SOIL HEALTH AND COTTON PRODUCTION IN THE SEMI-ARID TEXAS HIGH PLAINS

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ABSTRACT

Soil health has become a ubiquitous term in agriculture, but little is known about the impact of cropping system management on soil health metrics in semi-arid regions because of the majority of research has been conducted in humid or sub-humid regions of the United States. As a leading commodity of the semi-arid Southwest, cotton is an ideal candidate for soil health review. The purpose of this study was to assess a proposed set of soil health metrics in cotton production on the semi-arid Texas High Plains. The proposed metrics included soil C pools (soil organic C and permanganate oxidizable C), microbial biomass (phospholipid fatty acids), and microbial activity (mineralizable C, β-glucosidase and β-glucosaminidase). The metrics were evaluated at two locations: a native rangeland (NAT) near Wellman, TX and the Agricultural Complex for Advanced Research and Extension System (AG-CARES) near Lamesa, TX. The AG-CARES location included three continuous cotton (*Gossypium hirsutum*) cropping systems: 1) continuous cotton with fallow during winter (CT); 2) no-tillage with rye (*Secale cereal*) cover (R-NT); and 3) no-tillage with mixed species cover (M-NT). Results indicated most soil health metrics were reduced in the CT treatment compared to the NAT, M-NT and R-NT treatments. Mineralizable C was not impacted by treatment. There was no relationship between cotton yield and biological indicators of soil health. Conservation management practices in cotton monocultures exhibited soil health characteristics similar to a native rangeland, indicating intensive conservation can yield similar ecosystem services to native sites when compared to conventional cotton cropping. Further research is necessary to understand the relationship between cotton lint yield and biological indicators of soil health.

INTRODUCTION

Soil health can broadly be described as the continued capacity of a soil to perform a function that sustains humans, animals, and plants. The Natural Resources Conservation Service identified four methods for promoting soil health: 1) manage more by disturbing less, 2) diversity with crop diversity, 3) keep living roots throughout the year, 4) keep the soil covered as much as possible, 5) integrate livestock (NRCS, 2012, 2015). In agricultural production, the primary function of the soil is to produce a marketable crop. When coupled with the principles of soil health, there are several management practices to support this goal, including reduced tillage and cover cropping. The adoption of these practices can be impeded by the farmer’s perception of how these practices can impact yield. Lewis et al. (2018) reported that conservation management practices increased soil organic C (SOC) but reduced yield in a semi-arid cotton (*Gossypium hirsutum*) cropping system. Most of the soil health research has focused on carbon (C) management as it is a driver of soil biology and nutrient cycling (Follet at el., 1987; Nelson and Sommers, 1996). Due to the important role of soil biology, several soil health metrics have been proposed to relate their function in agricultural productivity (Haney et al., 2006; Nakajima et al., 2015; Moebius-Clune et al., 2016). These metrics have not been thoroughly evaluated in semi-arid ecoregions like the Texas High Plains where biological C pools are relatively small (Blair et al., 2001; Bronson et al., 2004). To this end, a project was implemented to determine how a set of proposed soil health metrics could be useful in cotton (*Gossypium hirsutum*) production on the semi-arid Texas High Plains. The objective of this study was to assess the usefulness and repeatability of proposed soil health metrics on the semi-arid Texas High Plains.

MATERIALS AND METHODS

Site description and experimental design

Two research sites were used for the soil health evaluation. The first was a native rangeland (NAT) located near Wellman, TX (33^{o}3’ N, 102^{o}24’ W) that has not been plowed in at least 80 years (K. Attebury, personal communication, 31 May 2018). The second was a continuous cotton cropping system located at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES) near Lamesa, TX (32^{o}46’ N, 101^{o} 56’ W) which contained three treatments with a randomized complete block design and three replications, including: 1) continuous cotton with winter fallow (CT); 2) no-tillage with rye (*Secale cereal*) cover (R-NT); and 3) no-tillage with mixed species cover (M-NT). The mixed species cover included hairy vetch (*Vicia villosa* Roth), Austrian winter field pea (*Pisum sativum* L.), rye and radish (*Raphanus sativus* L.). Both cover crop treatments were planted using a grain drill at 40 lb acre^{1} with the mixture comprised of 50% rye, 33% winter field pea, 10% hairy vetch, and 7% radish by weight. Cotton was planted annually as the main crop.

