2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

SPATIAL VARIABILITY OF ENZYME ACTIVITIES, CHEMICAL PROPERTIES, AND PLANT CHARACTERISTICS IN A SEMIARID SOIL

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Abstract

The selection of management practices that increase organic matter of soil is important in dryland in order to increase soil water holding capacity from precipitation as well as other properties important in soil function. This study investigated plant and weather characteristics and the potential of different soil properties to determine spatial variability in dryland. Soil samples were taken before and after the first summer growing season of the establishment of a field study on 4 ha of total land in Lubbock, TX. The study was established in 2003 as a complete randomized block design with three field replicates of a cotton (*Gossypium hirsutum L.*) -sorghum (*Sorghum bicolor L.*) rotation without winter cover crop, a cotton-sorghum rotation with a winter cover crop, and a continuous high biomass crop rotation with haygrazer (*Sorghum bicolor L.*) and winter cover crop. The winter cover crop was rye (*Secale cereale*). The crop rotations were under conventional and no-tillage practices. The land revealed a decrease in elevation of 1 m from north to south that affected the spatial variability of clay content and soil nutrients such as phosphorus and potassium. This slope caused nutrients and clay runoff to the south of the field, where they became more concentrated compared to the north. Higher nutrient and clay contents in the south part of the field resulted in higher vegetative indexes compared to the north part. Organic matter reflected the previous cropping history of the plots ranging from 0.3 to 1.10 mg kg^{-1} soil. Microbial biomass C reflected the organic matter content of this soil. Microbial biomass C was unaffected by the first tillage practices on the plots whereas alkaline phosphatase activity was significantly decreased by conventional tillage. Plant yields were higher on conventional tillage plots compared to no-tilled plots. This was not in agreement with the higher alkaline phosphatase activity under no-tilled plots, either because the first year under conservation tillage may still have not increased soil water conservation, and/or because the high land variability found did not allow an assessment of tillage impacts on plant yields. At this point of the study, the results provide indications that alkaline phosphatase activity may promise to provide early trends of soil changes in organic matter needed for our future management decisions.

Introduction

Soil variability assessments have been used to evaluate environmental impacts and efficacy of agrochemicals in soil. It is important to evaluate the variability of several soil properties in order to make management decisions that maintain or increase the quality of soils and the environment. Especially under dryland conditions, it is important to select management practices that increase organic matter of soil in order to increase its water holding capacity as well as other properties important in soil function.

Assessment of the variability of soil texture and organic matter content can be used to optimize fertilizer application to match predicted plant demand. The microbiological properties are correlated to the soil organic matter content, but they may show earlier trends of soil changes due to management. The nutrient availability and productivity of systems mainly depend on the size, activity and composition of the microbiological component of soil. The microbial biomass C comprises only 1-3% of total soil C, but is the biologically most active fraction of soil organic matter (Smith and Paul, 1990; Franzluebbers et al., 2001). The microbial population size and composition control soil processes and function because they are the main source of enzymes in soils (Tabatabai, 1994). Enzymes are present in soil within various biotic and abiotic components (Burns, 1982). Enzyme activities regulate the labile pools of organic matter and the transformation of elements in soils. For example, phosphatases are significantly affected by soil pH (i.e., alkaline and acid phosphatases) and controls phosphorus availability in soil (Tabatabai 1994). The value of the measurement of soil microbiological and biochemical parameters of soil, including the enzyme activities, arises from its simple analyses and because it requires low labor costs compared to other biological analyses (Ndiaye et al., 2000).

The objectives of this study were to describe soil variability using several properties that impact soil function including soil texture, organic matter content, phosphatase activity, and microbial biomass C of a semiarid soil under different cropping

systems; and to correlate the soil variability with the crop biomass and yields. Our goal was to identify the cropping systems with the potential to impact soil properties under dryland.

