Understanding Benefits to Soil Health Using no-Till and Stubble Management for Irrigated Cotton in a Semi-Arid Environment

by

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ABSTRACT

The Southern High Plains of Texas (SHPT) is an economically important area that produces around 25% of cotton of the United States. However, climate variability in the area is increasing the vulnerability of several agricultural goods produced in this area that has historically benefitted from stable climatic patterns. Droughts have become more frequent and stronger, rainfall events are more variable in time, and daily temperatures have reached higher records during the growing seasons. These environmental conditions have negative effects especially on agricultural soils managed with conventional techniques that are already known to be detrimental for soil health. There are however land management strategies that mitigate the negative environmental consequences of climate variability while promoting several physical, chemical, and biological factors that benefit soil health. Such soil health practices include crop rotations, use of cover crops and reduced tillage or no-till, and although the implementation of these strategies is on the rise in the SHPT, the use is not yet widespread.

My dissertation focused on describing how environmental factors of soil temperature variability and water content affect soil health characteristics related to chemical (Soil Organic Matter - SOM, Cation Exchange Capacity - CEC, NH_4^+-N, NO_3^--N and Labile Carbon) , and biological (Microbial Biomass Carbon - MBC, FAME profiles and Enzyme Activity) factors in three center-pivot irrigated fields where soil health management using no-till has been implemented for 13 years, and one field subjected to conventional management practices. Measurements of all fields were conducted monthly across the growing season from 2017 to 2019.

Volumetric Water Content (VWC) was observed to be significantly higher among no-till fields, suggesting that no-till fields had increased water holding capacity. However, temperature

variability (DTR) was over all observed to be similar across both land management types due to the increased heat capacity that water from irrigation provides to soil. This suggested that over-all, environmental conditions were similar throughout all fields despite the differences that tillage normally produces.

No-till fields had increased SOM levels, CEC and lower Labile Carbon amounts. Although no significant differences were observed in MBC, FAME indicators, and NH_4^+-N and NO_3^--N, among land management types, strong negative relations between these factors were observed only in the conventional-till field, suggesting that nitrogen dynamics are driven by abiotic controls instead of by biotic factors. Significantly higher levels of Labile Carbon observed in the conventional-till field were an indicator of increased organic matter degradation rates, consequence of tillage burying crop residue, which results in a decreased carbon storage capacity of soil. No significant differences were seen in enzyme activity and FAME markers among land management types. Knowing that soil moisture is an important driver of soil microbial communities and metabolic activity, irrigation could override potential benefits of no-till and stubble management and climatic constraints that would otherwise affect microbial community structure and enzyme activity.

Over the longer term, key soil health indicators were less variable under the no-till and stubble managed system with increases in soil organic matter under no-till and stubble management being a major indicator of future progress for developing a healthy soil in this semi-arid region. For irrigated semi-arid agroecosystems, moving towards a no-till and stubble management approach resulted in a better relationship between the microbial communities and carbon and nitrogen dynamics and developing a positive trajectory in soil health.

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CHAPTER I

INTRODUCTION

Soil Health

Soil health and quality is an increasingly important subject of concern given the importance and significance of soil being a critical component of earth's biosphere. Well-functioning soils, with a diverse and active microbial community provide essential processes that are critical for the functioning of local, regional and global systems (Doran and Zeiss, 2000). Soil health is recognized as crucial for the functioning of both natural and managed ecosystems. The functioning of agroecosystems and subsequent yields are linked directly to soil health and soil quality. Different types of crop production management will generate different outcomes over time, some of which can induce soil degradation and lead to loss of plant productivity with increasing economic costs. (Karlen et al., 1997).

The concept of soil quality has been suggested before as a tool for assessing long-term sustainability of agricultural systems (Karlen et al., 1994). Johnson *et al*. (1997) emphasized the importance of standardizing the definition of soil quality to make it meaningful within and across disciplines. They defined soil quality as "a measure of the condition of soil relative to the requirements of one or more species and/or to any human need or purpose". More recently, soil health or soil quality has been defined as "the capacity of soil to function within ecosystem boundaries to sustain biological activity, maintain environmental quality, and promote plant and animal health" (Doran and Zeiss, 2000). Healthy soils are assessed by both qualitative and quantitative abiotic and biotic indicators that inform how resilient the system can be to disturbances and crop management approaches. However, this assessment can be difficult due to evaluations being dependent on the immediate or past use of soils at a specific location as well as the climatic zone and soil type (Karlen et al., 1994). Still, there are stable and dynamic indicators that are influenced by soil properties and allow for an assessment of soil health. Stable indicators are shaped slowly by soil-forming factors like topography, parent material, climate and organisms. Dynamic indicators change due to land management or land use and the effects can be observed over the course of a short period of time, like changes in soil organic matter (SOM) and pH (Awale et al., 2017).

Soil Health Indicators

Soil aggregates are particles that are bound together by organic and inorganic materials (Tisdall and Oades, 1982). When aggregates are stable, they have the capacity of resisting damage from forces such as erosion from wind and water or tillage (Pulido Moncada et al., 2015). Stable soil-aggregates are good indicators of soil quality as they increase water infiltration rates, aeration, and facilitate plant root growth. In addition, better soil structure provides protection of SOM against fast microbial decomposition (Schmidt et al., 2011). Crop residue and addition of organic amendments promotes production of soil binding agents such as fungal hyphae and polysaccharides, mucilage and lipids from soil biological activity (Lynch and Bragg, 1985; Oades, 1984).

Soil compaction has been used as one indicator of soil health and can be measured by observing the ratio of the mass of oven-dry soil to its bulk volume with a high ratio indicating high soil compaction (Batey, 2009). Soil compaction happens when soil particles are pressed together resulting in reduced space between pores. In agriculture, soil compaction is mainly caused by wheel traffic from heavy equipment and from intensive tillage practices (Batey, 2009; Hamza and Anderson, 2005). Such physical disturbance reduces aggregate stability, destroying the soil particles and reducing soil pore space (Horn et al., 1995). Soil compaction also decreases root growth and the ability of plants to uptake nutrients, resulting in reduced crop yield (Hamza and Anderson, 2005; Whalley et al., 1995).

Water infiltration, which is defined as the rate of water entry into the soil is affected by the levels of soil aggregate stability, compaction and porosity (Allen et al., 2011a; Franzluebbers et al., 1995). Also, tillage, crop residue cover, and SOM levels influence the way water is retained and stored in soil (Smith and Elliott, 1990). Higher infiltration rates were reported in cropping systems with no-till, and lower infiltration in disc tilled systems (Feng et al., 2011). The same study observed that till systems increase water infiltration but only for the short term, whereas no-till systems sustained higher infiltration over the long term. In addition, crop residue left by no-till systems blocks direct impact from rainfall, preventing crusting and erosion. Crop residues provides insulation and shielding from high air temperatures, air movement across the soil surface, which increases evaporation and intense solar radiation, thereby reducing evaporation (van Donk and Klocke, 2012).

Many physical, chemical and biological processes in the soil are influenced by pH. Constant use of acid-forming N fertilizer like ammonium-based fertilizers decrease soil pH because of the production of hydrogen ions during the nitrification process (Mahler, 2002). Soil pH below 6 cause yield reductions and increase solubility of heavy metals like aluminum and manganese (Schroder et al., 2011). Acidic soils also cause negative impacts on soil microbial communities and earthworm populations, reducing rates of SOM decomposition (McCauley et al., 2009). Acidic soils hamper enzyme activity by damaging ion and hydrogen bonds in active sites, hence altering the shape of enzymes and in consequence decreasing enzyme activities with the exception of acid phosphatase (Acosta-Martinez and Tabatabai, 2000; Awale et al., 2017;

Dick et al., 1988; Sinsabaugh et al., 2008). Common strategies used to increase soil pH are lime application (Acosta-Martinez and Tabatabai, 2000; McLean, 1983), retention of crop residues (Butterly et al., 2013), and use of organic amendments (Angelova et al., 2013; McCauley et al., 2009). Crop residues keep basic cations like calcium, magnesium and potassium that neutralize soil acidity. Negative charges product of the decomposition of organic amendments buffer acidity and increase soil pH (Brown et al., 2008).

Soil organic matter contains organic materials in different stages of decomposition and is a key indicator of soil health as levels of SOM influence the soil properties mentioned above. Plant root and microbe exudates, plant and animal residues, and tissue of living soil organisms are among the elements constituting to the formation of SOM (Parton et al., 1987). Moreover, systems with higher levels of SOM are more efficient in sequestering atmospheric carbon and turning it into soil organic carbon via photosynthesis (Lal, 2004; Machado et al., 2006). Turnover of SOM is influenced by the type of management the soil is receiving. Ideally, there should be a balance between the carbon inputs (crop residue and organic amendments) and the carbon outputs (decay, leaching and erosion) to avoid initiating a downward spiral in SOM levels. Low quality and quantity of crop residue, for example, is attributed to decrease in SOM levels (Ghimire et al., 2017; Shahbaz et al., 2017). Increased biological degradation of SOM is associated with multiple tillage operations (Rasmussen and Collins, 1991; Shrestha et al., 2015). However, as changes in SOM are evident in the long term, there is an increasing interest in developing and evaluating soil health indicators that are sensitive to the effect of crop management practices on SOM dynamics (Machmuller et al., 2015; Sarker et al., 2018). Particulate organic matter (POM) is an intermediate pool of organic matter and is composed of plant residues, microbial and microfaunal debris of recent origin (from weeks to years) (Blanco-

Moure et al., 2016). Particulate organic matter, organic matter that retains evidence of its original cellular structure and is smaller than 2 mm (Wander, 2004), has an important role in formation of different forms of organic matter and microbial biomass. Another important indicator used to evaluate soil health is amount and stability of the soil microbial biomass over a growing season and among years (Pankhurst et al., 1995; Schloter et al., 2003; Singh and Gupta, 2018; Zhou and Ding, 2007). Determination of the amount of soil microbial biomass carbon indicates the total size of the microbial community. Microbial communities are important in decomposition of organic matter (Bending et al., 2002), nutrient cycling (Coleman et al., 1983) (Coleman et al 1983), stability of soil aggregates (Bossuyt et al., 2001; Lynch and Bragg, 1985; Tisdall and Oades, 1982), degradation of pollutants (Bollag et al., 1994; Neumann et al., 2014), plant health and disease suppression (Berendsen et al., 2012). Various components of SOM like particulate organic matter or dissolved organic matter (composed by organic acids, sugars and amino acids) are used and transformed by the microorganisms that inhabit soils (Wander, 2004). For example, bacterial communities can rise on rapidly available substrates rich in dissolved organic matter. Fungi can break down complex compounds like cellulose and lignin and thrive in substrates commonly found in particulate organic matter. Consequently, fungi are better at storing nutrients than bacteria. Fungal dominance is thereafter a positive indicator of the ability of soils to store and accumulate organic C (Strickland and Rousk, 2010). Accordingly, soil microorganisms respond rapidly to changes in the soil environment, thus making them good indicators of soil health dynamics, including changes in SOM quality and quantity (Lauber et al., 2013).

Land Management Effects

Soil deterioration in agriculture is often a consequence of land management decisions that have occurred over several decades. Tillage practices specifically have a negative impact on physical, chemical and biological characteristics of soil (Figure 1.1) (Kladivko, 2001).

Physical impacts

Physical disturbance of soil after tillage is known to influence soil compaction (Hamza and Anderson, 2005), soil water retention and infiltration (Abu-Hamdeh, 2004), and soil temperature (Kladivko, 2001). Agricultural equipment causes soil particles to come close together in a smaller volume. By crushing soil aggregates, compression between the particles reduces the pore space that usually is available to store air and water and is the main reason that aggregate structure, water retention and infiltration decreases in tilled agricultural systems (Horn et al., 1995). Soils with poor aggregate structure have poor water retention and tend to warm and cool faster than non-compacted soils. As tilling physically disturbs the soil surface, this disturbance increases air pockets and ultimately accelerate soil drying while increasing heating rates (Licht and Al-Kaisi, 2005).

Chemical impacts

Tillage also affects the distribution of nutrients and soil organic matter in the soil profile (Hussain et al., 1999). Nutrient profiles differ between tilled and non-tilled systems (Franzluebbers and Hons, 1996; Karlen et al., 1994). Tillage mixes the soil in ways that applied nitrogen decreases the pH (Blevins et al., 1983) and lime increases it (Kitur et al., 1994), depending on the depth of the disturbance. Organic carbon fluctuations as a consequence of tillage also affect cation-exchange capacity (CEC) of soil (Thomas et al., 2007). Cation exchange capacity is a measure of the amount of cations soil can retain adsorbed to particle surfaces

(Brady et al., 2008). In other words, CEC is a soil property that describes the capacity of soil to hold nutrients available for plants and microbes. Mahboubi et al. (1993) observed a significant increase in organic carbon and CEC after 28 years of no-till cultivation. Tillage systems have been observed to decrease SOM, especially when cultivating low residue producing crops (like soybean or cotton) (Edwards et al., 1992). In contrast, no-till systems along with high residue crops build SOM, which have a positive effect on organic C and N availability (Bayer et al., 2001; Christensen et al., 1994; Havlin et al., 1990; Lal, 2004, 2009).

Biological impacts

Along with physical and chemical properties, soil microbial changes reflect the extent and duration of physical disturbance through tillage across the growing season and across years. Soil microbial biomass carbon levels are affected by both organic matter input and decomposition rates of organic material throughout the season (He et al., 1997; Lee and Pankhurst, 1992). However, these two factors change according to the physical disturbance and management of the soil. These interactions may influence microbial dynamics by varying spatial and temporal distribution of organic inputs from rhizodeposition, roots and crop residue, and by altering soil moisture and nutrient availability (Franzluebbers et al., 1995). Moreover, the tillage type and intensity affect the soil microbial biomass carbon, exerting potential shifts on the structure of the microbial community (Feng et al., 2003; Frey et al., 1999; Mathew et al., 2012; Pankhurst et al., 2002).

Soil Microbial Ecology in Agriculture

Microorganisms have influential roles regulating vital surface and subsurface processes. Soil productivity is determined to a large extent by microbes breaking down complex nitrogen and carbon compounds from plant and animal residues to make them available for plant intake (Welbaum et al., 2004). Microbial communities in soil also regulate and destroy several environmental pollutants and biologically toxic compounds (Aislabie et al., 2013). In addition, microbial populations in the soil are tolerant to different environmental conditions given their numerical abundance, fast rates of reproduction, and diversity of types of metabolic activities (Doran et al., 1994). Agriculture practices have an effect on the structure and composition of microbial communities and alter community functionality (Lauber et al., 2013). Conventional tillage systems for example result in bacterial dominated soil microbial communities as tilling aerates the soil promoting aerobic bacteria and increases organic matter degradation (Six et al., 2006). On the other hand, tilling reduces fungal mycelium networks by breaking hyphal connections due to physical disturbance on the top 20cm of soil, thus lowering fungal abundance (Helgason et al., 2009). Tillage disruption is also associated with increased soil temperatures and decreased moisture levels (Franzluebbers et al., 1995). Tilled fields that result in bare soil, allows for direct sunlight to increase temperature on the top 5 cm of soil and as a consequence, microbial activity and biomass decrease (Biederbeck and Campbell, 1973; Dalal et al., 1991). Microbial activity, as measured by enzyme activity, has been observed to be strongly correlated to moisture and temperature fluctuations (Steinweg et al., 2012). Therefore, tilling practices may be influencing soil metabolic activity not only by creating a physical disruption, but by additionally altering temperature and moisture dynamics (Acosta-Martínez et al., 2008; Mbuthia et al., 2015).

Fertilizers and pesticides can alter microbial community composition, structure and dynamics (Geisseler and Scow, 2014; Kalia and Gosal, 2011) further decreasing soil health beyond outcomes from tillage disturbances. Chemical fertilizers have been observed to decrease mycorrhizal fungi abundance due to plants allocating more photosynthates to leaves and shoots rather to roots or mycorrhizal symbionts (Mbuthia et al., 2015). Moreover, rapid increase of key nutrients has been shown to have a similar effect in mycorrhizal colonization (Miao-Yan et al., 2009; Smith and Read, 2010). Nitrogen fertilizers are also known to decrease soil pH (McAndrew and Malhi, 1992), which have negative effects over population size of bacterial communities (He et al., 1997). On the other hand, organic fertilizers have positive effects over the soil microbiome. While chemical fertilizers often deliver more nutrients than the system needs, organic fertilizers supply a balanced amount of nutrients that often benefits microorganisms associated with the nitrogen cycle (Chen et al., 2012). Organic fertilizers stimulate nitrification, which provides an adequate substrate for denitrification and oxygen consumption that leads to anoxic environment that is favorable for denitrifiers to thrive (Miller et al., 2008), while simultaneously supply readily available organic carbon, which stimulates denitrification (Philippot et al., 2007).

Purpose of Research

Maintaining a healthy microbiome in agriculture soils under increasing climate variability is essential for soils to maintain continued capacity to sustain plant production. The Southern High Plains of Texas, an economically important region that contributes around 25% of the cotton produced in the United States is facing challenges to keep optimal production of cotton and other crops due increased risk of experiencing record-high temperatures, and changes in the frequency and magnitude of precipitation events (Steiner et al., 2017). For this reason, it is important to understand the effects of climate variability and different land management practices on cotton production systems in semiarid environments. Even though there is extensive literature on soil health characteristics and how these are influenced in various agriculture systems, there is little information for semi-arid cotton production systems located in the Southern High Plains of Texas. In addition, climate variability poses a risk to agriculture in this area (Steiner et al., 2017). The region has been impacted by higher mean temperature, longer and harsher droughts and fewer but stronger rainfall events (Steiner et al., 2017). As these conditions are expected to worsen (Wuebbles et al., 2017), it becomes necessary to understand the effects of climate variability on soil microbial dynamics as they are either negatively or positively impacted by crop management decisions. Farming strategies intended to recover soil productivity with less effort are being implemented in the region. These strategies include no-till, conservation till, use of cover-crops and diversification of crop-rotations, applied with the purpose of building soil health. The effect of this approach seeks to fulfill the four basic principles of soil management as stated by USDA NRCS (USDA NRCS, 2012), which are: "1. Keep the soil covered as much as possible, 2. Disturb the soil as little as possible, 3. Keep plants growing throughout the year to feed the soil, and 4. Diversify as much as possible using crop rotation and cover crops".

Research Objectives

The purpose of this research is to understand the effects of cropping system management and climate variability on microbial and nutrient processes and dynamics in a 13-year sustainable cotton production system and in a continuous conventional-till field within and across 3 growing seasons in a semi-arid environment. Soil disturbance is a key driver of subsequent microbial community responses and ecosystem processes that are both the response variables and the drivers through complex feedback loops (Figure 1.1) (Peters et al., 2011; Pickett, 1985; Pickett et al., 1989).

Specific Objective 1. To observe how land management (Till, No-till, Cotton, Corn, Cover crop rotations) influences soil health abiotic indicators (gravimetric water content (GWC), cation exchange capacity (CEC), plant available nitrogen (NO_3^--N, NH_4^+-N), Soil Organic Matter (SOM) and labile carbon) and biotic indicators (Microbial Biomass Carbon (MBC), and microbial community structure and function).

Hypothesis 1. No-till fields are expected to have higher levels of soil health indicators such as MBC, SOM and enzyme activity, and stable dynamics of plant available forms of nitrogen regardless of the crop growing at a given time, than tilled soils. This is expected because continuous tillage produces detrimental effects on soil physical properties like destruction of soil aggregates, that start a reaction of negatives effects on chemical and biological properties that may influence soil health indicators and linked drivers.