Soil characterization

Soil samples were collected to a 100-cm depth using a hydraulic soil probe (Giddings Machine Company, Windsor, CO) on 31 May 2019 and 1 June 2019 for the NAT and AG-CARES locations, respectively. Soil cores were subdivided into 0-5, 5-10, 10-35, 35-75, and 75-100 cm depths. Depths were selected because they correspond to the major soil horizons. For this report, we will only be presenting the results for the 0-5 and 5-10 cm depths. The soil at both sites was classified as an Amarillo series, a benchmark soil of the Southern High Plains of Texas with significant distribution in the region (3.04 M acres) and is described as a fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) with a pH of 7.5 (USDA-NRCS, 2016).
Soil organic carbon (SOC) was determined using instrumental combustion (Schulte and Hopkins, 1996). Potassium permanganate oxidizable C (POXC) was determined by reaction with dilute permanganate according to Weil et al. (2003). Mineralizable C was determined following a re-wetting of air-dried soil as described by Franzluebbers (2016). Total phospholipid fatty acids (PLFAs) were determined by the Soil Health Assessment Center at the University of Missouri. Two enzymes were analyzed during this study, β-glucosidase which is responsible for hydrolyzing complex sugars (Eivazi and Tabatabai,

1988) and β-glucosaminidase which is responsible for the degradation of chitin (Parham and Deng, 2000).

Statistical analysis
Analysis of variance for all parameters was calculated using a randomized complete block design with three replications (PROC GLIMMIX, SAS 9.4, 2015). Means of treatment effects were compared among treatments using Fisher's least significant difference (LSD) at alpha level = 0.05 for all analyses. Pearson correlation coefficient was utilized to determine the relationship between all treatments at $P<0.05$. Principle component analysis (PCA) was determined using JMP Pro 12 (SAS, 2015).

RESULTS AND DISCUSSION

Soil carbon
At the 0-5 cm depth, SOC was significantly greater in the R-NT, M-NT and NAT plots compared to the CT plots; however, at the 5-10 cm depth, SOC was greatest in the M-NT followed by R-NT, NAT, and finally CT (Fig. 1a). Tillage in the CT plots speeds the decomposition of organic material, resulting in less SOC. At the lower depth, SOC generally builds up from root C inputs into the soil (Neumann and Römheld, 2012). Carbon inputs were greatest in the M-NT and R-NT followed by NAT which is managed less intensively than the conservation management practices. There was significantly greater POXC in the R-NT and M-NT plots compared to the CT and NAT plots at both the 0-5 and 5-10 cm depths (Fig. 1b). The increases in POXC in the M-NT and R-NT treatments was likely the result of increased rhizodeposition which results in more bioavailable C compared to CT and NAT (Lucas and Weil, 2012). There was a positive linear relationship between SOC and POXC ($R^2 = 0.5196$, $p<0.0001$) which has been reported in other studies (Culman et al., 2012; Lucas and Weil, 2012; Culman et al., 2013; Morrow et al., 2016).

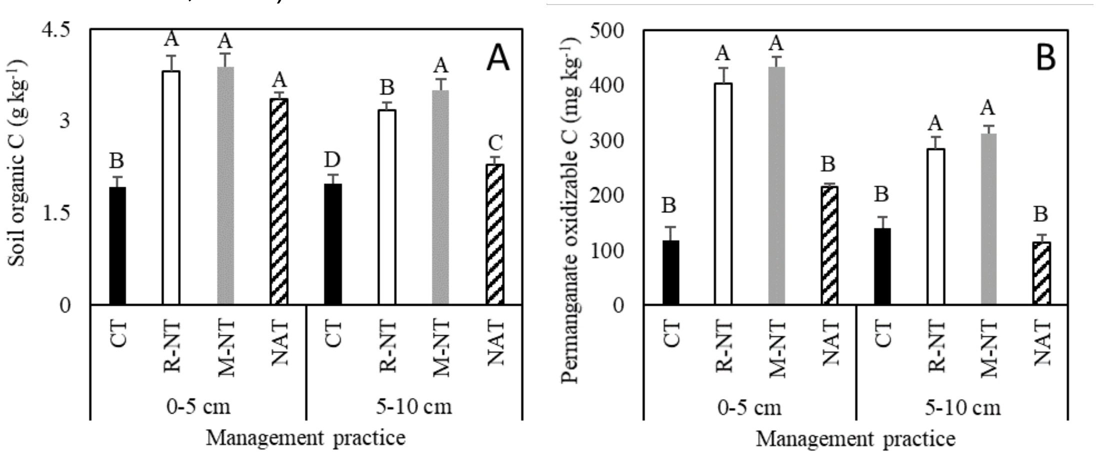

Figure 1. Soil organic carbon (A) and potassium permanganate oxidizable carbon (B) levels under different management practices. Mean concentration followed by the same letter within depth are not different at $P<0.05$ by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