Materials and Methods

Experimental Design

The High Biomass Crop (HBC) study was initiated in 2003 at the Liberty Farm of Lubbock, TX on 4 ha of total land area. The soil is a Olton series (Fine, mixed, thermic Aridic Paleustolls). Previously, from 1997-2001, the land was under a nitrogen rate study with corn (*Zea mays* L.) on the East side and cotton (*Gossypium hirsutum L.*) on the West side. In 2002, the complete land area was under dryland cotton, and it was followed with a winter cover rye (*Secale cereale*) crop. The HBC study evaluates 3 crop rotations: 1) cotton-sorghum rotation without winter cover crop, 2) cotton-sorghum rotation with a winter cover crop, and 3) continuous high biomass crop rotation with haygrazer (*Sorghum bicolor L.*) and winter cover crop. The winter cover crop was rye. Each crop rotation is under conventional and conservation tillage practices. Conventional tillage involved bed preparation and tillage during fall by listing down to 15 cm depth. Conservation tillage involved minimum traffic as pesticides were used to control weeds. The experimental design is shown in Figure 1.

Figure 1 shows fifty-four locations in the field that represent where neutron access tubes were located (this data is not shown at this time) where samples or measurements were generally taken. These locations represent three sample points within each plot yielding n=9 for each crop and tillage treatment combination. Biomass and soil samples were collected within 10 m^2 using the neutron access tubes as the center point of each sample location for mapping purposes.

Soil Sampling

Samples were taken from 0-15 cm depth in March 2002, before the initiation of the study, to determine residual impacts of the previous nitrogen rates study. A total of 112 soil samples were collected prior to the termination of the rye cover crop as shown on the maps (Fig 2, left side). These samples were analyzed for nitrates (NO_3-N), organic matter, potassium, phosphorus, and alkaline phosphatase activity.

Samples were taken from 0-10 cm depth in November 2003, following the first growing season, at 54 locations shown in Figure 1. These samples were again analyzed for same soil properties of the first samples, and in addition for soil microbial biomass C and N.

Soil and Plant Analyses

The soil samples were analyzed for nitrates, organic matter, potassium, and phosphorus content at a commercial laboratory.

Crop biomass measurements (area= 1 m^2 on cotton and sorghum; 1 m by ½ m on haygrazer) were made three times during summer growing season 2003 from the 54 locations across the study. Measurements included green leaf area and dry matter weights.

An Airborne Imaging Spectrometer (AISA) was used in monthly aerial flights to acquire images in 26 bands in the red/near infrared wavelengths. Figure 2A (right) shows an image of the field taken on June 23, 2003, where three bands (red, green, and near-infrared) are featured.

Cropscan Inc. radiometer measurements were collected in coordination with the monthly aerial flights. The radiometer measures reflectance from the crop in 16 wavelengths and can be used to calculate a normalized difference vegetative index (NDVI) used to assess crop biomass in a nondestructive manner.

The soil microbial biomass C (C_{mic}) was determined on a 15-g oven-dry equivalent field-moist soil sample (< 2 mm) by the chloroform-fumigation-extraction method as described by Vance et al. (1987), using 0.5 M K_2SO_4 as an extractant. In brief, organic C from the fumigated (24 h) and non-fumigated (control) soil were quantified by a C analyzer (Schimadzu Model TOC-V/$_{CPH}$-TN). The non-fumigated control values were subtracted from the fumigated values. The C_{mic} was calculated using a k_{EC} factor of 0.45 (Wu et al. 1990). Each sample had duplicate analyses and results are expressed on a moisture-free basis. Moisture was determined after drying at 105°C for 48 h.

Alkaline phosphatase activity was assayed using 1 g of air-dried soil (<2mm) without toluene with *p*-nitrophenol phosphate (substrate) at buffer pH 11 and incubated for 1 hour as described in Tabatabai (1994). Each sample was assayed in duplicate with one control, to which substrate was added after incubation and subtracted from a sample value. The results were expressed in mg of p-nitrophenol (PN) released kg^{-1} soil (moisture-free basis) h^{-1}.

Results and Discussion

The land area used revealed a decrease in elevation of 1 m from north to south that affected the spatial variability of clay and nutrients such as phosphorus and potassium (Fig 1, 2DE). This slope caused nutrients and clay runoff to the south of the field, where they became more concentrated compared to the north (Fig 1, 2). Higher nutrient and clay contents in the south part of the field resulted in higher vegetative indexes compared to the north part (Fig 2A). The higher vegetative index of the east side of the study must be reflecting the higher organic matter content on that area (Fig 2C). This was supported by the image taken with the hyperspectral unit on June 23, 2003 (Fig 2A right), where the east side of the field showed more biomass (green) and the west side showed more bare soil (red).