Hypothesis 2. Microbial community structure and composition is expected to differ between till and no-till fields, and similar between the no-till fields experiencing different crops at a given time. Physical disturbance created by continuous tillage exposes the soil surface to higher temperatures, leading to hotter soil surface temperature and increased water evaporation, affecting fungal communities that are more sensitive to these conditions (Sobek and Zak, 2003). Fungal:bacterial biomass ratios are expected to be different between till and no-till fields under the premise that crop residue covering the soil surface promotes fungal growth by providing a C-rich environment (Holland and Coleman, 1987).

Hypothesis 3. Enzyme activity will be higher across all no-till and stubble fields given the stronger capacity of fields with this kind of management to harbor a healthier and better structured microbiome (Acosta-Martínez et al., 2021).

Specific Objective 2. To evaluate the stability of soil health indicators and drivers under till and no-till management practices across growing seasons and among soil management practices.

Hypothesis 1. Both abiotic and biotic soil health indicators and drivers in no-till fields are expected to display stable dynamics across time due to the benefits that decreased physical disturbance have over physical, chemical and biological soil traits.

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Figures

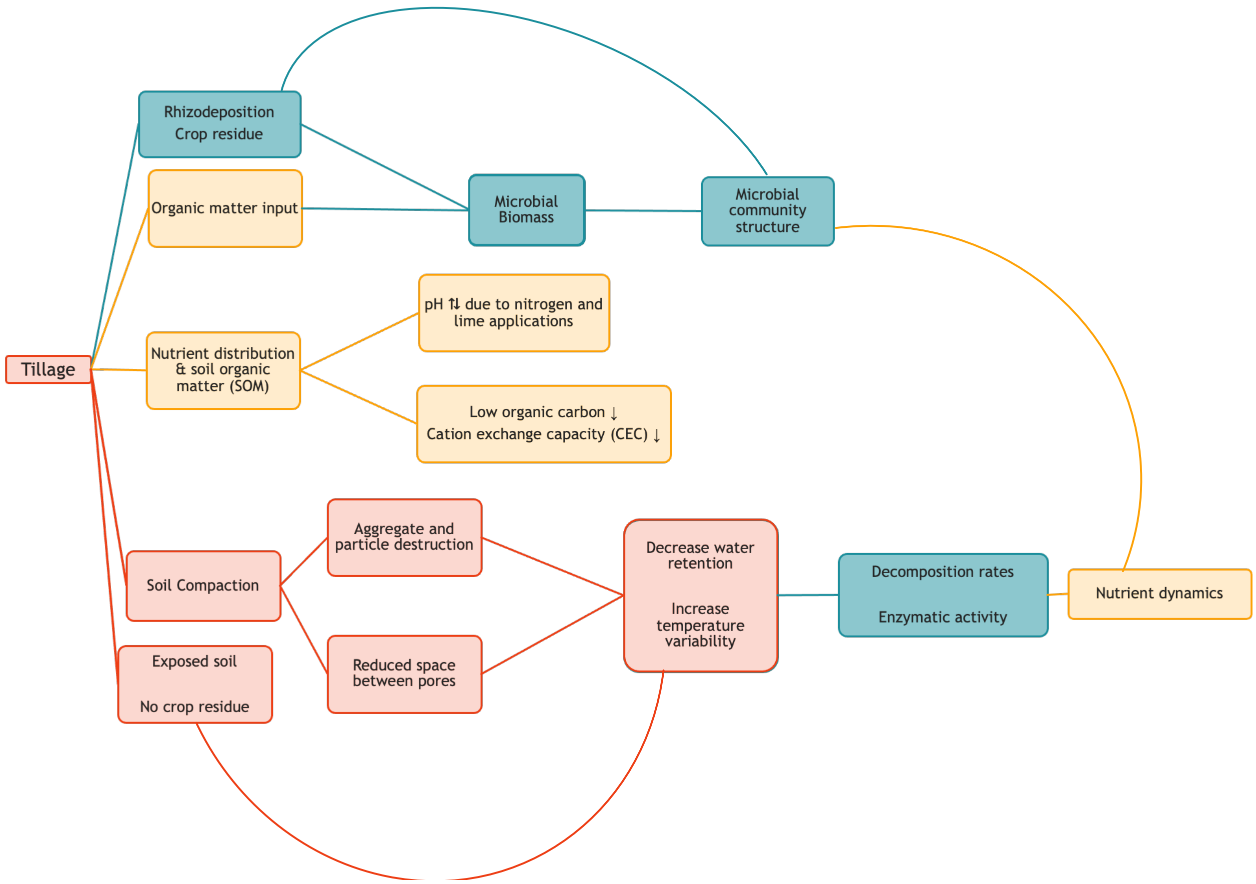

Figure 1.1 Simplified representation of the physical, chemical, and biological soil health factors (in red, yellow and blue respectively) that are affected by soil tillage, the main physical disturbance present in conventional agricultural systems.

CHAPTER II

SOIL HEALTH INDICATOR DYNAMICS UNDER DIFFERENT LAND MANAGEMENT TYPES OF PIVOT IRRIGATED COTTON CROP SYSTEMS IN THE SEMI-ARID SOUTHERN HIGH PLAINS OF TEXAS

Abstract

Vulnerability of agricultural systems to climate change and detrimental soil management practices can be mitigated by adopting management strategies that improve soil health. These strategies are known to buffer the effects of drought and extreme temperature variation while maintaining healthy crops. Although the implementation of soil health strategies is on the rise in the Southern High Plains of Texas, the use of such practices is not yet widespread. There is evidence of the positive effects that soil health management has on improving soil properties that conventional agriculture does not provide, but few comparisons involving growing season variability under irrigated cotton cropping systems have been made. In this study I evaluated a suite of soil health indicators and the response to environment and land management across three center pivot irrigated no-till and stubble fields and one center pivot irrigated conventional-till field with cotton production as the main commodity. Overall, no-till fields had a greater capacity to store water, increased soil organic matter level with stubble additions and had a more stable levels of microbial biomass carbon levels and pool of extractable NO_3-N than the conventional-tilled field. In the short-term, irrigation overrode any potential benefits of no-till and stubble management and climatic constraints in a given year. Over the longer term, key soil health indicators were less variable under the no-till and stubble managed system with increases in soil

organic matter under no-till and stubble management being a major indicator of future progress for developing a healthy soil in this semi-arid region.

Introduction

Interest and use of adaptive strategies known to mitigate climate change effects on soil at both intraannual and interannual scales is increasing (Brown and Herrick, 2016; Carlisle, 2016; Hills et al., 2020; Makate, 2019; Paustian et al., 2016; Steiner et al., 2017). These strategies seek to decrease the impact of detrimental factors affecting physical, chemical, and biological characteristics of soil, and can be measured using soil health indicators. Soil health indicators are a set of attributes related to functional processes (Doran and Jones, 1996) that can be used to evaluate the ability of any soil to be capable of supporting plant growth and provide critical ecosystem services in relation to climate impacts and land management. Use of soil health indicators can provide a suitable method to evaluate effects of land management techniques and environmental conditions, and their joint effects on the capacity of soil systems through time to be able to build soil organic matter, increase water storage, and facilitate nutrient mineralization (Allen et al., 2011b; Doran et al., 2002; Parihar et al., 2016; Sinha et al., 2014).

The Southern High Plains of Texas (SHPT) is an economically important region due to the extensive area used for agriculture. This region contributes to around 60% of Texas cotton (*Gossypium hirsutum*) production (USDA-NASS, 2017). Having a consistent climate with distinct patterns of temperature and rainfall has been key to the consistency of production of crops in the SHPT (Rottler et al., 2019), but farmers are facing challenges to keep optimal production due to increased climate variability (Modala et al., 2017; Steiner et al., 2017), and soil degradation generated by decades of continuous cropping and excessive tillage (Petermann et al., 2019). To face these challenges, growers could decrease the agrosystem vulnerability by implementing strategies that mitigate effects of climatic events and help restoring degraded soil from detrimental practices. Increasing carbon stocks is a shared goal of producers because promoting C levels in soil decreases vulnerability of the system. This requires changing soil disturbance practices and increase and diversify plant growth with rotations, and use of cover crops (Thapa et al., 2021). Because physical, chemical and biological properties in soil are interrelated, adjusting or enhancing any of the factors may result in a positive effect on the others (Dexter, 2004). Tillage is a strong physical disturbance on the topsoil layer that affects soil health indictors. When tillage is reduced, chemical soil properties like nutrient availability and distribution, pH, cation exchange capacity (CEC) and soil organic matter (SOM) (Balesdent et al., 2000; Franzluebbers and Hons, 1996; Godsey et al., 2007; Thomas et al., 2007), and biological properties like soil microbial community structure, composition and activity (Acosta-Martínez et al., 2010; Cotton and Acosta-Martínez, 2018; Degrune et al., 2017; Helgason et al., 2010; Helgason et al., 2009; Mbuthia et al., 2015) improve, enhancing the soil health and decreasing the system's vulnerability to adverse weather.

The purpose of this study was to observe the dynamics of soil health indicators in three no-till and stubble, and one conventional-till cotton production fields across three growing seasons on the semi-arid Southern High Plains. Specifically, the study was designed to determine the benefits of using conventional versus no-till and stubble management practices for center-pivot irrigated cotton production on soil health indicators, and to describe the dynamics on both intraannual and interannual basis on a semi-arid environment. I hypothesized that no-till fields will hold more water and have decreased mean soil temperature and daily temperature range (DTR) than the conventional-till field at any given year. Also, soil health indicators are expected to represent better conditions across the no-till fields. However, some variation is expected among the no-till fields given that different crops were growing on them each year due to the crop rotation program that the producer used. By following the fields across multiple crop rotations this study could also ascertain how crop type impacted soil health indicators in addition to soil management practices.

Materials and Methods

Study sites

The study sites were located on the Southern High Plains in Hale County, near Petersburg, Texas. The area is traditionally used for row crops and some rangeland. Soils are relatively productive, and the flat topography supports irrigation and mechanization. Management problems include limitation of soil moisture, wind erosion, and proper water management. This area is a leading producer of cotton, grain sorghums, and wheat in the region. Mean annual precipitation was 457 mm (range 188-931) for the 20-year period 2001-2020 according to the closest West Texas Mesonet weather station (Schroeder et al., 2005) located in Abernathy, TX. Precipitation mostly occurs at the beginning of the growing season in May and June and there is usually a second rainfall event during August and September (Table 2.1).

For this study, four center pivot irrigated fields were used as the locations for data collection. Three of the fields are located 5Km North of Petersburg and belong to producer Mr. RN Hopper (designed as RN-fields). These three fields will be henceforth known as F1 (Lat 33.9350 Lon -101.5793), F2 (Lat 33.9288 Lon -101.5716) and F3 (Lat 33.9356 Lon -101.5619). The fourth field is located 2 Km West of Petersburg and is a conventional tilled cotton production system operated by Mr. Tom Gregory. This field will be termed C1 (Lat 33.8729 Lon -101.6259).

No-till and Stubble Managed (RN) system

Soils in the RN farm are classified as deep, well drained, and slowly permeable Pullman Clay loams (Table 2.2). These fields have been under no-till management for approximately 10 years at the first year of observations. Each field is part of a three-step rotation system where a different crop is being grown at a given time. This rotation system includes cotton as the main commodity crop and corn. A mixed no-cash crop / cover-crop using grass, legume, radish, was introduced to the easternmost field (F3) in summer of 2017. In 2018 season, F1 was subjected to fallow after winter wheat. Black eyed peas were used as cover crop after winter wheat, on F2 in 2019 growing season. Crop per year and field area can be observed in Table 2.3. Each field is a center pivot irrigated system with irrigation and are 124 (F1), 184 (F2) and 116 (F3) acres.

Conventional tillage system

Soil in this field is categorized as Estacado Loam, which is described as a deep, well drained, moderately slowly permeable soil. This farm is a conventional cotton growing system subjected to tilling. The centerfield used for this investigation was divided in a half growing cotton and the other half growing corn. Each half was rotated to grow the other crop every growing season, and observations were taken from the half growing cotton. In 2019, a hailstorm destroyed the cotton seedlings early on the growing season. Because of this, the farmer decided to grow corn and the observations for that year were made on soil growing corn instead of cotton. This field is a center pivot irrigated system and is 122 acres.

Belowground measurements

Sampling begun in June 2016 after cotton was planted on field F1. In May 2017, F2 and F3 were incorporated in addition to F1, and in August of the same year, observations started on C1.

Six sites were selected for each field at the beginning of each growing season with sampling moving from the edge of the field to the center of the field. Decagon Em50 data loggers with 5TM probes just below the soil surface and at 15 cm (designated as root depth) to record soil temperature and volumetric water content every 60 minutes for the extent of the growing season. Data loggers were occasionally removed for a few days or weeks depending on the farmer's needs. Loggers were set back in their original site once it was allowed. Average, minimum, and maximum temperatures were calculated for each day of data collection. Daily temperature range (DTR) was calculated by subtracting minimum daily temperature from maximum daily temperature (van Gestel et al., 2011).

Composite soil samples of approximately 300 g were collected from the upper 15 cm of soil near each data logger site. Soils were kept cold during transit from the field to the lab, in which were transferred to a 4 °C cold room until analyzed.

Soil microbial biomass carbon (MBC) was measured using field-moist soil within one week of collection following the chloroform-fumigation extraction technique (Brookes et al., 1985; Vance et al., 1987). Two 5 g dry weight equivalent replicates of each soil sample were fumigated with chloroform while two more replicates were kept unfumigated for 48 hours at 4 °C until extraction. Chloroform fumigations lyse the living cells of the microbial community, which release C and increase extractable C levels in the soil replicate compared to the unfumigated replicate. The four replicates were then shaken in 50 mL of 0.5M K_2SO_4 to extract soluble C compounds and filtered using Whatman Grade 43 filter paper. The filtered solution was measured spectrophotometrically at 280 nm to obtain the concentration of organic C compounds. Microbial biomass C (MBC) was calculated using the difference of the absorbance between the fumigated and the unfumigated replicates (Nunan et al., 1998). Labile organic C measurements were obtained with the spectrophotometer readings of the unfumigated replicates only. Extractable ammonium (NH_4^+), nitrate (NO_3^-), soil organic matter (SOM) and soil texture were measured by Waters Agricultural laboratories (Owensboro, KY, USA) within one week of sample collection. Gravimetric water content (GWC) was evaluated within one day of collection by oven-drying soils at 60 °C for 48 h to determine soil moisture conditions at the moment of sampling and to calculate the dry-weight equivalent amount of soil to be used for microbial biomass assessments.

Statistical analyses

Violin plots using yearly means within fields and within years for each land management approach were generated using *ggplot2* (Wickham, 2009) in RStudio (Team, 2015) to visualize the distribution of the microbial and soil edaphic and nutrient data for each field and growing season. Data were log-transformed to homogenize the variances to perform multivariate analysis of variance (MANOVA) and determine if there were significant differences between the soil health indicators among fields per year, and for each field across time, and subsequent post hoc analyses were conducted using Tukey's honestly significant difference (HSD) with confidence interval of 95% in IBM SPSS Statistics for Windows, Version 26.

Ordinations were performed to better understand the relations between environmental and edaphic factors of each field. Discriminant function analysis (DFA) was performed on soil and environmental variables within fields across growing seasons, and between fields per year to test the probability of the observations from a given field to be classified as belonging to a different field. This analysis was done in IBM SPSS Statistics for Windows, Version 26. Principal components analysis (PCA) was also performed on soil microbial responses and environmental variables with the software Canoco 5 (ter Braak and Smilauer, 2012) using monthly means for each field per year. This process compared the relationships between the indicators, and the type of land management that a field was under at a given year. In both ordination analyses, plots were generated using all variables to describe the general outcome involving all factors. Ordinations were also done separating environmental variables from the measured soil health indicators to observe the presence of confounding effects.

Results

Yearly Patterns for Environmental Parameters

According to the two-way MANOVA, significant interaction effects, at $P < 0.05$, among field and between years on the environmental parameters were observed only in VWC at both depth measurements and in DTR at 15 cm depth (Table 2.4). Comparisons of main effects were conducted using Tukey's HSD posterior tests establishing differences at $P < 0.05$ to describe broad patterns of each environmental variable among years per field, and to compare variable means among fields per year. Across all years and fields, the no-till and stubble managed fields (RN) displayed the highest and lowest VWC, Mean and Maximum Temperatures at both surface and 15 cm depth measurements. However, C1 displayed the highest DTR recorded for all fields at 15 cm in 2019 (Table 2.5). Surface VWC was observed to increase across years on F1 and F3, but no significant differences were perceived on F2 and C1 (Figure 2.1a). At root depth, an increase in VMC was observed in all three fields in the no-tilled system from 2017 to 2019, while there were no significant differences in VMC at 15 cm in C1 between 2017 and 2019 (2.1b). Between field comparisons showed significantly higher levels of VWC between RN fields and C1 in 2017 at surface (F1, F2 and F3: $P < 0.001$) (Figure 2.2a) and root depth (F1, F2 and F3: $P < 0.001$) (Figure 2.2b). Surface VWC levels in 2018 were significantly higher in F2 than in the rest of the fields (F1, F3 and C1: $P < 0.01$), while root depth water levels were the lowest in F3 and C1, and similar for the rest of the fields (Figure 2.2b). In 2019 surface VWC was the lowest in C1, even though it shared similar levels with F1 and F2. Root depth VWC in 2019 was significantly lower ($P < 0.001$) in C1 compared to F3, but shared similar levels with F1 and F2.

Both surface and root depth DTR was the lowest in 2017 for all fields (Figure 2.1 a and b). At the surface, DTR increased significantly each year through 2019 reflecting regional weather trends. At root depth, DTR increased strongly from 2017 to 2018, then decreased significantly from 2018 to 2019 in F2 and F3 (Figure 2.1b). In contrast F1, and C1 root depth DTR increased from 2017 to 2018 and remained high in 2019. Between fields comparisons for surface DTR showed C1 and no-tilled fields with similar levels in 2017 and 2018, and no differences whatsoever in 2019 (Figure 2.2c); root depth DTR had similar levels between fields in 2017 and 2018, but in 2019, C1 had significantly higher levels (F1m F2 and F3: $P < 0.001$ for all fields) than the no-till fields (Figure 2.2d).

In all fields, surface and root depth Mean Temperature were lowest in 2017 (Figure 2.1 e and f). No-tilled fields F1 and F2 experienced strong increase of surface Mean Temperature from 2017 to 2018, but only F2 root depth Mean Temperature had a significant increase ($P < 0.001$) those same years. Between field comparisons of Mean Temperature showed no strong differences at any year, nor at sampling depth (Figure 2.2 e and f).

Maximum Temperature was the lowest in 2017 at both measured levels with a strong increase from 2017 to 2018 in all no-tilled fields at the surface (Figure 2.1 h and i). Field F2 was the only field that had a significant Maximum Temperature increase ($P < 0.001$) at root depth from 2017 to 2018 (Figure 2.1i). Between field comparisons of Maximum Temperature showed similar levels shared by all fields at every year and sampling depth (Figure 2.2 h and i).

Continuous data output across each growing season for VWC, DTR, Mean and Maximum temperatures are located in Figure 2.3.

Soil Edaphic Factors Across Years

According to the two-way MANOVA, significant interaction effects at $P < 0.05$ among field and year on the edaphic parameters were observed in GWC, CEC, NO_3^--N, SOM, Labile C and MBC (Table 2.4). Comparisons of main effects were conducted using Tukey's HSD posterior tests establishing differences at $P < 0.05$ to describe broad patterns of each edaphic variable among years per field, and to compare variable means among fields per year. Gravimetric water content (GWC) levels increased significantly in F3 ($P = 0.048$) and C1 ($P = 0.001$) from 2017 to 2018, and remained similar towards 2019, while F1 and F2 kept similar levels form 2017 and 2019 (Figure 2.4a). Between field comparisons showed no-tilled fields with statistically strong higher levels of GWC with C1 across all years (in 2017 and 2018 $P < 0.01$ with all no-tilled fields, in 2019 $P = 0.014$ with F1 and $P = 0.001$ with F3) except with F2 in 2019 (Figure 2.4b). Differences in GWC levels were also observed between the no-tilled fields in 2017 and in 2019, highlighting the range of variability that can occur among fields at a location even under the same management approach.