Microbial activity

Microbial activity was not significantly different between any treatments at either depths using the 3-day CO_2 flush for mineralizable C (Fig. 2a). However, when examining microbial biomass using Total PLFAs, there was significantly greater PLFAs in the NAT plots, followed by the R-NT and M-NT, and finally the CT plots at the 0-5 cm depth (Fig. 4). At the 5-10 cm depth, PLFAs were significantly greatest in the R-NT, M-NT, and NAT compared to the CT plots (Fig. 2b). In semi-arid soils, the limited microbial activity might not reflect a difference between treatments in a 3-day CO_2 flush, but a longer incubation period might yield significant differences between treatments. While the NAT treatment yielded a greater microbial diversity, as seen with PLFAs, compared to the other treatments, there was generally greater microbial activity as measured by enzyme production in the M-NT treatments compared to the other plots (Fig. 3a and 3b). The increased microbial activity is likely linked to increases in overall primary plant productivity. The increases in plant productivity stimulates microbial activity through C deposition to the root zone (De Nobili et al., 2001; Demoling et al., 2007). These C additions stimulate microbes to increase enzyme production. This is an important distinction for soil health in semi-arid cropping systems. The biological function of soil might not necessarily be limited by the microbes present, but by the quality of the C substances available to the microbes.

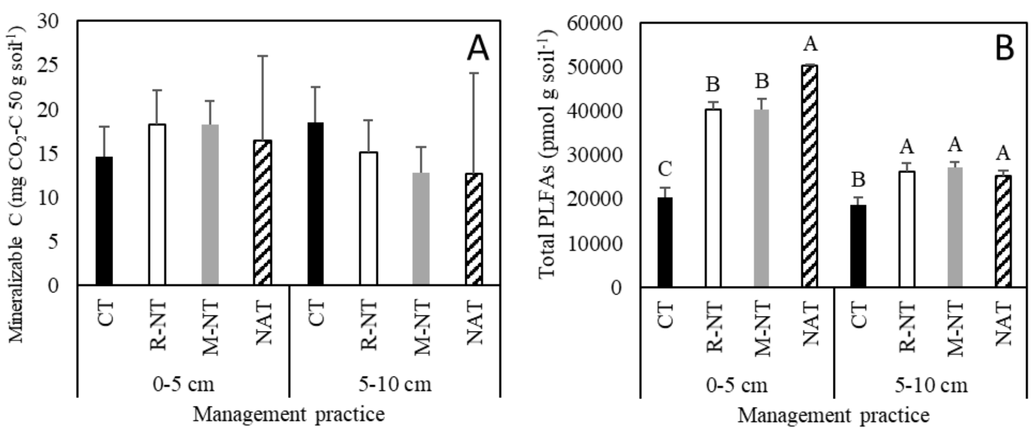

Figure 2. Mineralizable C following a three-day rewetting (A) and Total phospholipid fatty acids (PFLAs) (B)under different management practices. Mean concentration followed by the same letter within depth are not different at P<0.05 by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