Soil organic matter did not show the same spatial variability of the clay, phosphorus, and potassium contents as affected by the difference of elevation (Fig 2C). The soil organic matter content was affected by the previous cropping systems history on the field. Higher organic matter content was found on the east side, which was previously under corn, compared to the west side, which was under cotton. This demonstrated that changes in organic matter could be induced by alternative systems than continuous cotton in semiarid soils. Soil nitrate content reflected the organic matter content of the soil (Fig 2BC).

From the fall soil sampling, the map of organic matter content remained similar compared to the first map (sampling) (Fig 2C right). However, it appears to be a decrease in organic matter content in the west side of the study, which may be caused: (1) by the difference in sampling density in the two samplings (112 for the first map vs. 54 for second map), or (2) changes may have already occurred in organic matter of the west side as all the plants died in field rep 3 before the other field reps (sections) (Fig 2A, right).

Alkaline phosphatase activity reflected mostly the trends of soil organic matter (Fig 2F). However, the second map reflected some opposite trends compared to the first map. Perhaps, this enzyme activity is reflecting changes in soil nutrients or microbial diversity (i.e., changes in microbial types) not reflected by the other soil properties.

The spatial variability of soil microbial biomass, an indicator of the number of soil microorganisms, reflected the soil organic matter content (Fig 2G). Microbial biomass C was unaffected by the first tillage practices on the plots whereas alkaline phosphatase activity was significantly decreased by conventional tillage (Fig 3AB). Generally, the influence of soil tillage practices on organic matter has been detected in temperate soils only over extended periods, whereas changes in microbial biomass and microbial processes have been manifested over shorter time scales (Christensen, 1996). Gupta et al., (1994) reported changes in microbial biomass and microbial respiration without changes in organic matter in the first year following a range of stubble management and tillage practices onto a conventionally tilled soil. Previous studies in long-term plots showed that alkaline phosphatase activity, organic C and microbial biomass N were increased by reduced and minimum tillage in the 0-10 cm layer of the bulk soil (Kandeler et al., 1999). Tillage operations are known to have effects on the loss of soil organic matter as a result of mixing the soil, disruption of aggregates, and increased aeration (Balesdent et al., 1990). Conversely, reduced tillage practices and increasing the amounts of surface residue inhibit loss of organic matter from the soil (Angers et al., 1993).

Leaf area and crop biomass were unaffected by the tillage practices (Fig 4AB). There was a high variability in these plant measurements as all the plants died in field rep 3 before the other field reps (sections). Cotton yields were higher on conventional tillage plots compared to no-tilled plots (Fig 4C). This was not in agreement with the trend of alkaline phosphatase activity in response to tillage practices. The results of plant yields must be because: (1) the first year under conservation tillage may still do not increase soil water conservation, and (2) the high land variability did not allow an assessment of tillage impacts on plant yields.

The rainfall in 2003 was lower than in previous years. The normal average precipitation is 465 mm whereas this year was about 254 mm (Fig 5). The maximum temperatures of June were also lower than expected. Thus, even though the study received the most rainfall during June, the crops were adversely affected by the low temperatures, which did not allow them to take advantage of the available moisture.

In our early assessment, the results provide indications that alkaline phosphatase activity was more sensitive to soil management than microbial biomass C, and it may promise to provide early trends of soil organic matter changes. This information is important for our future management decisions in dryland.