Within field comparisons across years showed no differences in Cation Exchange Capacity (CEC) in the no-tilled fields (Figure 2.5a). In C1 CEC increased strongly ($P < 0.001$) from 2017 to 2018 and decreased significantly ($P < 0.001$) back to previous levels in 2019 (Figure 2.5a). Between field comparisons of CEC showed C1 with significantly lower levels all years (in 2017 and 2019 $P < 0.001$) except in 2018 when it had similar CEC levels with F2 (Figure 2.5b). Among the three no-tilled fields, F2 had the lowest levels consistently across 2017, 2018 and 2019.

In F1, NH_4^+ increased significantly from 2016 to 2018 (P = 0.001) and decreased back to previous levels in 2019 (Figure 2.6a). In F2 and C1, NH_4^+ levels were statistically lower in 2019 than 2018 (F2: P = 0.035; C1: P = 0.001), but neither of those years were significantly different to the levels of 2017. Field F3 had significantly higher levels of NH_4^+ in 2018 than in 2017 (P = 0.011), but no difference was observed between 2019 and the two previous years. Nitrate (NO_3^-) levels decreased significantly in F1 from 2016 to 2018 (P = 0.035) (Figure 2.7a). No differences of NO_3^- levels were observed in F2 across years, and C1experienced a significant increase of NO_3^- from 2017 to 2018 (P < 0.001) and 2019 (P < 0.001). Overall, the levels of NH_4^+-N and NO_3^--N where more variable in the conventional system than under the no-till and stubble managed system reflecting the capacity of the no-till and stubble managed approach to maintain stable levels of nitrogen as compared with the conventional system. While yearly levels also reflect differences in producer application rates, the no-till system was able to reduce wide swings in nitrogen availability which increases the potential for leaching and non-use by the crop and the soil microbial community to build critical biomass.

Soil organic matter (SOM) in the no-tilled fields were at highest levels in 2017 (in F1 P < 0.001 for 2016, P = 0.036 for 2018 and P = 0.002 for 2019; in F2 P = 0.004 for 2018 and P = 0.012 for 2019; in F3 P = 0.031 for 2018 and P = 0.403 for 2019) and decreased significantly through 2018 and 2019 (Figure 2.8a). In contrast, SOM levels in C1 were the lowest in 2017 and then 2019 after increasing strongly in 2018 (P < 0.001 for 2017 and P = 0.001 for 2019). Between field comparisons showed that SOM levels in C1 were always significantly lower than levels of the no-tilled fields (P < 0.001 with all fields in 2017; P = 0.06 with F1 and P < 0.001 with F3 in 2018; P < 0.001 with all fields in 2019) (Figure 2.8b), although similar levels were observed between C1 and F2 in 2018. Among the no-tilled managed fields, F1 and F3 had similar levels during 2017 and 2018, but F3 had significantly higher levels of SOM in 2019 ($P = 0.002$ for F1 and $P = 0.001$ for F2).

Labile carbon levels were highest in 2017 and decreased significantly towards 2019 in both no-tilled (in F1 $P < 0.001$; in F2 $P = 0.009$; in F3 $P = 0.007$) and conventional-tilled fields ($P < 0.001$) (Figure 2.9a). Between field comparisons showed C1 Labile carbon levels significantly higher than most no-tilled fields in 2017 ($P = 0.004$ with F2 and $P < 0.001$ with F3), 2018 ($P < 0.001$ with all fields) and 2019 ($P < 0.001$ with F1 and F3 and $P = 0.01$ with F2), while similar levels with F1 in 2017 (Figure 2.9b).

Within field comparisons across years showed a strong decrease in Microbial Biomass Carbon (MBC) levels from 2017 to 2018 in F2 ($P < 0.001$) and C1 ($P = 0.002$) before increasing significantly in 2019 ($P = 0.008$ in F2 and $P = 0.039$ in C1), while F1 and F3 MC levels remained similar from 2017 to 2019 (Figure 2.10a). Between field comparisons showed higher levels of MBC in C1 compared to F1 ($P = 0.03$) and F3 ($P = 0.04$) in 2017, and higher levels of MBC than F1 ($P = 0.02$) in 2019. No significant differences were observed in levels of MBC in 2018 (Figure 2.10b). The seasonal patterns for each indicator per field is presented in figures 2.11-2.17. monthly fluctuations for every indicator per field and year can be observed in Figures 2.11 to 2.17.

Discriminant Function Analyses

Discriminant function analysis indicated low misclassification of seasonal observations of environmental and edaphic parameters in F1 with only 15% of the time being classified as a different year (Figure 2.18a) (Table 2.6). Fields C1 (Figure 2.18d) and F3 (Figure 2.18c) had increased misclassification compared to F1 with years categorized wrong approximately 20% and 22% of the time respectively (Table 2.6). Misclassification was considerably higher in F2

(Figure 2.18b) were DFA indicated that season was wrongly categorized 25% of the time (Table 2.6). Between-field DFAs indicated low overlap in a given year suggesting that the crop dominated the responses each year despite planting into a no-till and stubble managed system. Across all fields, misclassification was the lowest in 2017 (Figure 2.19a) and in 2019 (Figure 2.19c) with approximately 14% of observations being wrongly categorized in a different field and having F3 as the field that was misclassified more frequently (Table 2.7). In 2018 (Figure 2.19b) misclassification was 17%, with F1 as the field most misclassified (Table 2.7). Because of possible confounding effects, DFA was done separately for edaphic parameters and environmental variables (Figure 2.20). Using only the edaphic parameters, fields where misclassified 17%, 28% and 21% of the time respectively in 2017, 2018 and 2019 (Figures 2.20a, 2.20b, 2.20c) (Table 2.8). Misclassification was higher using environmental variables only, with54% of the time in 2017 and 2019, and 55% in 2018 (Figures 2.20d, 2.20e, 2.20f) (Table 2.8).

Principal Component Analyses

Low dispersion and high overlap across the Y axis were observed on PCAs done on environmental and edaphic variables in no-tilled fields F1 (Figure 2.21a) and F3 (Figure 2.21c), while F2 (Figure 2.21b) had higher dispersion and overlapping mostly between 2018 and 2019 observations. Conventional-tilled field C1 (Figure 2.21d) had higher data dispersion and fewer overlap between years, reflecting the high inherent variability associated with conventional cotton production in the semi-arid region even with supplemental irrigation. Within field across-years PCAs showed DTR as a consistent positive association with 2019 observations in every field except for F3 while having a negative association in the same fields with observation from 2017, year that experienced decreased DTR. No-tilled fields F1 and F2, and partially F3, were positively associated with GWC and VWC in 2017, while in C1 these variables were observed positively associated to 2018 and 2019. No-tilled fields F1 and F2 and conventional-tilled field C1 had positive associations between 2017 observations and MBC, indicating that higher levels of MBC were more frequently observed when DTR was lower. Fields F1 and F2 were positively associated with SOM in 2017, while SOM had positive associations with C1 in 2018. In the conventional-tilled field, SOM was positively associated with 2018 observations and MBC with 2017 observations. Both NO_3^- and NH_4^+ were consistently associated positively with 2018 observations across all fields. In 2017, GWC and VWC were observed to have a positive effect on F1 and F2 observations but not in F3 and C1.

The amount of variation in the microbial and soil edaphic parameters in response to soil management that could be explained was very similar for every field. Cumulative explained variation was the lowest for F3 (39.8%), followed by F1 and F2 (43% each), and C1 had the highest with 55.7%. Cumulative explained variation increased when PCAs were conducted separating edaphic variables from environmental variables (Figure 2.22). When using only edaphic variables, total explained variation by the PCAs ranged between 46.4% in F3 (Figure 2.22c) and 60.2% in F1 (Figure 2.22a). Principal components analyses done using only environmental variables resulted in the highest explained variation ranging from 71% in F2 (Figure 2.22f) to 83.2% in F1 (Figure 2.22e). The structure of the observations of the PCAs conducted using soil health variables had the tendency to separate 2017 and 2018, but 2019 overlapped over the other two years in all fields, while no structure or dispersion trend was perceived when PCAs were built using environmental data only. This suggests that crop had a stronger effect than environment over the observed responses.

Among-fields, PCAs were developed for each year to explore the similarity in responses among the soil management practices in a given year. Crop type and associated differences in weather for a given growing season resulted in differences in the association of edaphic parameters and MBC among the three fields associated with the no-till and stubble managed system and in comparison, with the conventional field. For 2017 (Figure 2.23a) Field F1 clustered separately from the other fields, with positive associations to CEC, SOM, NO_3^- and GWC, and negative associations to labile C and NH_4^+. In 2018 (Figure 2.23b), F1 also grouped apart with positive associations to SOM and CEC. In 2019 (Figure 2.23c), F1 overlapped with F3, and had positive associations to SOM, CEC and VWC. In 2017, DTR did not appear to have strong effects over any field. In contrast, DTR had strong positive associations with F2 and C1 in 2018 and 2019. In 2017 and 2018 MBC was observed partially positively associated with F2 and F3, but because of the direction of the MBC vector and the dispersion pattern of the observations across the Y axis in 2017, and the X axis in 2018, MBC was also seen to have a negative correlation with F2 and F3. A similar trend was observed between MBC and all the no-tilled fields in 2019.

Explained variation was similar across all years. Cumulative explained variation was 48.1% in 2017 (Figure 2.23a), 45.5% in 2018 (Figure 2.23b) and 46.4% in 2019 (Figure 2.23c). To separate possible confounding effects, PCAs were developed separating edaphic variables from environmental variables. In general, Better structure was observed in PCAs constructed with edaphic variables only (Figures 24a, b and c). Overlap of all fields was observed across all years in PCAs done with environmental variables only (Figures 24d, e and f).

Redundancy Analyses

The predictors of soil health and linkages with environmental conditions that would allow for positive microbial responses were not consistent among the three fields under no-till and stubble management nor were the predictors of soil health the same across the years. For 2016 (Figure 2.25) GWC was a strong predictor of SOM and MBC and was positively related to DTR in the F1 no-till field. The levels of labile carbon in these fields were strongly related to mean and maximum temperatures. In 2017 (Figure 2.26), SOM was negatively related to DTR, for all three fields indicating the negative impact of high temperatures variability across the growing season (Figures 2.26a, b & c); during this growing season SOM was positively related with MBC levels in at in no-till fields F2 (Figure 2.26b) and F3 (Figure 2.26c). During the 2017 growing season levels of SOM, MBC and levels of labile carbon were negatively related to maximum and mean temperatures in the conventional cropping system (Figure 2.26d) and in several of the no-tilled fields. As all fields were center pivoted irrigated, VWC and GWC were positive predictors of SOM levels in all fields during 2017 as the irrigation overrides all benefits derived from the no-till and stubble management. In 2018 the levels of labile carbon were negatively related to DTR in all fields (Figures 2.27a, b, c, & d) and positively related to levels of MBC in F2 (Figure 2.27b) and F3 (Figure 2.27c). Mean and max temperatures for that growing year had negative impacts on MBC, levels of labile carbon and SOM levels in F2 and F3, and in the conventional-till field (Figure 2.27d). Soil organic matter levels in 2018 had a negative relationship with, VWC and GWC in two of the no-tilled and conventional field, while MBC in all no-tilled fields responded positively to soil moisture. The magnitude of the soil DTR continued to have a negative impact on MBC levels for both soil management systems. However, MBC levels in F2, which was planted on winter wheat and subsequently into black-eyed peas was positively related to DTR suggesting a crop type impact on subsequent soil temperatures (Figure 2.27b). Daily temperature range was also positively related to labile C and SOM at least one of the no-tilled fields (Figure 2.28a) for the 2019 growing season. Levels of MBC continued to be negatively impacts by maximum and mean temperatures in all fields for this year. In general, the impact of soil moisture on SOM levels varied across crop type and soil management for 2019 and had little impact on soil health metrics as these systems were irrigated. Across all four growing seasons, DTR and soil temperatures had the greatest negative impacts on SOM levels and MBC dynamics in both land management systems (Figure 2.28a, b, c and d), while VWC and GWC had generally a positive impact over MBC and SOM levels in the no-tilled stubble management except in F1 (Figure 2.28a).

Discussion

The objective of this study was to describe soil health properties in relation to land management practices and environmental variables in three no-tilled and stubble managed fields with rotations and use of cover crops, and one conventional-tilled field in the SHPT. Water content levels showed a significant trend to be higher in the no-tilled with stubble fields. All no-tilled fields had winter wheat as a cover crop (leaving wheat stubble after harvest) and corn as a rotational step every two or three years since no-till management was implemented in these fields. Corn residue can be influential to the water retention capacity of soil when corn stover is not removed (Blanco-Canqui et al., 2006). In that study, it was observed that corn stover subtraction from the soil surface reduced aggregate stability approximately 300% after one year. In general, constant accumulation of crop residue benefits soil surface physical properties that indirectly improve soil sorptivity, which is the capacity of soil to absorb water. (Shaver et al., 2013) showed that crop residue decreases bulk density and enhances soil porosity and macroaggregation, and that these characteristics are strongly related with increasing sorptivity in the system, conducing to better water infiltration efficiency. Even though the conventional-tilled field rotated cotton with corn, tillage removed and subsequently burial any plant residue from the surface following plowing and plant bed development eliminating the potential of corn residue to enhance of the soil characteristics key for increasing water infiltration and retaining soil moisture.

A body of research has pointed to the capacity of no-till and crop residue on reducing soil temperature (Blanco-Canqui and Ruis, 2018; Franzluebbers et al., 1995; Gauer et al., 1982; Johnson and Lowery, 1985; Kladivko, 2001; Licht and Al-Kaisi, 2005; Wierenga et al., 1982), although results from this study were rather modest. No strong differences of Mean and Maximum temperatures were observed between fields. Daily temperature range (DTR) was significantly lower only in 2019 at root depth in the no-till stubble managed fields than in the conventional-till field. Even though crop residue influence soil temperature by insulating the surface and reflecting solar radiation (Shinners et al., 1994), heat flux through the soil surface towards the root depth was likely to be influenced by the water content (Hillel, 1998) in both land management strategies, which included pivot irrigation regardless of being tilled or not. Hillel (1998) observed that tillage creates additional air pockets that can reduce the heat capacity of a tilled area. Since soil particles already have a low heat capacity and greater heat conductivity than water, drier soils respond to surface temperature quicker than wet soils, resulting in faster warming and cooling dynamics throughout a day (Licht and Al-Kaisi, 2005). Additionally, irrigation through the growing season will maintain soil water content at levels that will satisfy crop needs, and provide soils with a greater heat capacity capable of keeping temperature changes from varying drastically across the day. (Radke, 1982; Zhang et al., 2011).

Previous research has established that reduction of soil physical disturbance with plant residue covering the soil surface allow soil to build up C and SOM (Bayer et al., 2000; Bell et al., 2003; Halvorson et al., 2002; Peterson et al., 1998; Sherrod et al., 2003). In this study, all no-till fields except one were observed with larger amounts of SOM than the conventional-till field in at least two years. The fields with larger amounts of SOM were the ones with higher amounts of clay content, which was consistent with observations from other studies for the relationship between SOM and clay content (Burke et al., 1989; Parton et al., 1987; Rottler et al., 2019; Six et al., 2002). However, decomposition rate of SOM is also be affected by climate and soil texture profile. Scott et al. (1996) suggested that it is the combination of soil texture and water content what controls the decomposition rate of SOM rather than the individual effect of these in the short term. In the long term, the decomposition rate of the SOM is controlled by size, activity an efficiency of the microbial biomass (Scott et al., 1996). Differences in clay content could explain the contrasting levels of SOM in no-till field F2 and conventional-till field C1 against F1 and F3 as F2 and C1 had lower levels of clay then the other two fields. Soil texture is also known to play a role defining CEC along with SOM (Kaiser et al., 2008; Tan and Dowling, 1984). In this study CEC was observed to differ significantly between the two types of land management, possibly mediated by the larger amounts of SOM found in the no-tilled fields. Even though differences in CEC may not be directly related to the type of field management, difference can be an indirect response to the ability of no-till to enhance of other physical, chemical or biological soil properties that are usually interrelated (Lienhard et al., 2013; Thomas et al., 2007).

Increase of MBC due to lack of a physical disturbance like tillage has been documented in several studies (Acosta-Martinez et al., 2007; Feng et al., 2003; Frey et al., 1999; Sapkota et al., 2012; Shi et al., 2013; Spedding et al., 2004; Zuber and Villamil, 2016), but results from this study did not show major differences in MBC between the two land management systems. Modification of soil structure and substrate inputs alters soil microbial communities and at the same time creates a relation between the physical environment and biological activity with feedback mechanisms (Young and Ritz, 2000) that contribute to build up of MBC. Aggregates become stable due to rhizodeposition, fungal hyphae and byproducts from microbial metabolism (Tisdall and Oades, 1982), and aggregate heterogeneity creates space for microbial biomass to thrive, including space for saprophytic and arbuscular mycorrhizal fungi, functional groups of microbes that contribute greatly to the biomass of a healthy microbial community (Helgason et al., 2009). Other studies however have not observed this positive impact from no-till effects on MBC (Acosta-Martínez et al., 2010; Carpenter-Boggs et al., 2003; Drijber et al., 2000; Mbuthia et al., 2015). Length of time from conversion from conventional-tillage to no-till systems may play a role in the magnitude of the differences in MBC levels for this semi-arid environment (Kay and VandenBygaart, 2002). These contrasting results for the responses of MBC to moving from conventional tillage to no-till and stubble management practices may suggest that there are other underlying mechanisms that determine Microbial Biomass Carbon levels in no-till systems as compared to tillage systems that are the response of other factors in addition to differences in physical disturbance. In this study, the similar levels of MBC that occurred within the two approaches to field management could be related to irrigation overriding all climatic constraints or eliminating any potential benefits from employing no-till and stubble management, having corn rotations in both systems, and planting cotton as the major cash crop. The potential benefits from carbon inputs from corn roots and the buried stubble in this semi-arid environment could have been sufficient to maintain MBC levels in the conventional-tilled filed that were similar to the no-till fields by maintaining optimum soil moisture levels during periods were carbon was adequate from crop production to support greater microbial growth than would be expected in a conventional tillage system (Balota et al., 2003; Drury et al., 1991; Wright et al., 2005; Xue et al., 2016, 2017; Zhang and Marschner, 2018). The higher levels of labile C in the conventional-tilled field than in the no-tilled fields in two of the three years suggests that the higher temperatures observed in the conventional tilled field may have also contributed to greater MBC when labile carbon was available. However, the use of labile carbon in the conventional field by the microbial biomass is one of the factors that contributed to the lower SOM levels in the conventional field (Muñoz-Romero et al., 2015). If turnover rates are high for the labile fraction of soil organic C, soils have a reduced ability to sequester C on the long term (Silveira et al., 2008). This outcome is observed for the conventional cotton system irrespective of irrigation levels and indicates the detrimental impact of tillage on the capacity of the soil to build SOM despite having an amount of MBC comparable to no-tilled systems in the region.