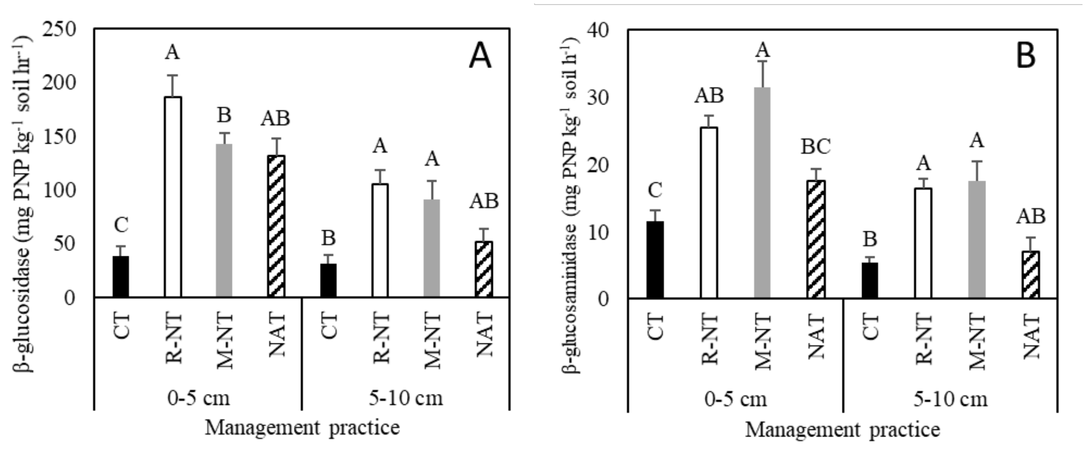

Figure 3. β-glucosidase (A) and β-glucosaminidase (B) activity under different management practices. Mean concentration followed by the same letter within depth are not different at P<0.05 by Fisher's protected LSD. Conventional tillage winter fallow, no-tillage mixed cover, no-tillage rye cover, and native rangeland treatments are denoted as CT, M-NT, R-NT, and NAT, respectively. The vertical bars represent the standard error of the mean.

Yield and soil health

An important component for the adoption of soil health management practices is that they support ecosystem services. The ecosystem service most important for agricultural producers is the maintenance and enhancement of crop production or yield. For this study, we compared the relationship between yield and the soil health parameters measured for biological activity (Fig. 7). Yield was not significantly correlated to any soil health measurements (Table 1). Further research is necessary to determine why there is no relationship between yield and biological indicators of soil health.

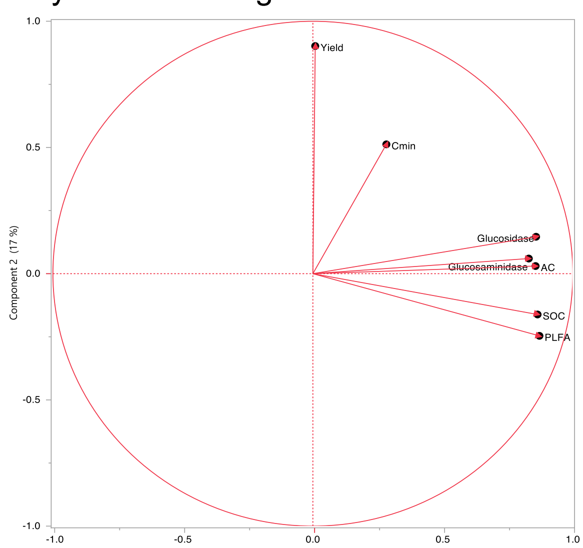

Figure 4. Principle component analysis (PCA) for all treatments. Mineralizable C, B-glucosidase, B-glucosaminidase, permanganate oxidizable C, soil organic C, and phospholipid fatty acids are designated as Cmin, Glucosidase, Glucosaminidase, AC, SOC, and PLFA, respectively.

Table 1. Pearson correlations among yield and soil measurements.

Variables	Yield†	SOC‡	POXC§	C-min¶	Total PLFAs#	β-glucosidase	β-glucosam.††
Yield	1.000	-0.640^{ns}	0.108^{ns}	0.144^{ns}	-0.244^{ns}	0.116^{ns}	0.077^{ns}
Soil organic C		1.000	0.721^{***}	0.112^{ns}	0.747^{***}	0.643^{***}	0.631^{***}
POXC			1.000	0.091^{ns}	0.645^{***}	0.667^{***}	0.682^{***}
C-min				1.000	0.268^{*}	0.272^{*}	0.158^{ns}
Total PLFAs					1.000	0.699^{***}	0.620^{***}
β-glucosidase						1.000	0.657^{***}
β-glucosam							1.000

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; *** Significant at the 0.001 probability level; ns Not significant at 0.05 probability level; † Yield, 2018 cotton lint yield; ‡ SOC, soil organic C; § POXC, potassium permanganate oxidizable C; ¶ C-min, mineralizable carbon; # Total PLFAs, total phospholipid fatty acids; †† β-glucosam. β-glucosaminidase

CONCLUSION

Conservation management practices can significantly increase biological soil health metrics when compared to a conventional cotton cropping system. However, there was no relationship between the proposed soil health metrics and cotton yield which is the primary function of soil in Texas High Plains agricultural production. Microbial activity was greatest in the mixed species cover, although microbial biomass was greatest in the native rangeland. These results indicate that intensive conservation management can build soil health to the same, and even greater extent, than native rangelands in semi-arid ecoregions. Further study is needed to quantify chemical and physical soil health metrics in cotton production to see if this trend continues and identify the relationship with cotton yield.

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