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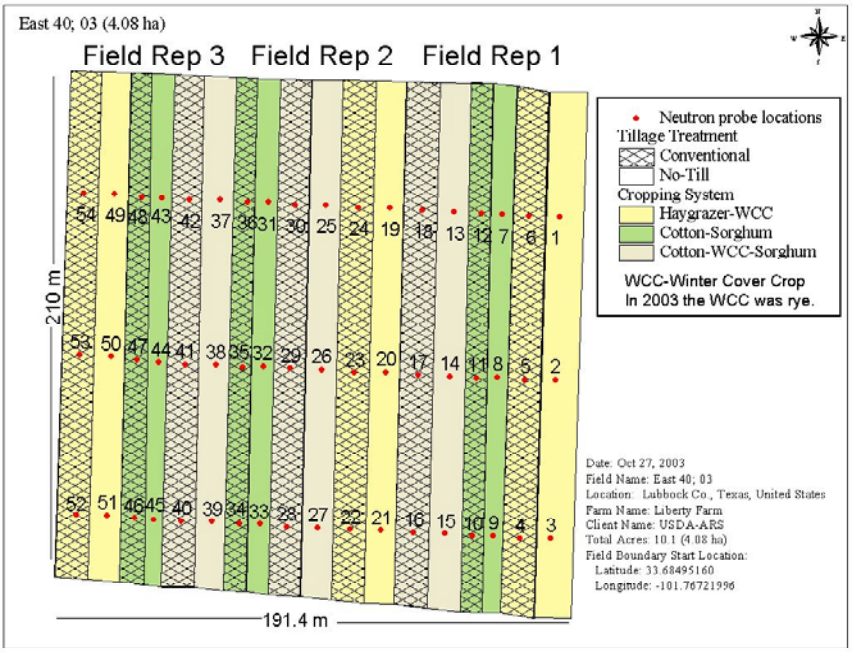

Figure 1. Experimental layout of the HBC study.

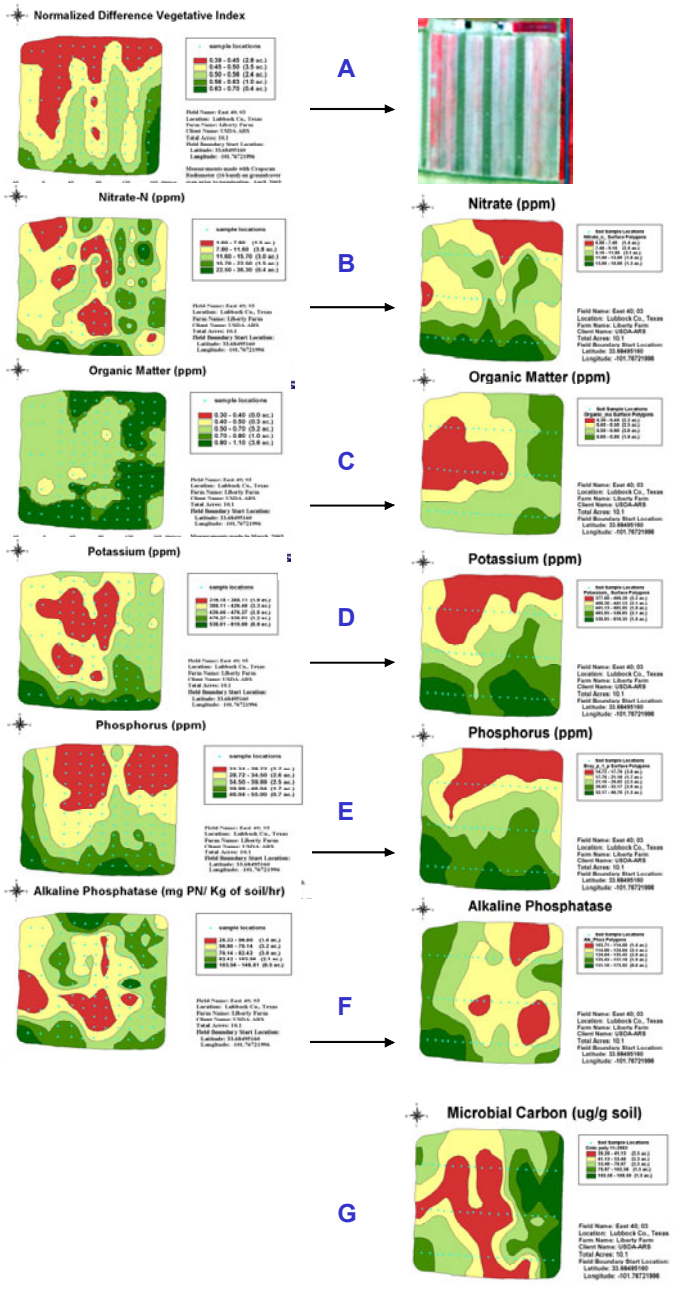

Figure 2. Spatial variability of plant surface coverage (A), soil nitrate (B), organic matter (C), potassium (D), phosphorus (E), alkaline phosphatase activity (F) and microbial biomass (G) of the field studied. For the first set of maps (left), the measurement of plant surface coverage and soil samples were taken before initiation of the study in March under rye at 0-15 cm depth from 112 points (circles), and for the second set of maps (right) the soil samples were taken from 54 locations (circles). Microbial biomass was measured only in the second sampling.