The similarity in seasonal patterns of extractable NO_3^- -N and NH_4^+ -N levels between the two land management approaches for crop production reflect, in part, the climatic and irrigation controls on mineralization dynamics coupled with producer applied nitrogen fertilizer. However, despite fertilizer applications occurring for all fields across the year, the levels of the nitrogen pools under the different crops were more consistent across the growing season in the no-tilled fields than in the conventional systems. One potential benefit of no-tilled and stubble management for this semi-arid region when using irrigation for cotton production is the stabilization of nitrogen availability thus reducing potential losses from leaching and denitrification (van Es et al., 2020). The more uniform levels that were observed in the no-tilled fields than from the conventional field also indicates that nitrogen that is mineralized or introduced from fertilization is likely immobilized by the crop and soil microbial biomass to a greater extent than what occurred in the conventional tilled system. High variability in extractable NO_3^--N pools are indicative of stress and rather than increased mineralization capabilities (van Gestel et al., 2011).

While the differences in microbial community size (MBC) observed in this study between conventional cotton production and no-till and stubble managed systems were modest, the positive responses in water content and SOM levels under no-till and stubble management serves as evidence that supports the incorporation of no-till practices and stubble management to promote soil health across agricultural systems in the SHPT. In the long-term, benefits associated by supporting microbial community development through development of SOM will be crucial to water conservation on the SHPT with ongoing depletion of the Ogallala aquifer and increased climate variability (Deines et al., 2020). In addition, it is important to note that climate and soil management practices that influence soil health may have different outcomes across different soil textures (Amsili et al., 2021; Cardoso et al., 2013) irrespective of field proximity. Even within the no-till and stubble fields in this study, which can be found within a mile of distance, field F2 had enough difference in sand and clay content to express different responses physically, chemically, and biologically across multiple growing seasons often responding more like a conventional field than one that was managed as no-till with stubble. Finally, these differences are also predicated on the rate at which the soil system responds to the initial conversion from tilled system to no-till.

In the context of the SHPT, farmers that use strategies that build up soil capabilities of storing water are setting up a “safety net” given the current climate variability in the area while water for irrigation becomes more limited. Given the data presented in this study, no-till strategies support the development of SOM while maintaining generally higher levels of water content in this semi-arid environment. In this scenario, farmers can decrease irrigation costs knowing that soils in their fields will retain water for longer periods of time in case drought events occur or in case water from the Ogalala aquifer becomes scarcer.

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Tables

Table 2.1. Rainfall amounts (millimeters) for each month from 2010 to 2020 obtained from the Abernathy West Texas Mesonet station. The years of this study are in bold.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total Year
2010	41	53	66	108	44	18	132	62	21	15	4	0	563
2011	1	8	35	0	6	0	6	0	26	44	26	38	189
2012	0	15	19	17	14	173	13	13	83	8	0	18	373
2013	23	38	0	0	10	69	56	97	8	28	9	9	348
2014	0	3	4	10	94	90	43	15	113	12	52	6	443
2015	44	3	8	55	218	104	51	10	14	105	32	17	663
2016	**8**	**3**	**11**	**33**	**98**	**17**	**18**	**177**	**36**	**11**	**19**	**15**	**446**
2017	**43**	**11**	**24**	**28**	**23**	**74**	**75**	**177**	**78**	**12**	**0**	**0**	**546**
2018	**0**	**8**	**22**	**2**	**24**	**39**	**12**	**36**	**91**	**95**	**5**	**34**	**369**
2019	**0**	**1**	**25**	**45**	**130**	**45**	**12**	**19**	**102**	**9**	**22**	**14**	**424**
2020	13	11	69	2	20	43	32	5	12	21	7	3	237

Table 2.2. Soil texture for each field in Petersburgh, TX. N=6 per field.

Soil textures				
Field	**Sand %**	**Clay %**	**Silt %**	**Soil type**
F1	44.6	32	23.4	Clay Loam
F2	54	24.4	21.6	Sandy Clay Loam
F3	42.6	33.9	23.5	Clay Loam
C1	73.2	16.3	10.4	Sandy Loam

Table 2.3. List of crops per field and year planted from 2014 to 2019 for no-till and stubble managed m and conventional cotton fields located in Petersburgh, TX. Samples for this research were collected during the bolded years. Only F1 was sampled in 2016. Field area in acres inside parenthesis. MCC = mixed cover crop. BEP = black eyed peas.

		Fields			
		F1 (124)	**F2 (184)**	**F3 (116)**	**C1 (122)**
	2019	Cotton	Wheat/BEP	Corn	Corn
	2018	Wheat/Fallow	Corn/Wheat	Cotton	Cotton
	2017	Corn/Wheat	Cotton	Wheat/MCC	Cotton
Year	**2016**	Cotton	Corn	Corn/Wheat	Cotton
	2015	Corn	Corn	Cotton	Cotton
	2014	Corn	Cotton	Corn	Cotton

Table 2.4. Mean and the standard error of environmental and edaphic variables under field irrespective of year and year irrespective of field, and P value from a two-way MANOVA. Values in bold are significant at P < 0.05.

Variables	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	2017 (Mean ± SE)	2018 (Mean ± SE)	2019 (Mean ± SE)	Field *P* value	Year *P* value	Field x Year *P* value
VWC 0 cm (°C)	17.2 ± 0.5	20.8 ± 0.4	19.3 ± 0.7	15.2 ± 0.9	18.4 ± 0.6	16.8 ± 0.4	22.6 ± 0.5	**<0.001**	**<0.001**	**<0.001**
VWC 15 cm (°C)	23.8 ± 0.4	24.7 ± 0.5	24.3 ± 0.7	19.9 ± 1.0	22.7 ± 0.6	22.5 ± 0.4	28.2 ± 0.5	**<0.001**	**<0.001**	**<0.001**
DTR 0 cm (°C)	7 ± 0.3	7.5 ± 0.4	6.1 ± 0.4	8.6 ± 0.7	3.5 ± 0.2	8.9 ± 0.3	9.1 ± 0.3	**<0.001**	**<0.001**	0.079
DTR 15 cm (°C)	2.5 ± 0.1	3.1 ± 0.1	2.3 ± 0.1	3.8 ± 0.2	1.6 ± 0.08	3.5 ± 0.1	3.1 ± 0.1	**<0.001**	**<0.001**	**0.005**
Max T 0 cm (°C)	24 ± 0.7	24.2 ± 0.8	24.2 ± 0.8	23.7 ± 1.15	18.6 ± 0.5	25.1 ± 0.7	27.9 ± 0.7	0.087	**<0.001**	0.57
Max T 15 cm (°C)	21.3 ± 0.5	21.2 ± 0.6	20.2 ± 0.6	21.4 ± 0.9	18.0 ± 0.5	21.4 ± 0.6	23.7 ± 0.5	0.743	**<0.001**	0.597
Mean T 0 cm (°C)	19.9 ± 0.5	19.6 ± 7.2	19.6 ± 0.7	18.4 ± 1	17.3 ± 0.5	19.6 ± 0.6	22.6 ± 0.6	0.06	**<0.001**	0.49
Mean T 15 cm (°C)	19.7 ± 0.5	19.5 ± 0.6	18.8 ± 0.6	19.1 ± 0.9	17.0 ± 0.5	19.5 ± 0.5	21.8 ± 0.5	0.584	**<0.001**	0.529
GWC (%)	15.3 ± 0.2	14.6 ± 0.2	16.8 ± 0.2	12.2 ± 0.3	14.9 ± 0.2	15.2 ± 0.2	15.4 ± 0.2	**<0.001**	**<0.001**	**<0.001**
CEC (meq/100g)	26.1 ± 0.1	21.2 ± 0.1	26.0 ± 0.2	19.6 ± 0.4	23.4 ± 0.3	24.0 ± 0.2	23.5 ± 0.3	**<0.001**	**<0.001**	**<0.001**
NH4 (µg/g)	1.7 ± 0.04	1.8 ± 0.06	2.2 ± 0.08	2.1 ± 0.1	1.7 ± 0.05	2.3 ± 0.09	1.8 ± 0.07	**<0.001**	**<0.001**	0.131
NO3 (µg/g)	9.5 ± 0.5	8.7 ± 0.5	11.9 ± 0.8	20.5 ± 2.6	7.3 ± 0.4	13.1 ± 1.1	13.4 ± 0.8	**0.001**	**<0.001**	**<0.001**
SOM (%)	1.3 ± 0.2	1.1 ± 0.02	1.6 ± 0.02	0.9 ± 0.03	1.4 ± 0.02	1.3 ± 0.03	1.2 ± 0.2	**<0.001**	**<0.001**	**0.004**
Labile C (µg/g)	1011.4 ± 24.9	1101.1 ± 24.2	945.8 ± 20.3	1344.7 ± 30.9	1240.1 ± 27.2	1023.8 ± 21.3	969.7 ± 20.1	**<0.001**	**<0.001**	**0.004**
MBC (µg/g)	267.7 ± 14.6	353.1 ± 21.1	345.5 ± 18.7	372.4 ± 524.4	390.2 ± 20.5	286.5 ± 16.0	356.3 ± 16.0	0.052	**<0.001**	**0.028**

Table 2.5. Yearly means (± Standard Error) of soil variables from 2016 to 2019 growing season from a no-till and stubble system (F1, F2 and F3) and a conventional-tilled (C1) cotton production systems in semi-arid west Texas.

Variables	2016	2017				2018				2019			
	F1 (Mean ± SE)	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)
MBC (µg/g)	166.0 ± 16.8	345.5 ± 36.2	462.6 ± 45.6	321.0 ± 28.5	525.1 ± 54.1	289.2 ± 29.8	249.9 ± 24.0	314.2 ± 36.1	295.6 ± 39.6	272.8 ± 26.1	373.3 ± 35.8	405.2 ± 30.2	382.3 ± 30.2
Labile C (µg/g)	1057.0 ± 57.5	1310.0 ± 53.3	1228.4 ± 50.5	1075.9 ± 35.9	1579.4 ± 50.0	928.4 ± 30.6	1066.1 ± 33.1	856.4 ± 29.6	1354.5 ± 51.4	799.7 ± 25.6	1029.0 ± 39.8	916.2 ± 33.5	1216.2 ± 36.3
NH4(µg/g)	1.7 ± 0.09	1.5 ± 0.07	1.8 ± 0.1	1.9 ± 0.07	1.8 ± 0.1	2.1 ± 0.08	2.0 ± 0.1	2.4 ± 0.1	2.7 ± 0.4	1.6 ± 0.06	1.7 ± 0.09	2.2 ± 0.2	1.6 ± 0.1
NO3(µg/g)	11.6 ± 1.4	10.8 ± 1.2	6.8 ± 0.4	5.5 ± 0.4	4.4 ± 0.8	8.0 ± 0.7	8.6 ± 0.5	12.6 ± 1.2	27.9 ± 5.3	7.9 ± 0.5	10.3 ± 1.4	17.57± 1.8	20.2 ± 2.7
SOM (%)	1.0 ± 0.05	1.6 ± 0.03	1.3 ± 0.02	1.7 ± 0.03	0.8 ± 0.07	1.4 ± 0.04	1.1 ± 0.04	1.5 ± 0.06	1.1 ± 0.05	1.3 ± 0.03	1.14 ± 0.04	1.6 ± 0.04	0.8 ± 0.02
CEC (meq/100g)	26.6 ± 0.5	25.5 ± 0.2	20.8 ± 0.3	26.0 ± 0.4	17.1 ± 0.9	26.2 ± 0.2	21.4 ± 0.2	25.7 ± 0.3	22.1 ± 0.7	26.0 ± 0.4	21.4 ± 0.2	26.4 ± 0.4	18.2 ± 0.5
pH	8.1 ± 0.03	8.16± 0.02	8.1 ± 0.04	7.9 ± 0.03	7.9 ± 0.1	8.0 ± 0.02	8.2 ± 0.02	7.8 ± 0.02	8.2 ± 0.03	8.0 ± 0.02	8.2 ± 0.02	7.9 ± 0.03	8.3 ± 0.03
GWC (%)	13.1 ± 0.4	16.7 ± 0.4	14.6 ± 0.4	15.5 ± 0.4	9.3 ± 0.7	15.3 ± 0.4	15.1 ± 0.3	17.1 ± 0.4	12.6 ± 0.6	16.0 ± 0.4	14.1 ± 0.3	17.7 ± 0.4	13.1 ± 0.3
VWC 0 cm (°C)	14.1 ± 0.9	19.7 ± 1.0	21.8 ± 0.9	20.7 ± 1.2	19.3 ± 2.1	14.3 ± 0.9	20.1 ± 0.5	16.2 ± 0.7	18.7 ± 1.3	22.0 ± 0.9	21.1 ± 0.8	26.4 ± 1.0	18.7 ± 1.0
VWC 15 cm (°C)	19.9 ± 0.5	25.3 ± 0.5	24.3 ± 0.7	26.3 ± 1.5	21.3 ± 2.3	22.1 ± 0.7	24.9 ± 0.6	23.6 ± 0.9	23.2 ± 1.4	28.4 ± 1.0	28.3 ± 1.4	31.2 ± 1.0	24.6 ± 0.7
DTR 0 cm (°C)	7.5 ± 0.4	3.0 ± 0.2	2.9 ± 0.3	2.4 ± 0.3	3.7 ± 1.0	10.2 ± 0.7	10.9 ± 0.5	8.1 ± 0.7	9.2 ± 1.1	8.7 ± 0.6	9.8 ± 0.6	8.4 ± 0.7	10.2 ± 1.2
DTR 15 cm (°C)	3.1 ± 0.2	1.2 ± 0.09	1.6 ± 0.1	1.2 ± 0.1	1.5 ± 0.5	2.9 ± 0.2	4.8 ± 0.3	3.6 ± 0.3	3.4 ± 0.4	2.8 ± 0.2	3.0 ± 0.2	2.2 ± 0.1	5.0 ± 0.4
Max T 0 cm (°C)	25.2 ± 1.1	22.2 ± 1.1	20.8 ± 1.1	21.2 ± 1.2	22.1 ± 1.4	30.8 ± 1.3	31.2 ± 1.1	27.4 ± 1.0	29.0 ± 1.5	27.2 ± 1.5	29.0 ± 1.4	27.3 ± 0.8	28.3 ± 1.5
Max T 15 cm (°C)	23.4 ± 0.9	21.3 ± 1.6	20.3 ± 0.9	21.5 ± 0.9	21.0 ± 1.8	25.1 ± 1.3	26.4 ± 1.1	23.8 ± 0.9	25.0 ± 1.3	23.2 ± 1.0	23.7 ± 1.3	23.4 ± 0.8	25.0 ± 1.4
Mean T 0 cm (°C)	19.7 ± 1.0	20.0 ± 1	18.8 ± 1.0	19.5 ± 1.2	19.6 ± 1.6	24.3 ± 1.3	24.4 ± 1.1	22.5 ± 1.0	23.5 ± 1.5	22.2 ± 1.1	23.2 ± 1.5	22.4 ± 0.8	22.4 ± 1.5
Mean T 15 cm (°C)	19.7 ± 0.9	20.5 ± 0.9	19.3 ± 0.9	20.3 ± 1.2	20.0 ± 1.7	23.4 ± 1.3	23.9 ± 1.1	21.8 ± 0.9	22.9 ± 1.3	21.7 ± 1.0	22.0 ± 1.4	21.6 ± 0.8	22.1 ± 1.4

Table 2.6. Discriminant function analysis outcomes for the classification of no-till fields (F1, F2, F3) and conventional tilled fields (C1) using edaphic and environmental variables within fields for each growing season and across years. Percentage of cases that kept original classification per field: F1: 84.9%, F2: 75%, F3: 78.3% and C1: 80.4%.

	F1 Predicted membership (%)				F2 Predicted membership (%)			F3 Predicted membership (%)			C1 Predicted membership (%)		
Year	**2016**	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**
2016	78.6	2.4	16.7	2.4									
2017	0	97.5	2.5	0	81.3	14.6	4.2	83.3	6.3	10.4	90.9	9.1	0
2018	2.9	5.7	85.7	5.7	5.7	75.5	18.9	2.3	76.7	20.9	3.6	75	21.4
2019	13.8	0	10.3	75.9	13	26.1	60.9	10.3	17.2	72.4	0	17.6	82.4

Table 2.7. Discriminant function analysis outcomes for the classification of crop management types (no-till = F1, F2, & F3) and Conventional tillage (C1) within years, (2017, 2018 and 2019) using edaphic and environmental variables. Percentage of cases that kept original classification for 2017: 85.4%, 2018: 82.5 and 2019: 85.7%.

	2017 Predicted membership (%)				2018 Predicted membership (%)				2019 Predicted membership (%)			
Field	**F1**	**F2**	**F3**	**C1**	**F1**	**F2**	**F3**	**C1**	**F1**	**F2**	**F3**	**C1**
F1	85	5	10	0	65.7	14.3	17.1	2.9	89.7	3.4	6.9	0
F2	4.8	95.2	0	0	0	97.6	0	2.4	8.7	82.6	4.3	4.3
F3	18.9	8.1	73	0	9.3	11.6	79.1	0	10.3	6.9	82.8	0
C1	0	9.1	0	90.9	4.2	8.3	0	87.5	0	11.8	0	88.2

Table 2.8. Discriminant function analysis outcomes for the classification of crop management types for edaphic and environmental variables separately among fields for each fields season (2017, 2018 and 2019). Percentage of cases that kept original classification for edaphic variables DFA in 2017: 82.4%, 2018: 72.2% and 2019: 79.7%. Percentage of cases that kept original classification for environmental variables DFA in 2017: 46%, 2018: 44.8% and 2019: 45.9%.

