5	56.0	10.3	245	1.6	12.3	2.3	2.5
Pie 4	S	1987	5	8.2	0.5	2.4	8.4	5.8	206	1.4	7.4	0.8	2.0
Pie 4	S	1988	6	8.0	2.2	2.4	9.0	5.8	245	1.4	18.0	2.9	2.6
Pie 4	S	1989	7	8.1	0.8	2.6	43.0	9.5	292	1.4	12.4	2.6	2.9
Pie 4	S	1996	14	7.9	0.8	2.7	35.0	19.9	335	2.4	15.8	2.9	2.7
Pie 4	S	1998	16	7.8	1.8	2.3	70.6	27.1	331	2.1	12.8	3.1	2.0
Pie 4	S	1999	17	7.9	0.6	2.2	20.0	22.8	339	2.2	13.5	1.9	3.0

Table D-9. Raw soil test data for Field 9 from GFF archives

Field	Sec.	Yr.	Yr. In Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Black 1		1988	4	8.0	0.5	2.5	14.0	11.5	197	2.5	13.4	3.4	3.6
Black 1		1989	5	8.1	0.7	3.2	39.0	7.0	435	1.0	11.4	2.6	3.5
Black 1		1991	7	7.6	0.9	2.6	35.0	11.5	172	1.6	8.1	1.5	2.6
Black 1	S	1993	9	7.8	0.9	2.9	28.0	24.5	218	2.4	10.7	4.1	6.8
Black 1	N	1993	9	7.9	0.9	2.9	20.0	13.1	206	1.9	10.9	3.1	2.6
Black 1		1995	11	8.1	0.4	2.1	19.0	22.7	273	2.0	11.6	2.2	2.2
Black 1	E	1996	12	7.9	0.5	2.4	19.0	14.0	224	2.4	11.0	2.1	4.2
Black 1	W	1996	12	7.9	0.6	3.0	23.0	26.8	285	2.7	11.1	2.3	2.5
Black 1		1997	13	7.8	1.0	3.1	27.0	40.2	490	3.8	15.4	8.2	3.5
Black 1		1997	13	7.8	1.1	3.3	22.0	43.0	410	2.8	23.2	7.9	2.7
Black 1	W-NNE	1999	15	7.8	0.9	2.5	77.0	38.1	461	3.0	13.4	3.3	3.0
Black 1	SE	1999	15	7.8	0.7	2.3	35.0	24.4	389	2.2	11.2	2.6	2.8
Black 1		2000	16	7.8	1.2	3.1	65.0	30.0	316	3.0	15.2	4.1	3.0

Table D-10. Raw soil test data for Field 10 from GFF archives

Field	Sec.	Yr.	Yr. In Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K Ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Black 2		1986	2	8.0	0.5	2.4	33.0	11.1	198	2.8	14.0	2.8	2.8
Black 2		1987	3	8.1	0.5	2.0	28.0	6.2	253	1.4	6.5	1.1	2.1
Black 2		1988	4	8.1	0.5	2.0	7.0	10.1	205	4.1	11.0	2.4	2.7
Black 2		1989	5	8.2	0.5	2.2	16.0	11.9	206	1.9	13.4	2.1	2.5
Black 2		1991	7	7.7	1.2	2.6	28.0	18.2	165	16.4	8.0	1.8	2.5
Black 2		1997	13	8.0	0.8	2.1	13.0	30.2	330	3.0	15.2	4.4	2.5
Black 2		1997	13	8.0	0.7	2.8	18.0	28.0	438	2.6	15.9		3.2
Black 2		1997	13	7.9	1.1	2.3	17.0	22.0	242	2.4	12.0	3.9	2.5
Black 2		1997	13	7.8	0.7	2.5	17.0	20.0	359	2.6	11.9	4.3	2.6

Table D-11. Raw soil test data for Field 11 from GFF archives

Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K Ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Black 3		1988	4	8.0	0.4	1.9	5.0	18.5	336	1.6	11.6	2.6	2.7
Black 3		1989	5	8.1	0.4	2.4	9.0	13.1	190	1.5	9.4	1.9	2.4
Black 3		1991	7	7.6	1.1	2.1	54.0	12.3	206	11.3	5.8	1.5	2.3
Black 3		1993	9	7.8	1.2	2.5	31.0	19.8	251	1.5	11.3	2.7	2.6
Black 3		1995	11	7.9	0.5	1.9	19.0	19.9	275	1.7	7.2	1.5	2.2
Black 3		1997	13	7.8	0.8	2.4	5.0	29.2	393	2.7	11.9	2.0	2.6
Black 3		2000	16	7.9	0.7	2.5	24.3	33.0	396	2.7	15.6	3.1	2.5

Table D-12. Raw soil test data for Field 12 from GFF archives

Sample ID	Field	Sec.	Yr.	Yr. in Org. Prod.	pH	EC Mmhos/cm	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
12a	Black 4		1986	2	7.8	0.5	3.0	32.0	16.5	240	2.5	12.4	3.0	2.2
12b	Black 4		1987	3	8.1	0.4	2.2	22.0	4.9	182	1.2	5.6	0.9	2.0
12c	Black 4		1988	4	8.0	0.4	1.9	5.0	18.5	336	1.6	11.6	2.6	2.7
12d	Black 4		1989	5	8.1	0.5	2.5	21.0	13.1	312	2.1	11.8	2.8	3.2
12e	Black 4		1991	7	7.6	1.1	2.2	34.0	14.4	288	11.3	6.1	1.9	2.6
12f	Black 4		1993	9	7.8	1.2	2.9	28.0	23.8	295	1.6	9.5	2.7	2.5
12g	Black 4	E	1995	11	8.0	0.5	2.1	15.0	16.2	285	1.5	7.2	1.5	1.9
12h	Black 4	W	1995	11	8.0	0.4	2.1	14.0	40.5	384	2.3	12.1	2.0	2.1
12i	Black 4	E	1996	12	7.8	0.7	2.9	35.0	28.0	408	1.6	10.3	2.4	2.0
12j	Black 4	W	1996	12	8.0	0.5	2.6	18.0	39.9	419	2.0	10.8	2.2	2.2
12k	Black 4		1997	13	7.7	1.0	2.6	15.0	21.6	428	2.2	12.5	4.0	2.5
12l	Black 4		1997	13	7.7	1.3	2.7	14.0	24.6	338	2.1	11.8	3.5	3.1
12m	Black 4	W	2000	16	7.6	1.2	3.0	26.8	43.0	319	2.8	17.5	3.2	2.9