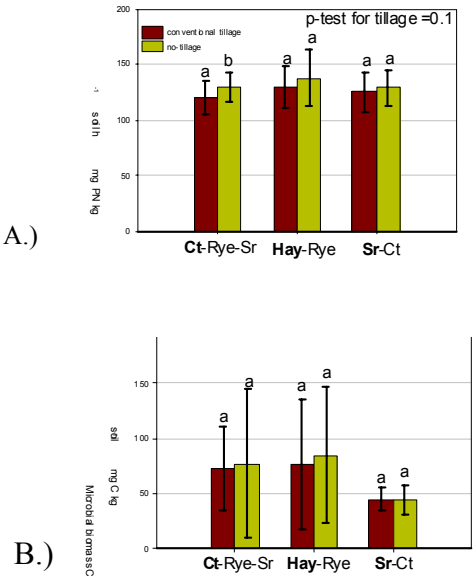

Figure 3. Alkaline phosphatase activity (A), and microbial biomass (B) as affected by the cropping systems studied (tillage and crop rotation). The crop in bold was the crop of summer 2003.

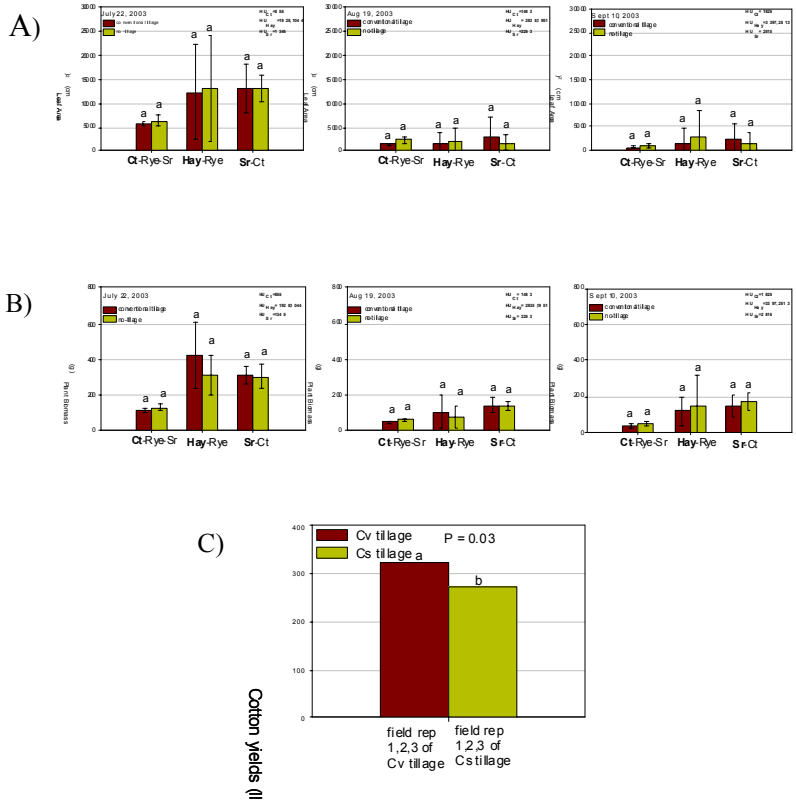

Figure 4. Leaf area (A), plant biomass (B) and cotton yields (C) on the growing season of 2003.

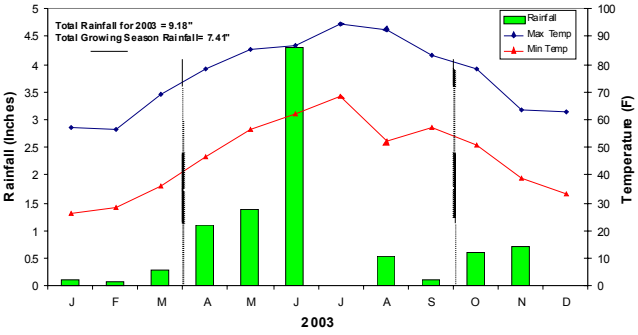

Figure 5. Rainfall, and the maximum and minimum temperatures for 2003.