	Edaphic variables				**Environmental variables**			
	Predicted membership (%)				**Predicted membership (%)**			
2017	**F1**	**F2**	**F3**	**C1**	**F1**	**F2**	**F3**	**C1**
F1	78.6	4.8	16.7	0	44.4	37.8	17.8	0
F2	7.1	92.9	0	0	31	40.5	28.6	0
F3	20.8	2.1	77.1	0	20.8	2.1	77.1	0
C1	0	12.5	6.3	81.3	6.7	20	26.7	46.7
2018								
F1	66.7	7.4	24.1	1.9	20	28.6	37.1	14.3
F2	0	92.6	1.9	5.6	7.3	75.6	14.6	2.4
F3	16.7	13	70.4	0	27.9	16.3	53.5	2.3
C1	9.4	40.6	0	50	16.7	33.3	37.5	12.5
2019								
F1	79.2	4.2	16.7	0	48.3	3.4	34.5	13.8
F2	8.3	79.2	6.3	6.3	43.5	4.3	34.8	17.4
F3	12.5	10.4	77.1	0	27.6	6.9	65.5	0
C1	0	14.3	0	85.7	35.3	0	0	64.7

Figures

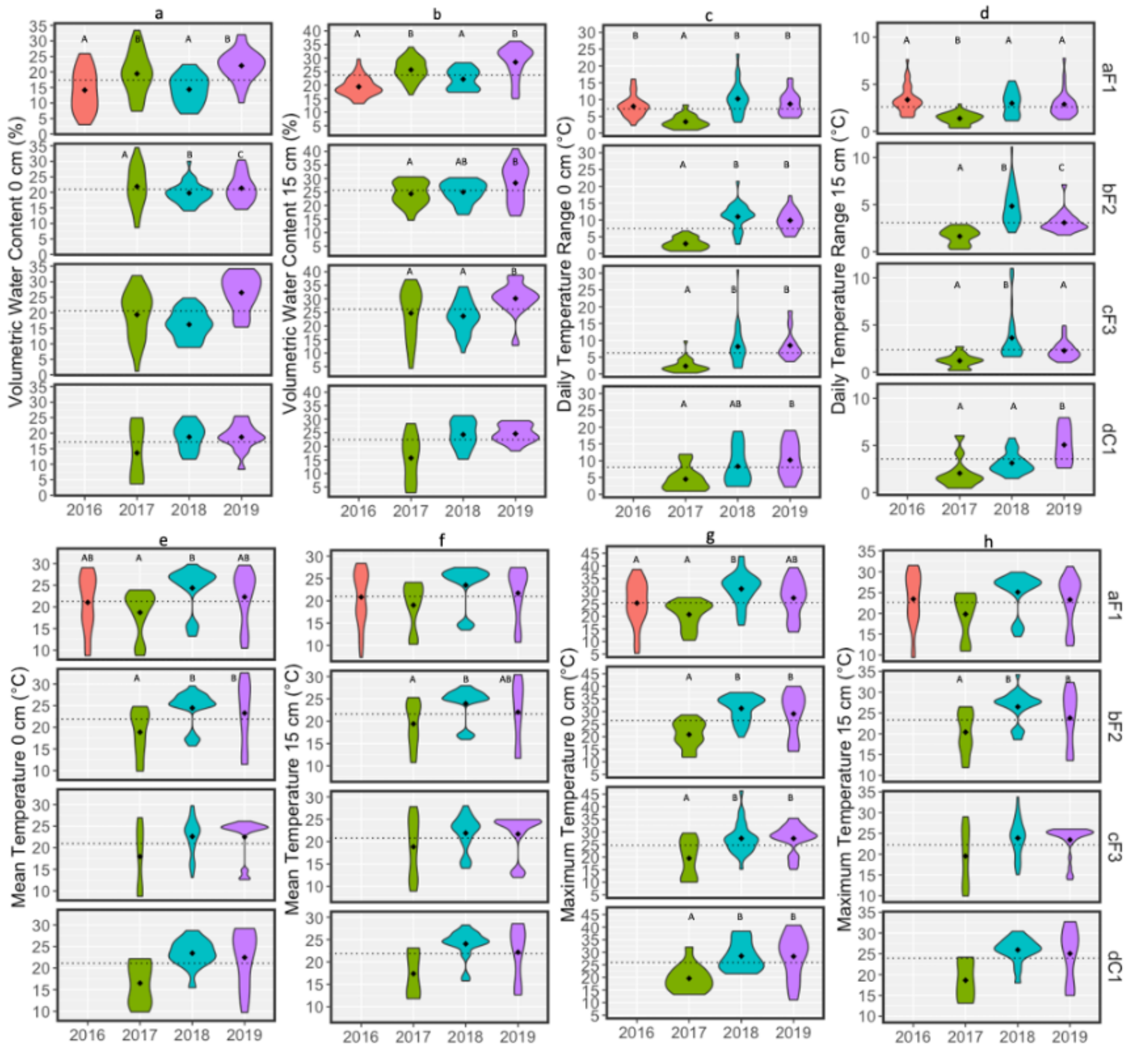

Figure 2.1. Among-year comparisons of each field's yearly mean measurements of: volumetric water content (a and b), daily temperature range (c and d), mean temperature (e and f), and maximum temperature (g and h) just below the soil surface (1 cm) and root depth (15 cm) across years 2016 to 2019 in F1, and across years 2017 to 2019 in F2, F3 and C1. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. No-till and stubble managed fields = F1, F2, and F3. Conventional Field = C1. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

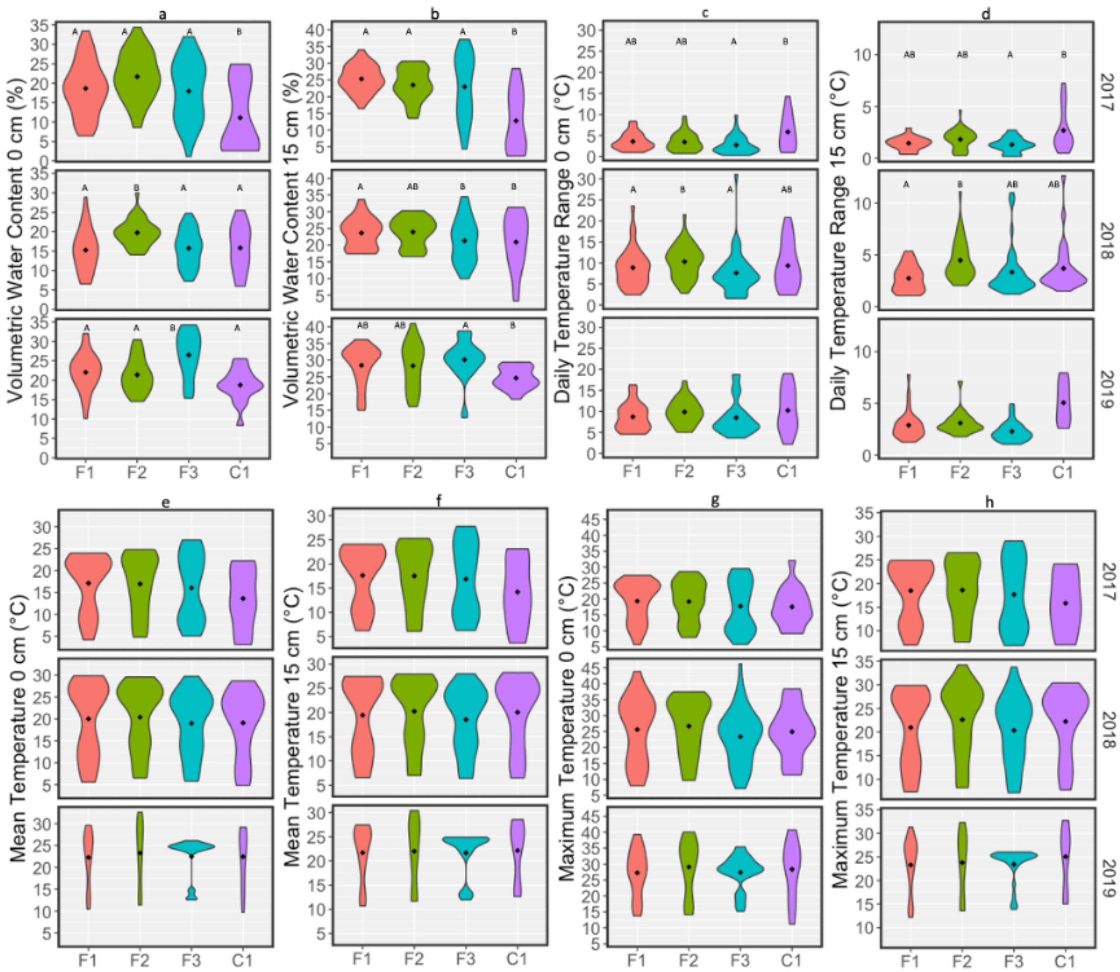

Figure 2.2. Among-fields comparisons of yearly mean measurements of: volumetric water content (a and b), daily temperature range (c and d), mean temperature (e and f), and maximum temperature (g and h) just below the surface (1 cm) and root depth (15 cm) for 2017, 2018 and 2019. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32 Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences. Field designations are presented in Figure 2.1

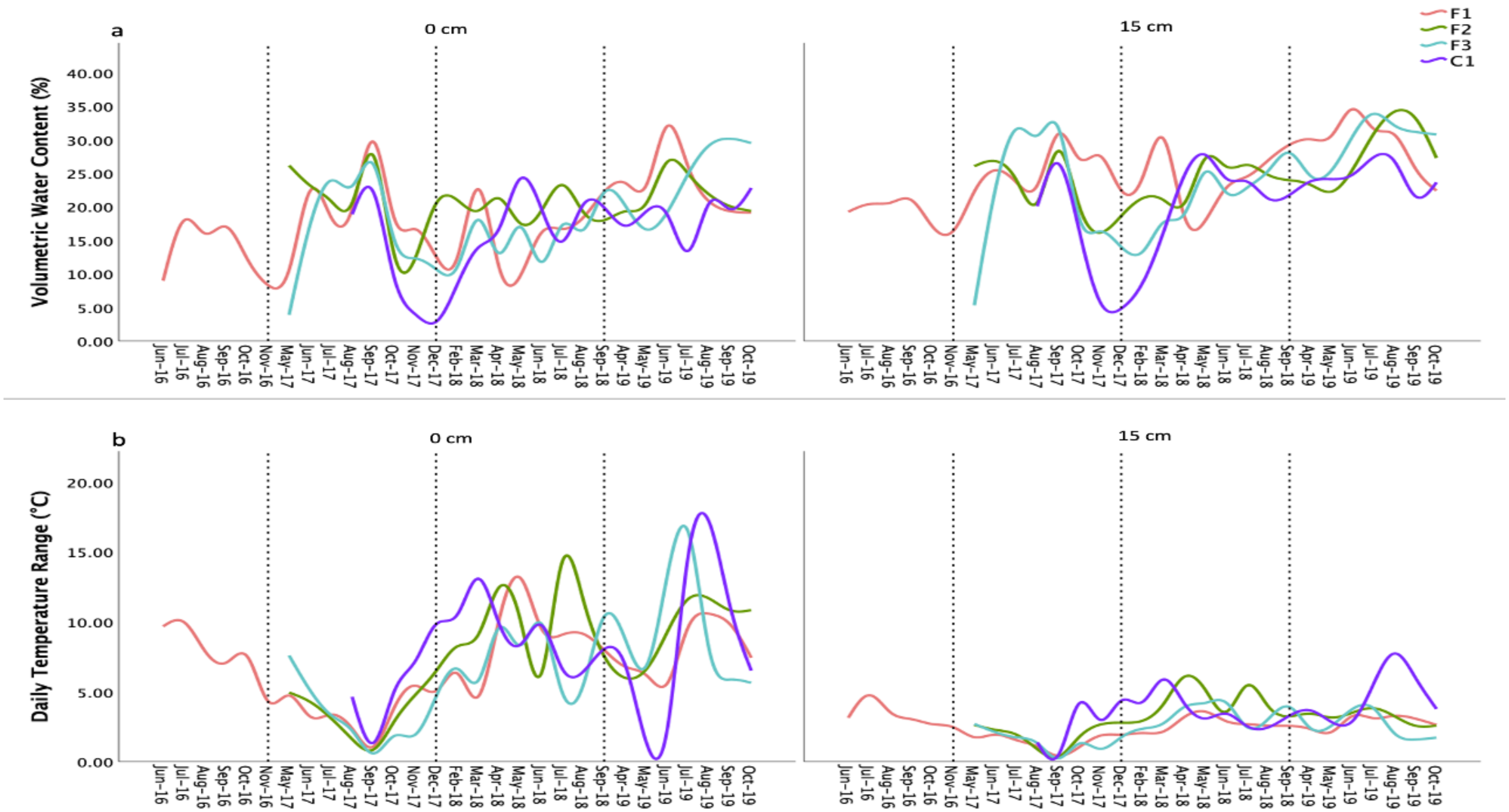

Figure 2.3. Five-day average of volumetric water content (a), daily temperature range, mean temperature (c) and maximum temperature (d) at surface (0 cm) and root depth (15 cm) from June 2016 through October 2019 in no-till and stubble fields F1, F2, F3, and conventional-till field C1.

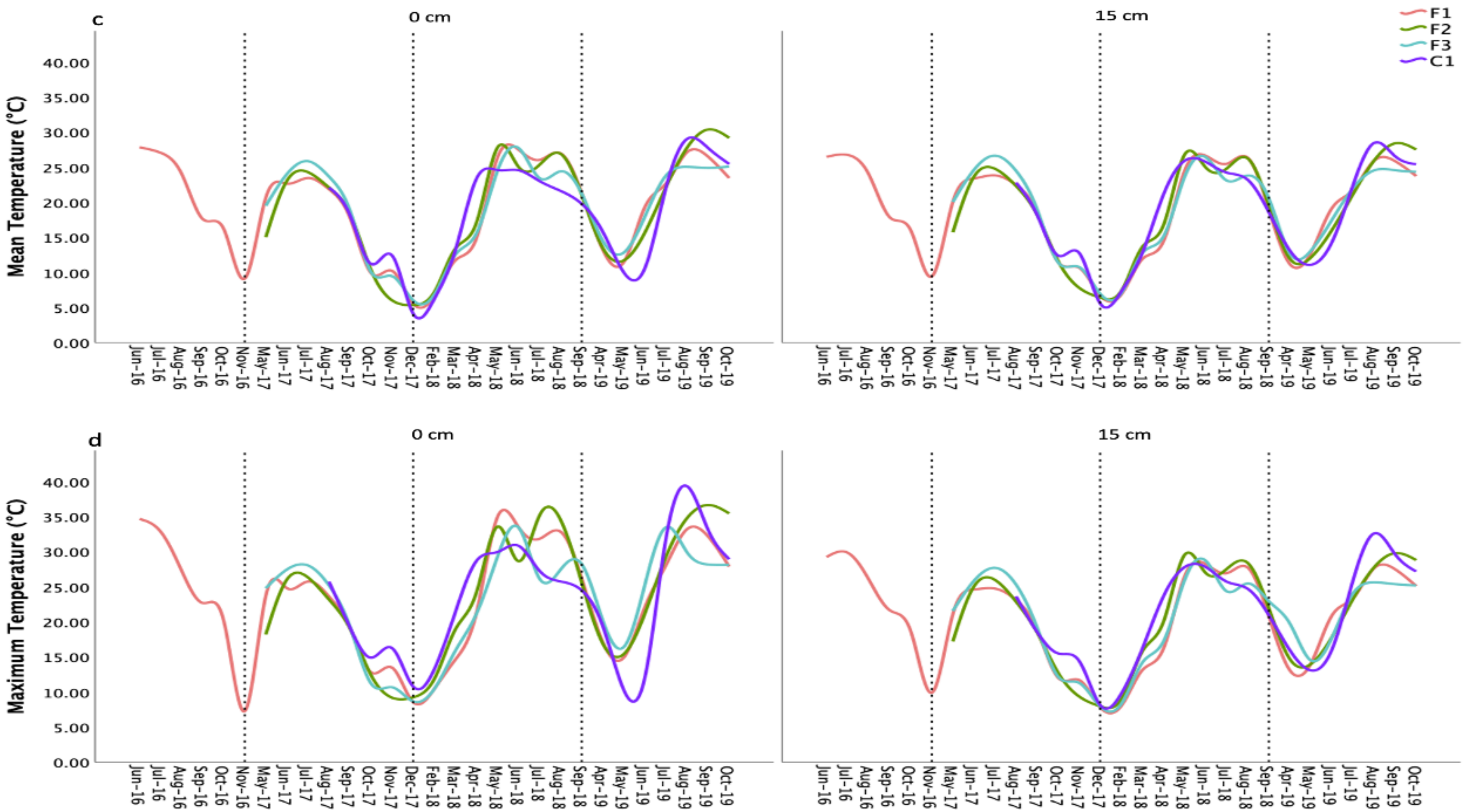

Figure 2.3 Continued. Five-day average of volumetric water content (a), daily temperature range, mean temperature (c) and maximum temperature (d) at surface (0 cm) and root depth (15 cm) from June 2016 through October 2019 in no-till and stubble fields F1, F2, F3, and conventional-till field C1.

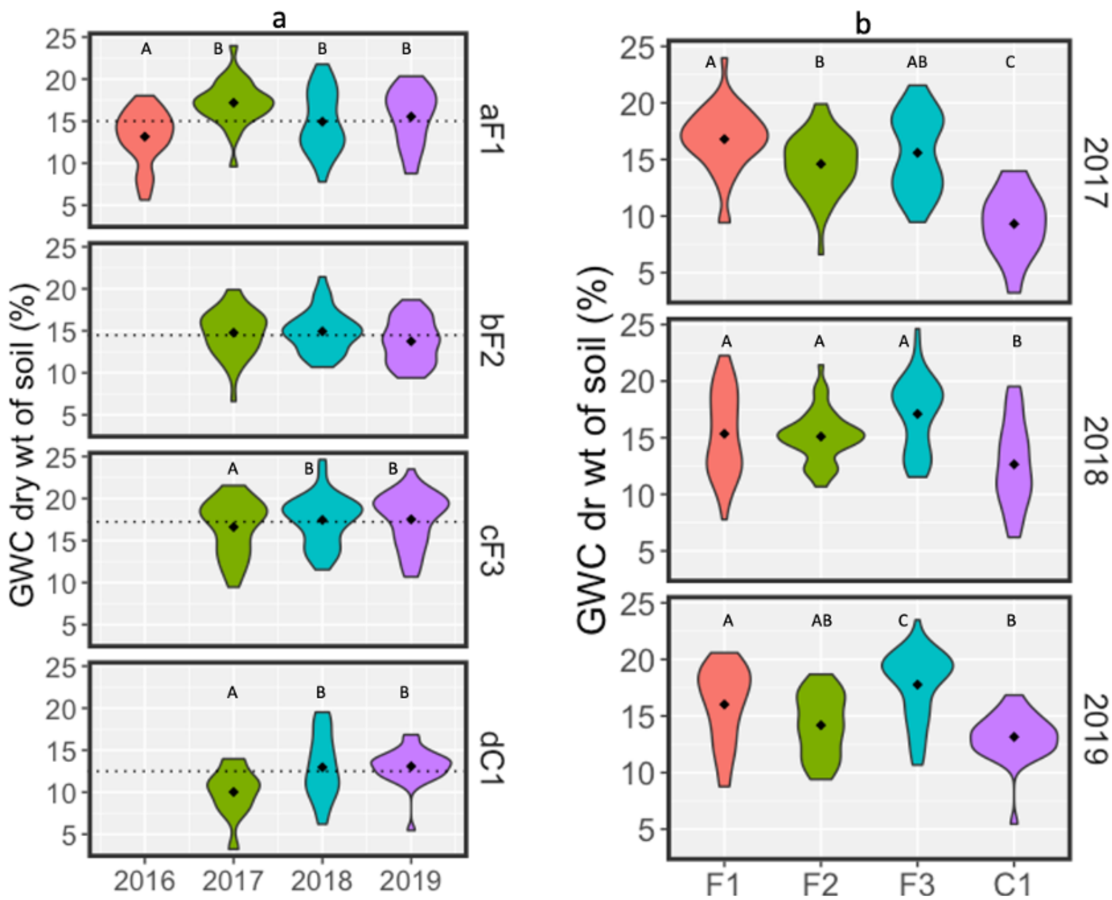

Figure 2.4. Gravimetric water content comparisons of each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences calculated using Tukey's HSD posterior tests.

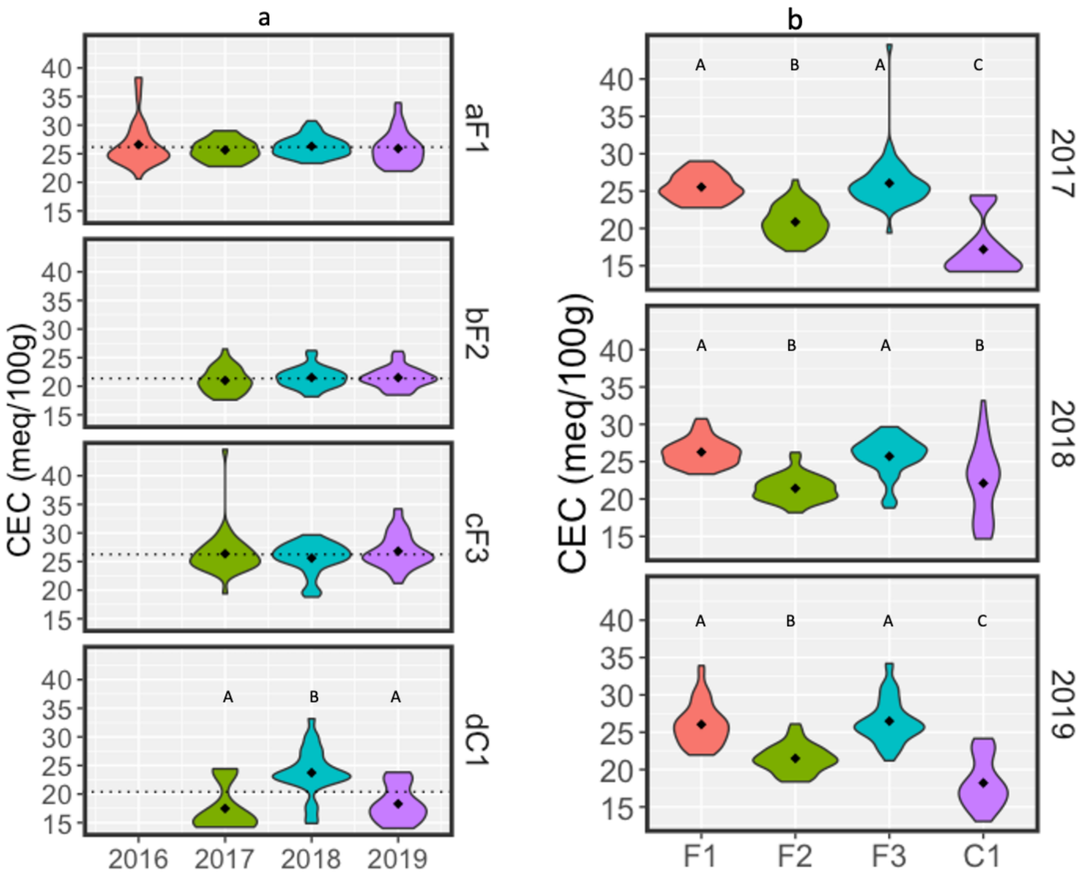

Figure 2.5. Cation exchange capacity of each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

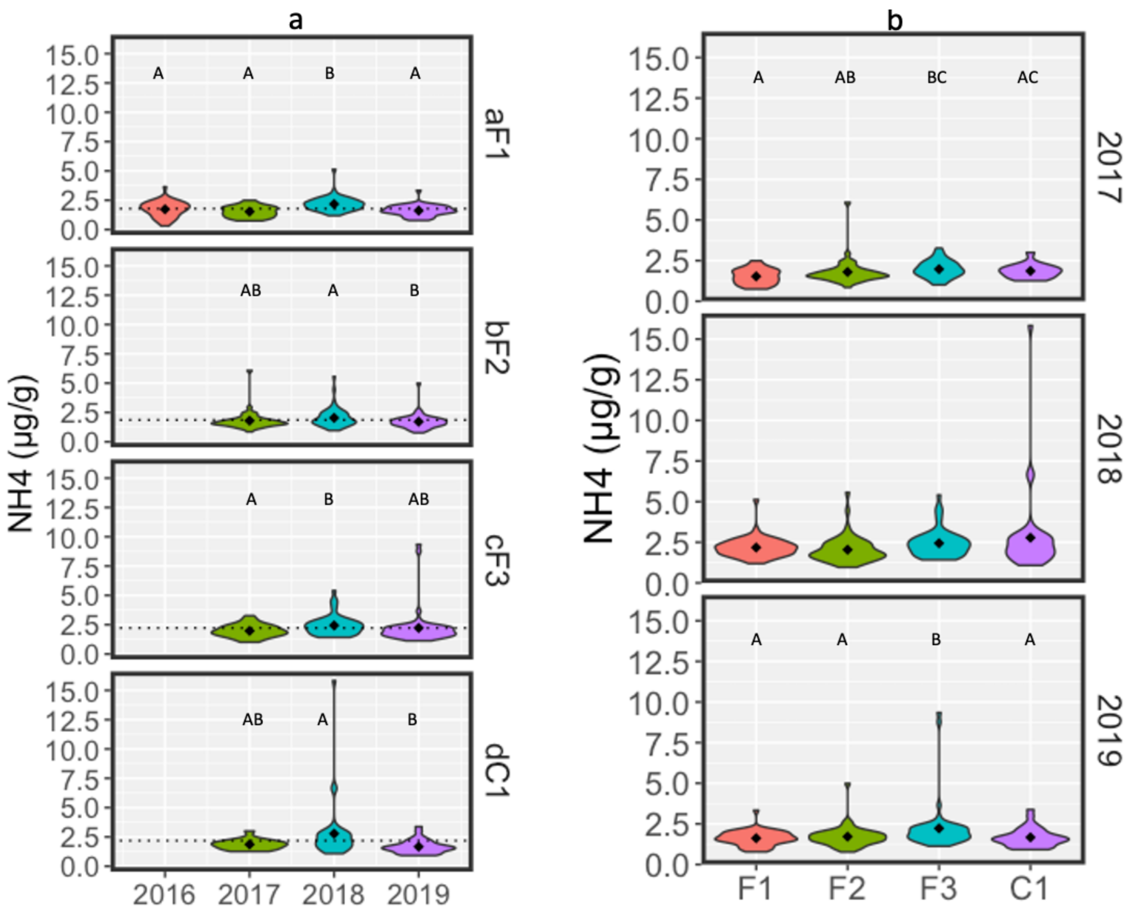

Figure 2.6. Extractable levels of NH_4^+-N for each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field C1 in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

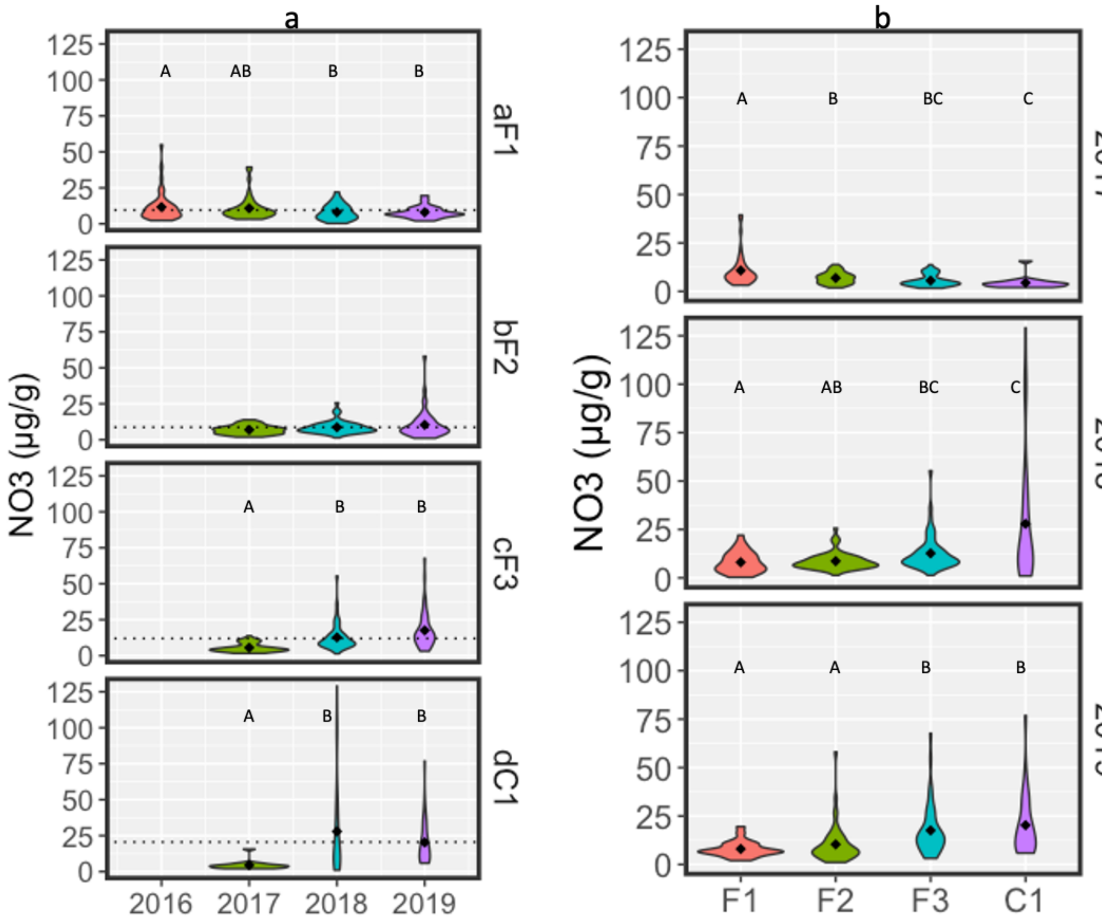

Figure 2.7. Extractable levels of NO_3^--N for each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

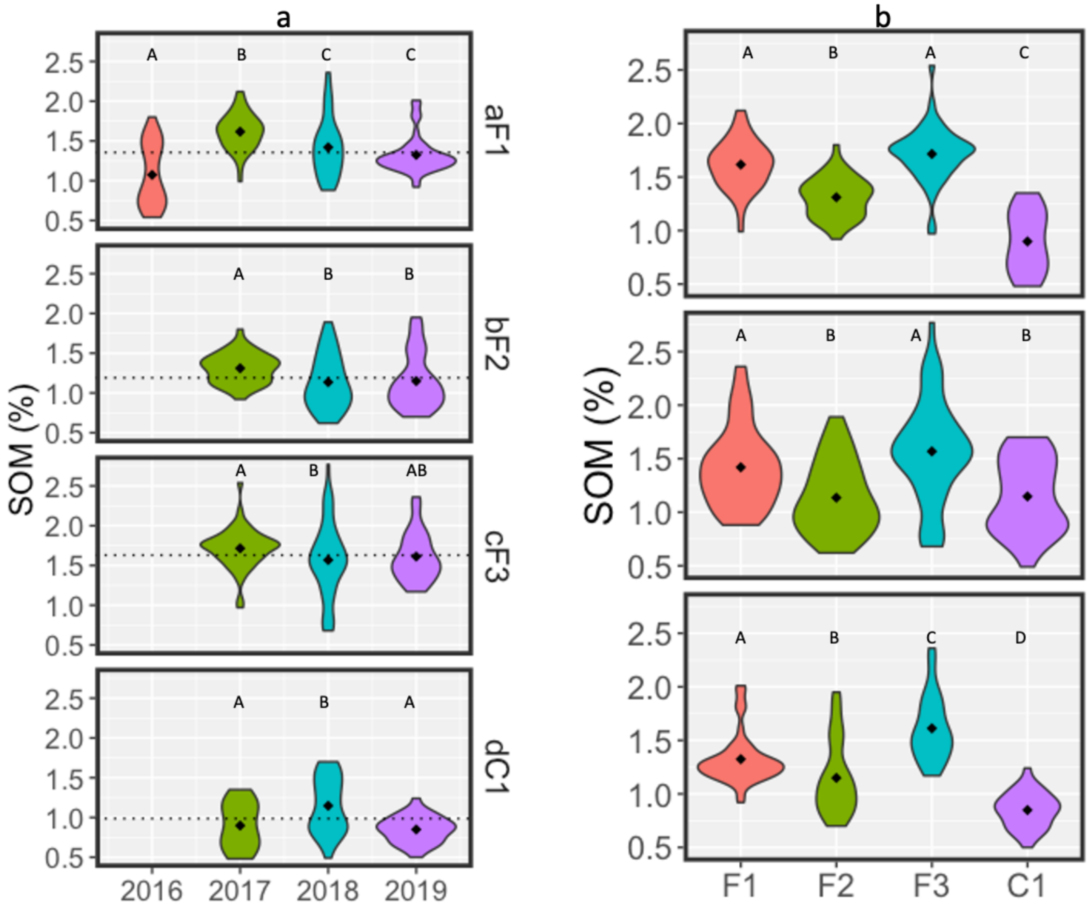

Figure 2.8. Soil organic matter levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

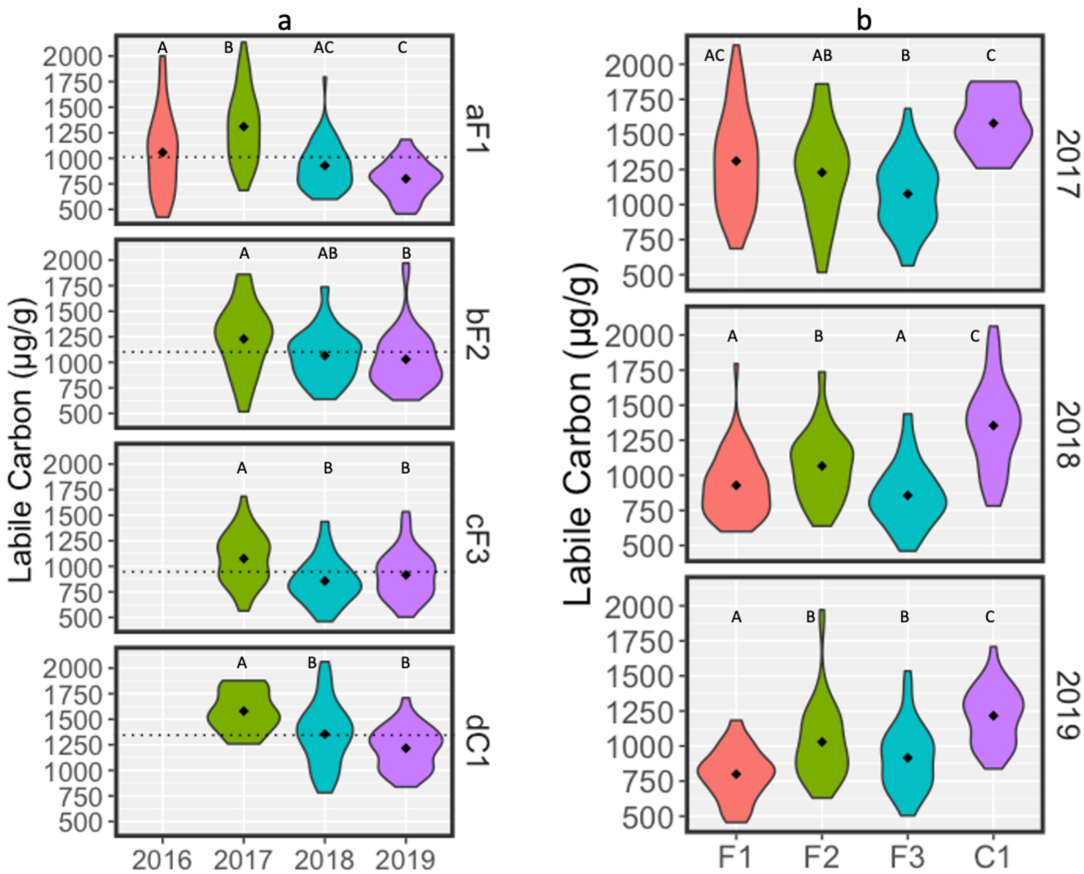

Figure 2.9. Labile carbon levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F)3, and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

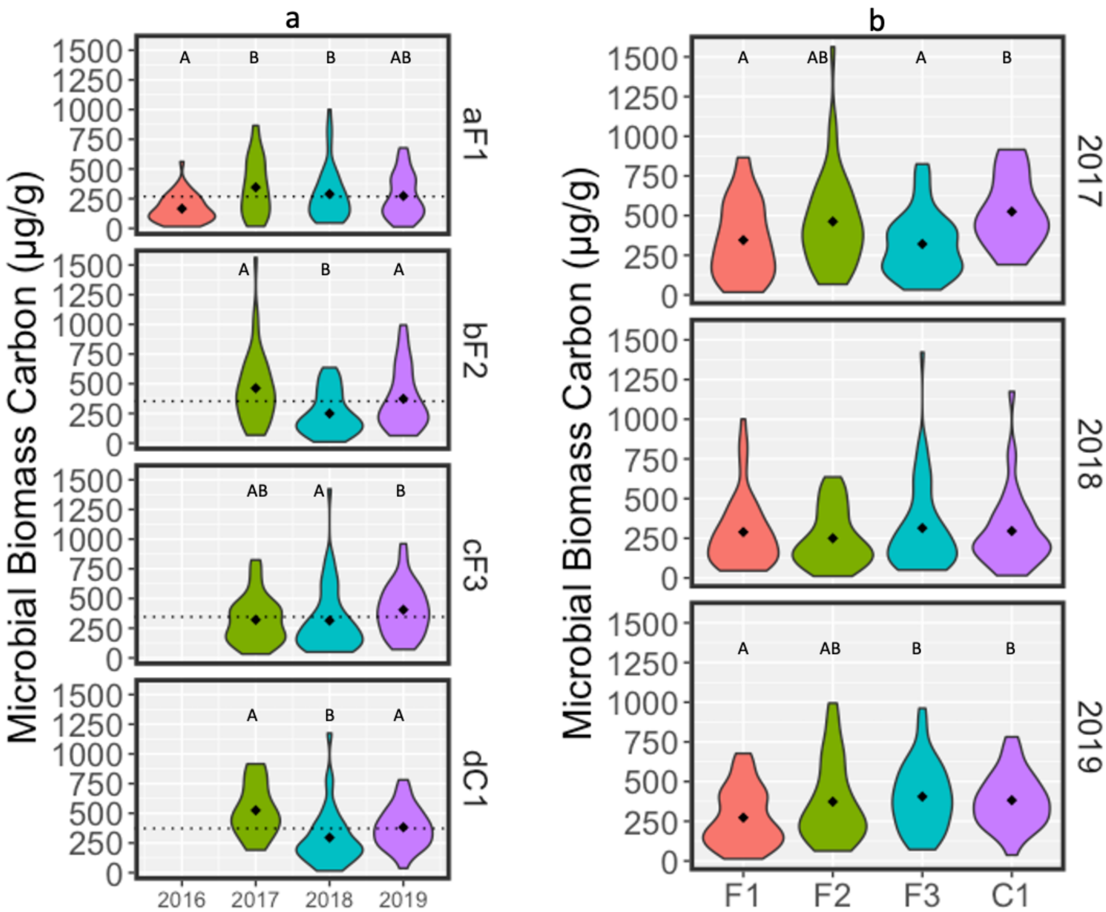

Figure 2.10. Microbial biomass carbon levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2016 n = 46, 2017 n = 42, 2018 n = 54, 2019 n = 48; conventional-till field 2017 n = 16, 2018 n = 36, 2019 n = 32. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

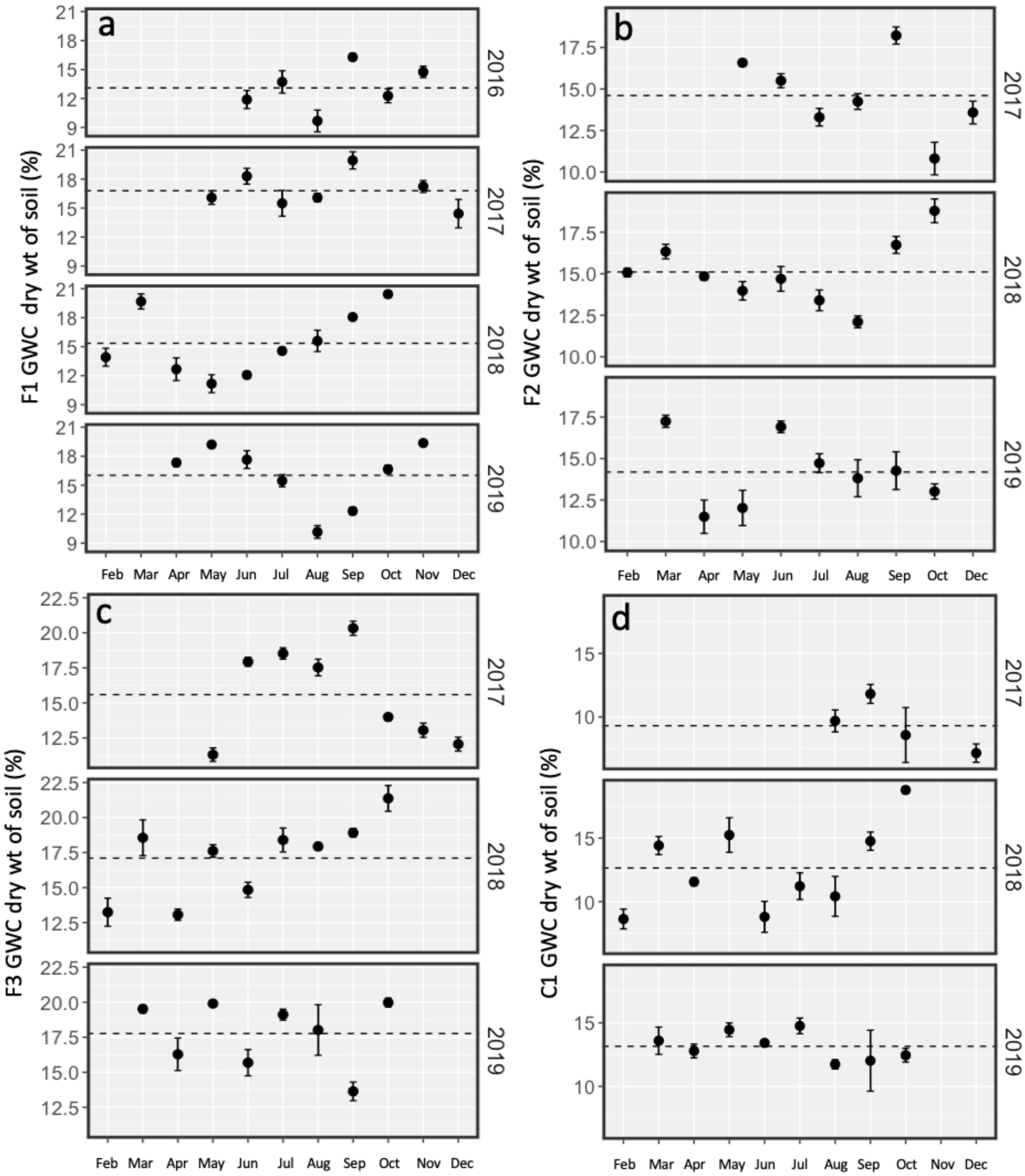

Figure 2.11. Monthly levels of gravimetric water content within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

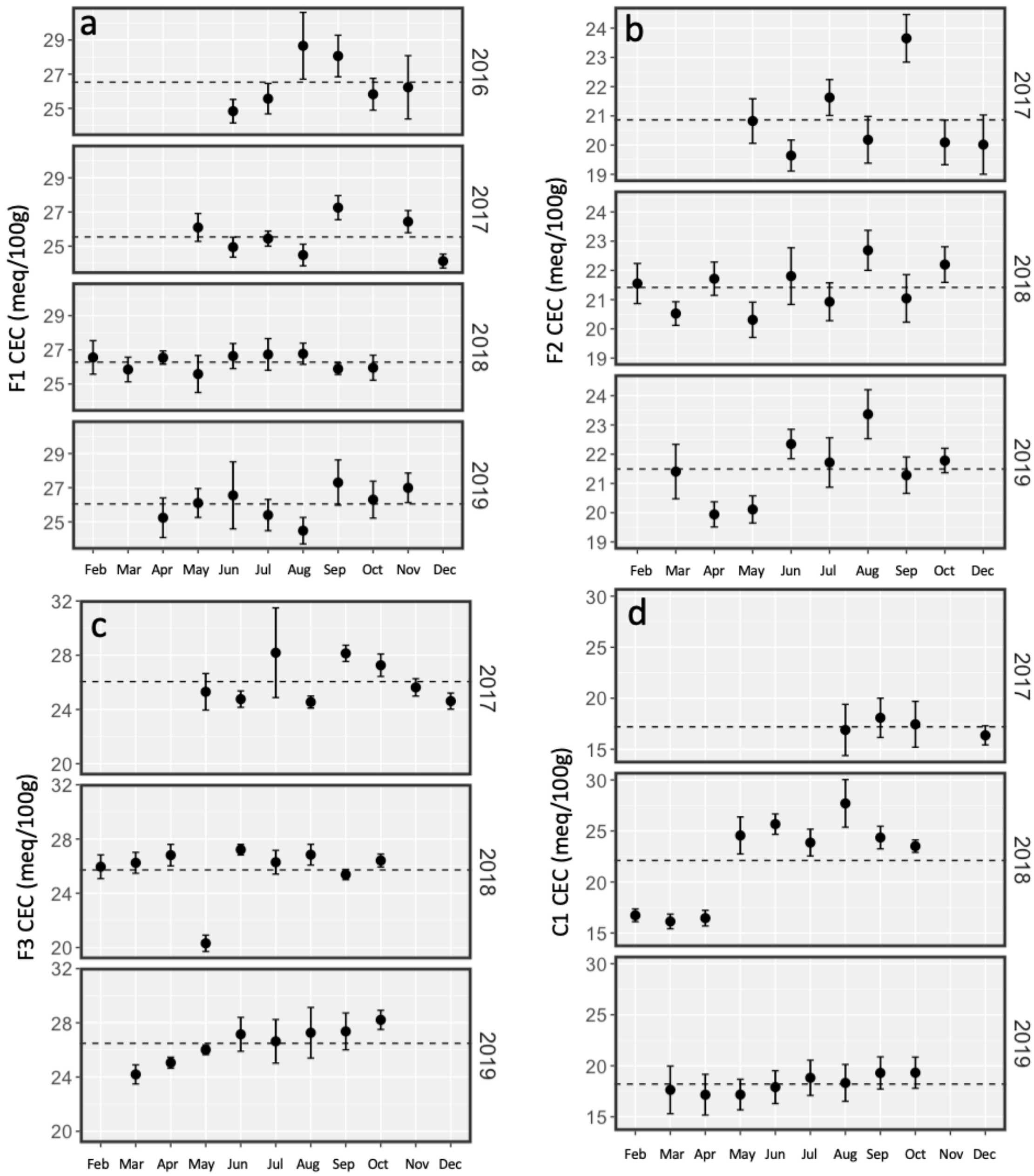

Figure 2.12. Monthly levels of cation exchange capacity within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

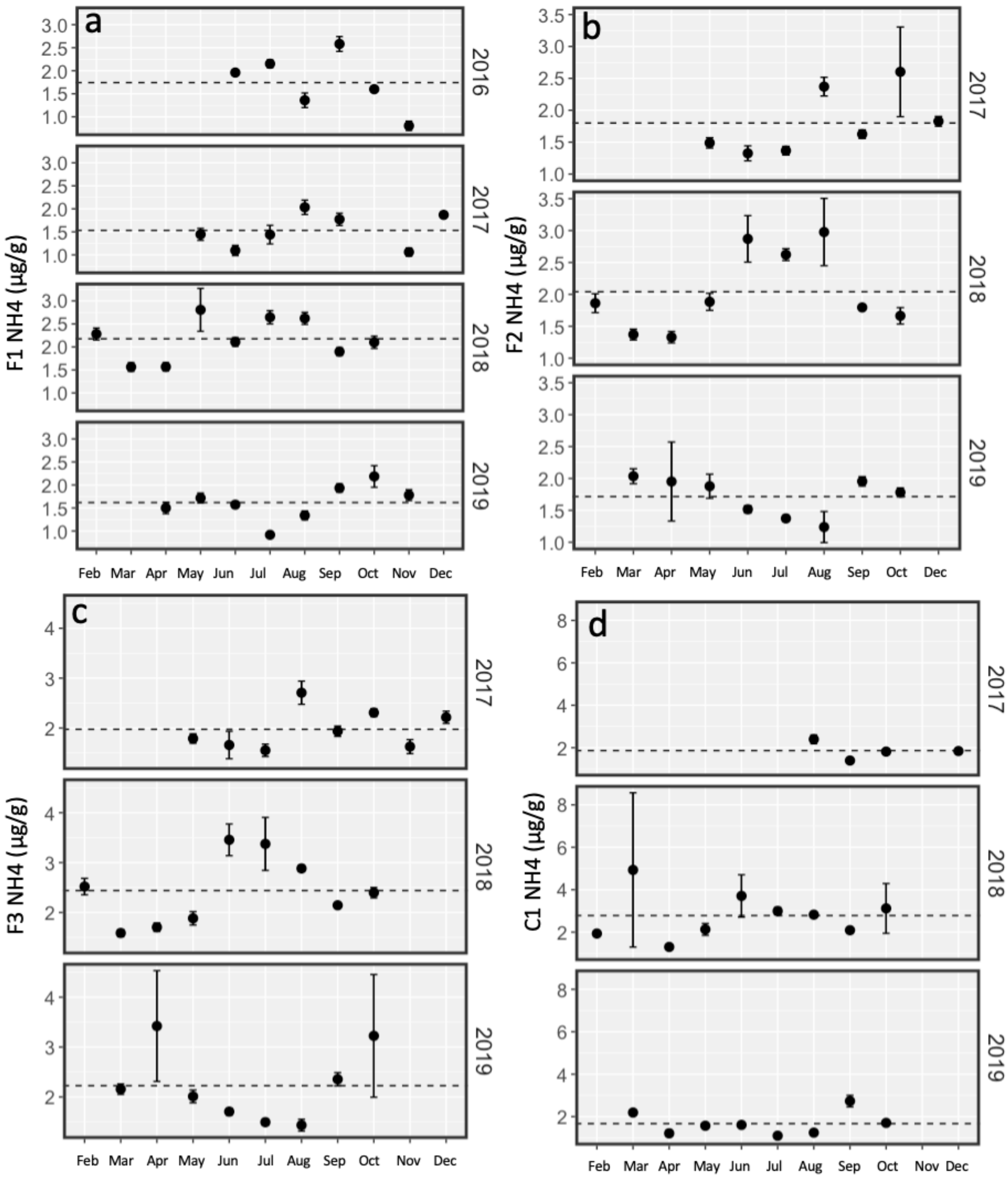

Figure 2.13. Monthly levels of extractable levels of NH_4^+ -N within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

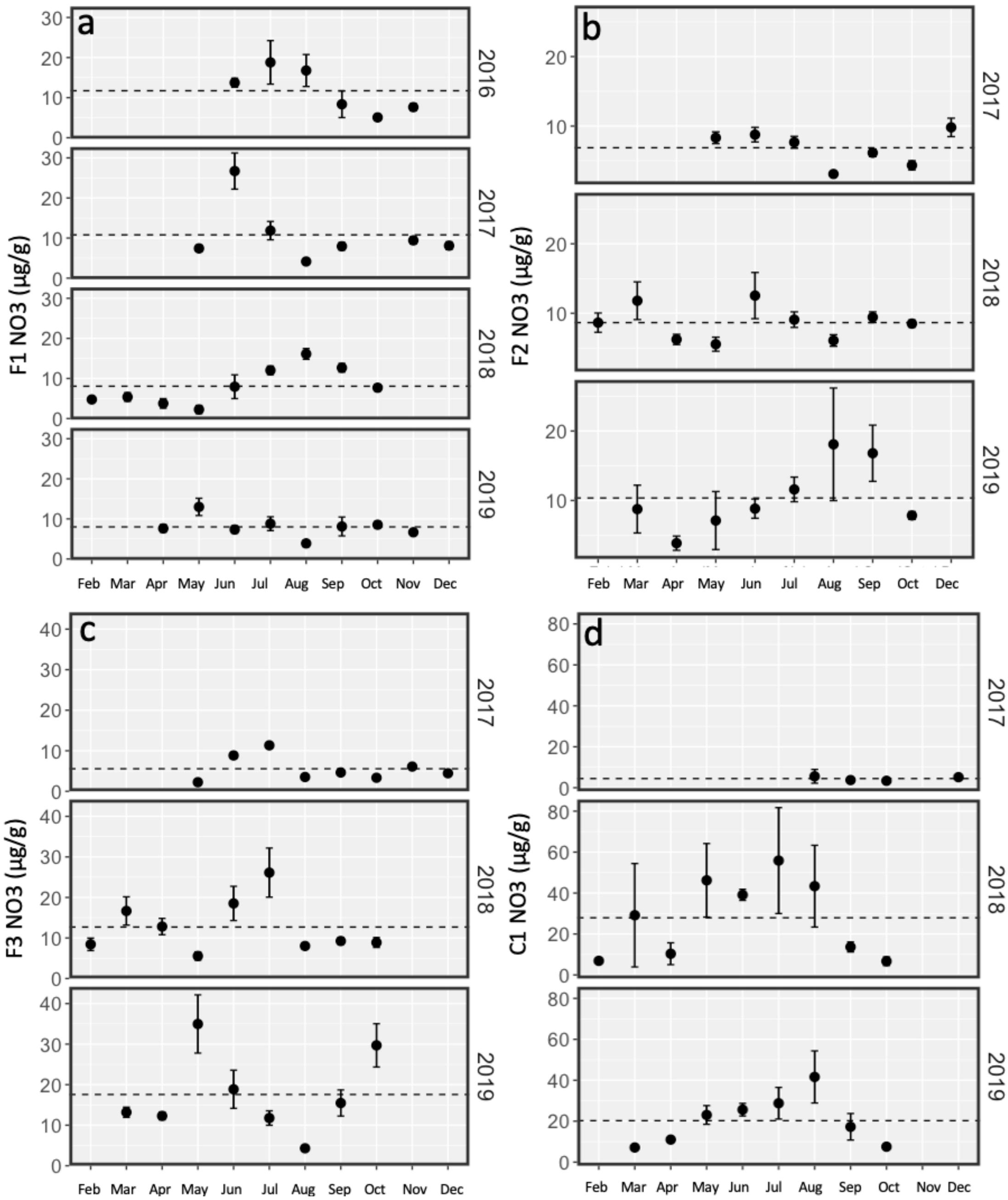

Figure 2.14. Monthly levels of extractable levels of NO_3^- -N within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

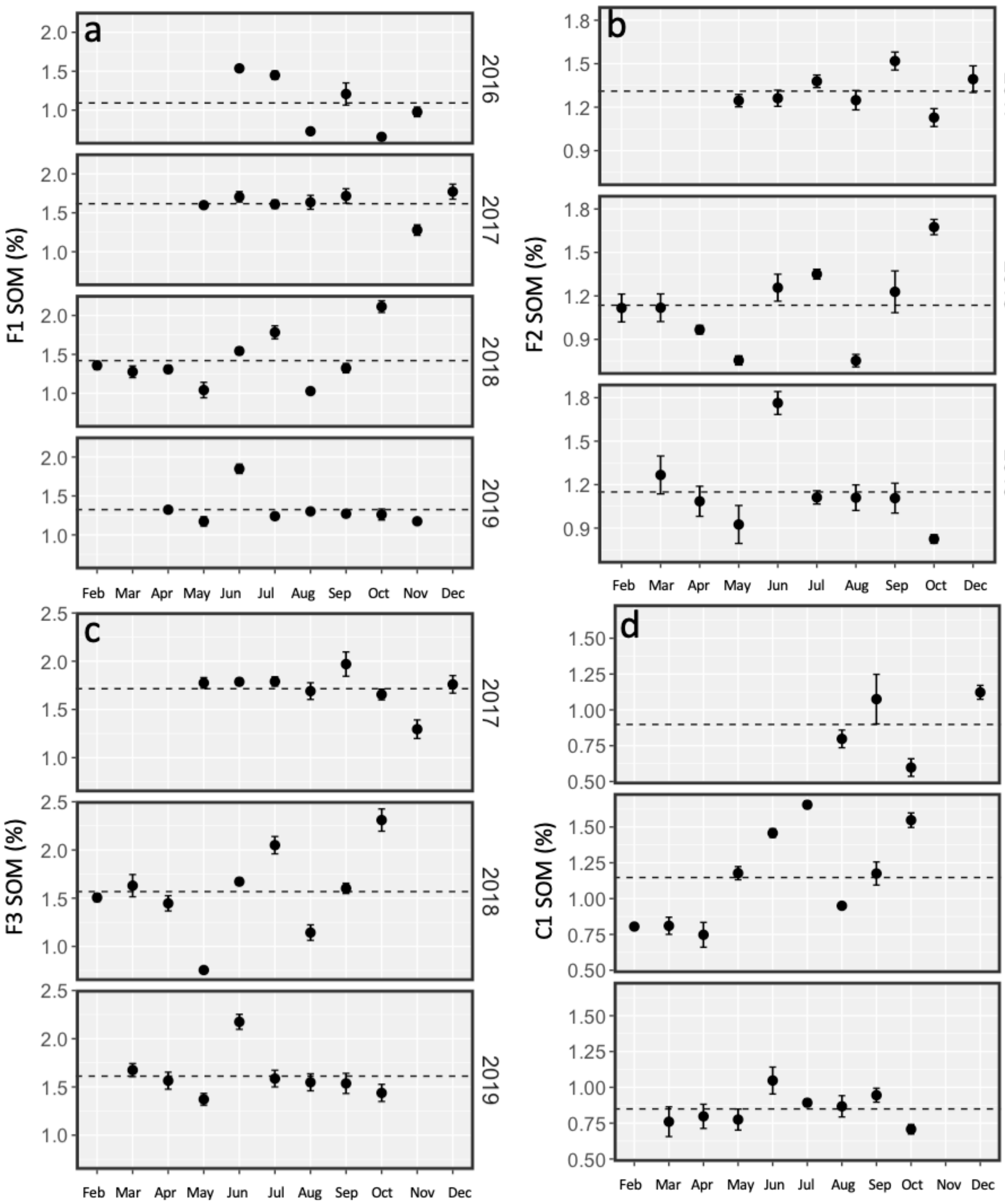

Figure 2.15. Monthly levels of soil organic matter within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

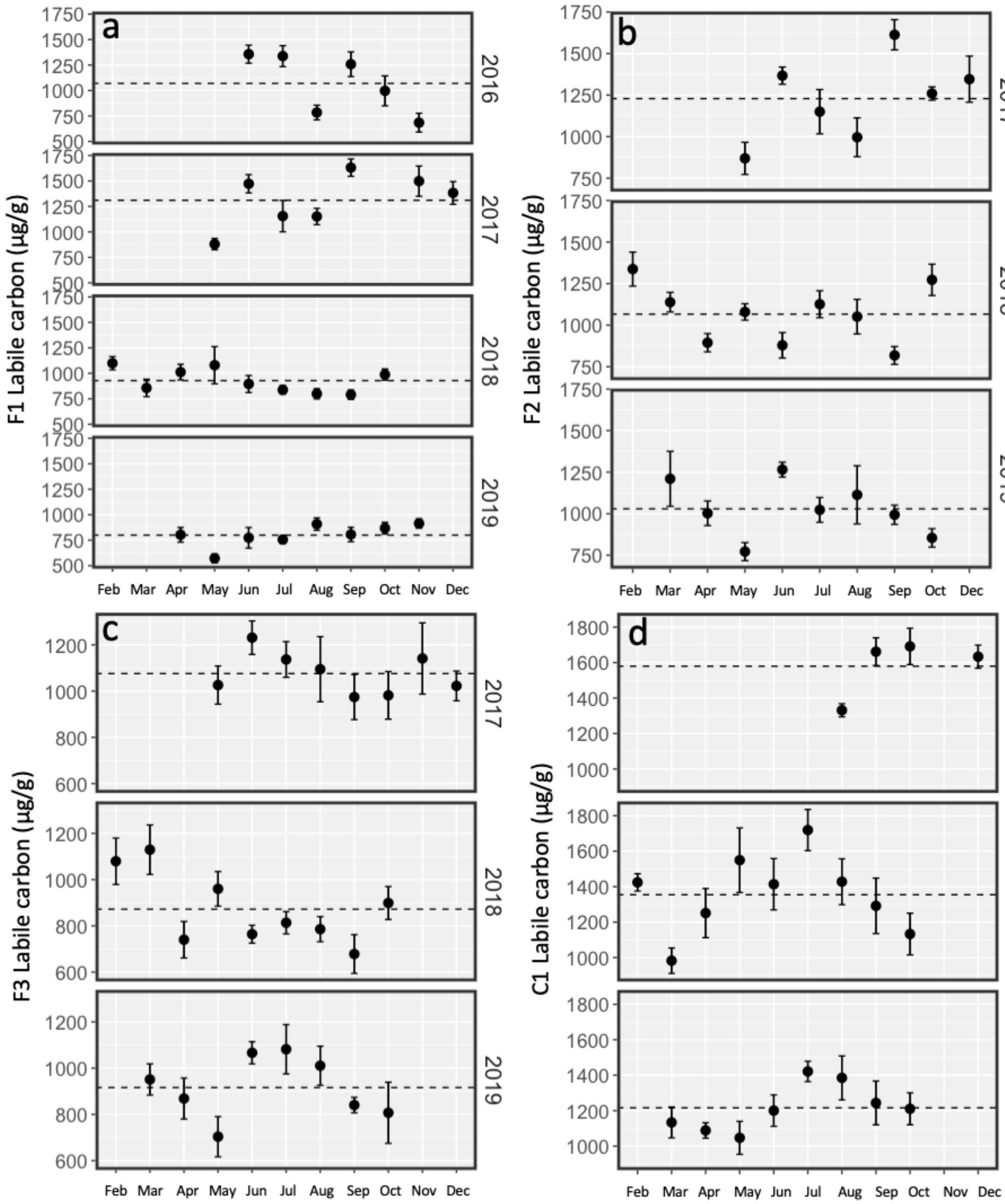

Figure 2.16. Monthly labile carbon dynamics of each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

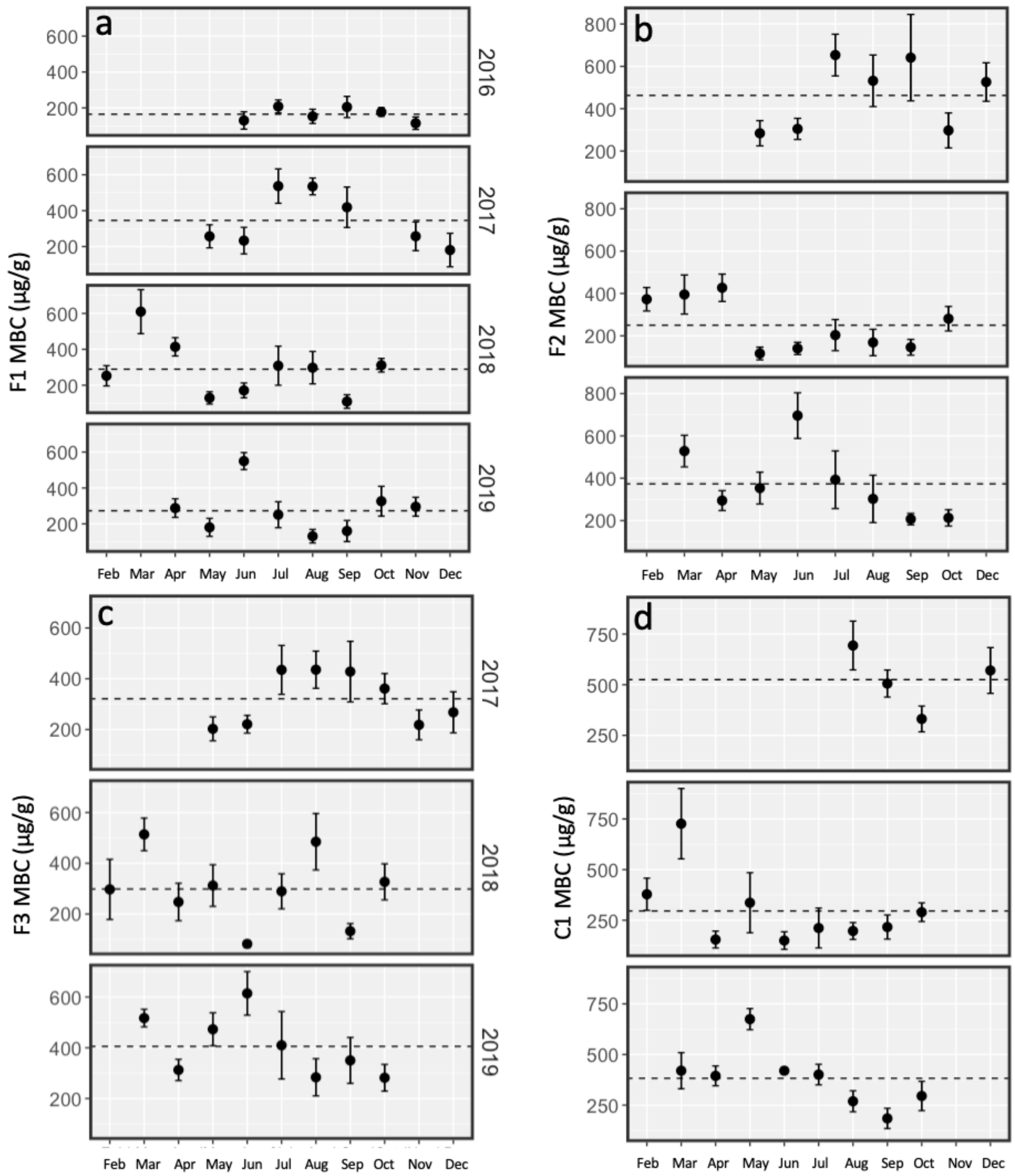

Figure 2.17. Monthly microbial biomass carbon dynamics of each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

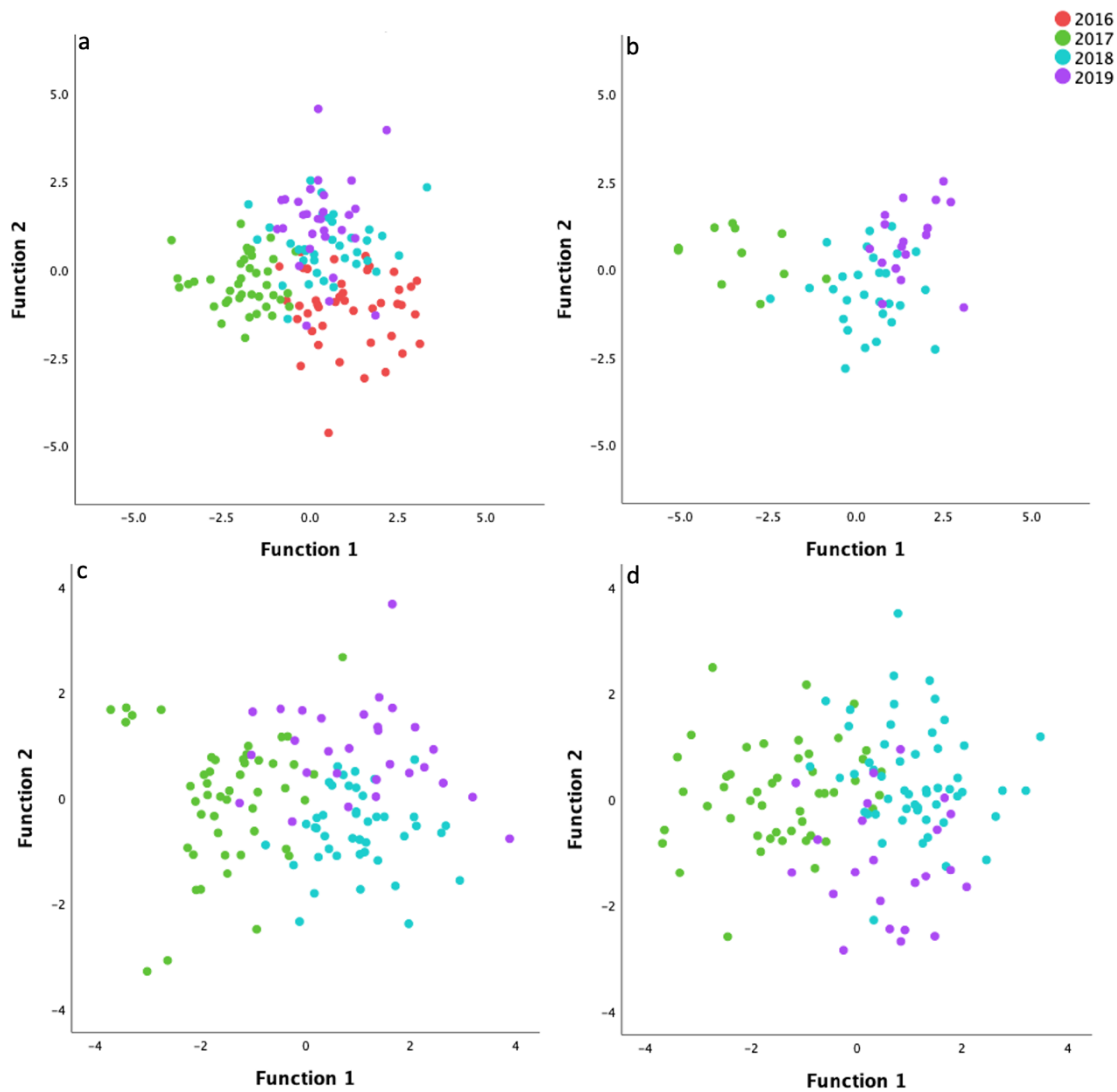

Figure 2.18. Graphical representation of discriminant function analysis (DFA) using environmental and edaphic variables for no-till and stubble fields F1 (a), F2 (b), F3 (c) and conventional-till field C1 (d) in semi-arid west Texas within-field and across years

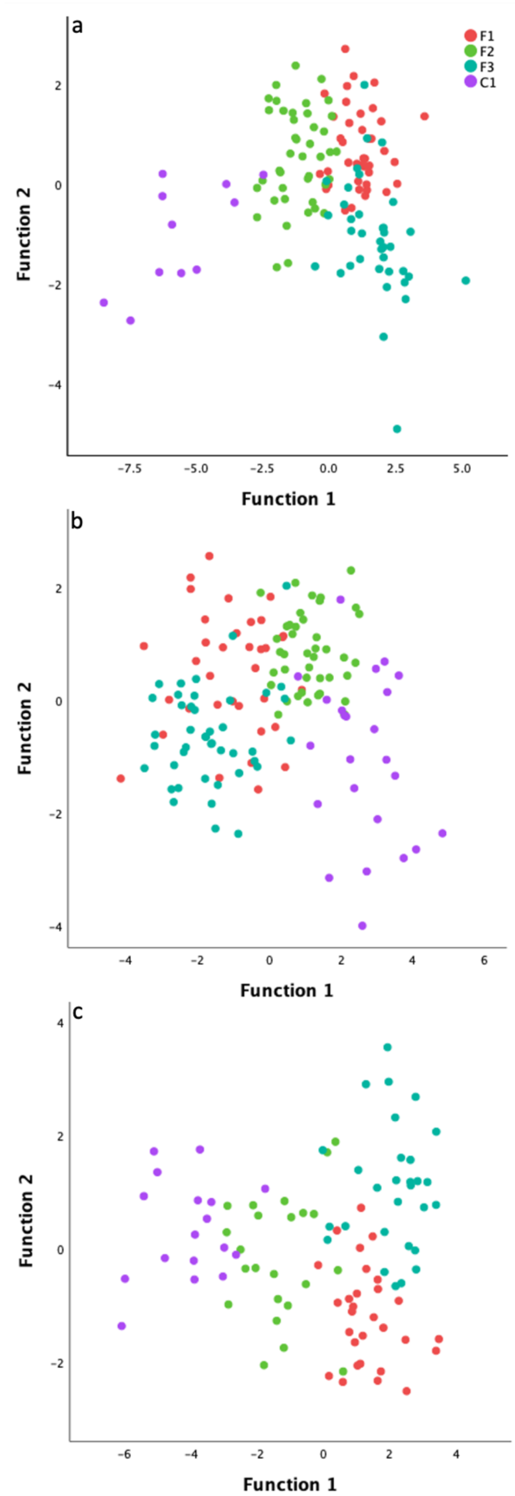

Figure 2.19. Graphical representation of a discriminant function analysis (DFA) with environmental and edaphic variables for no-till and stubble fields (F1, F2, F3) and conventional-till field (C1) in years 2017 (a), 2018(b) and 2019(c) in semi-arid west Texas among-fields per year.

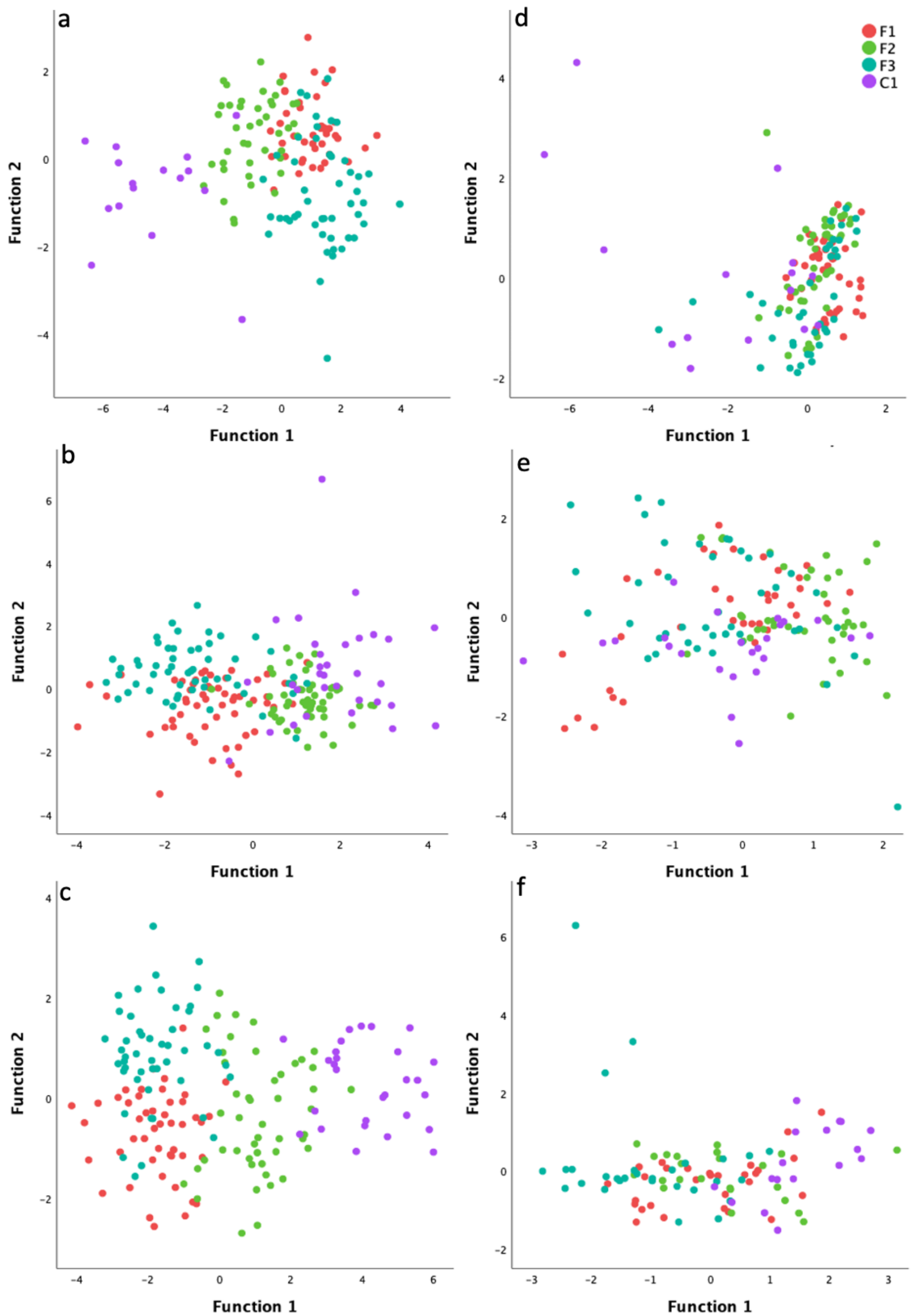

Figure 2.20. Graphical representation of a discriminant function analysis (DFA) using only edaphic variables for years 2017, 2018 and 2019 (a, b, and c), and using only environmental variables from the same years (d, e, and f) for no-till and stubble fields F1, F2, F3 and conventional-till field C1 in semi-arid west Texas.

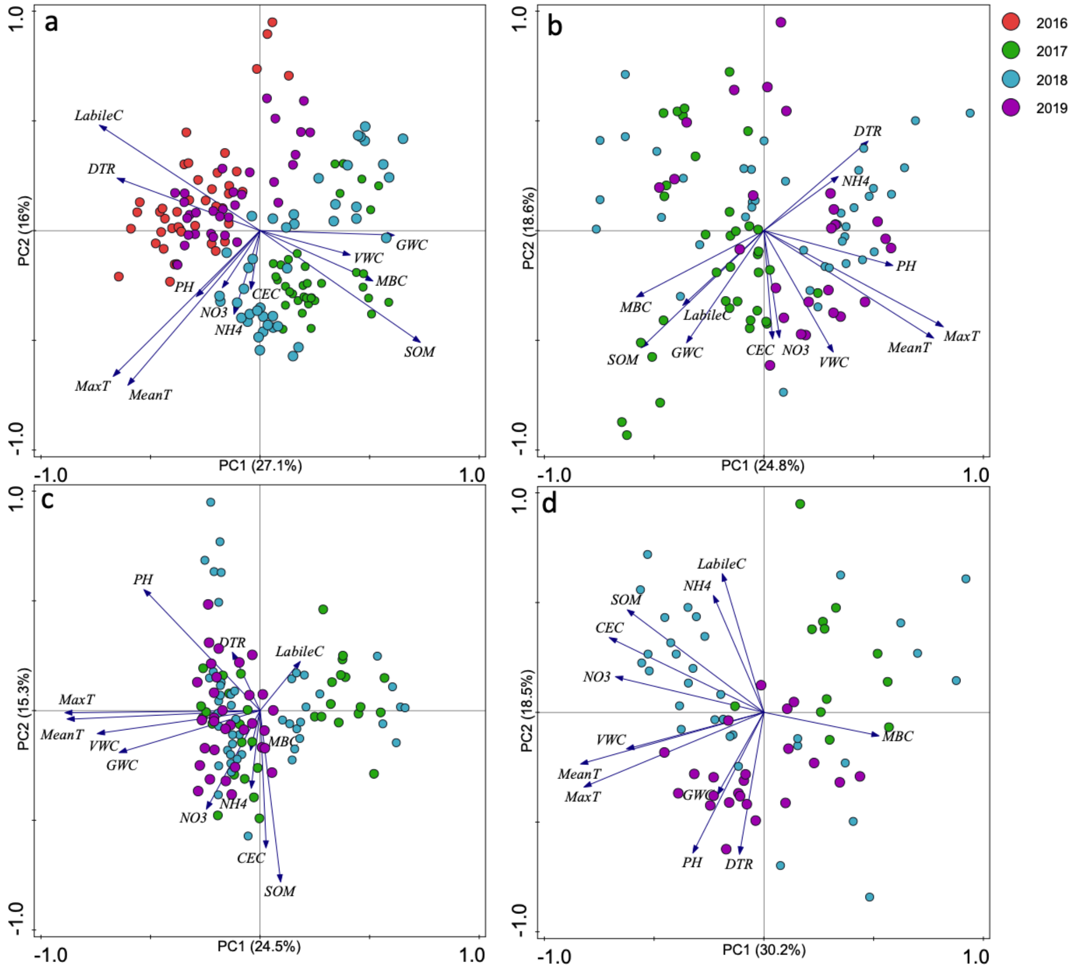

Figure 2.21. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables of each no-till and stubble field F1 (a), F2 (b), F3 (c) and the conventional-till field C1 (d), and scores with the explained variability for principal components 1 and 2. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable-ammonium (NH4), extractable-nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC).

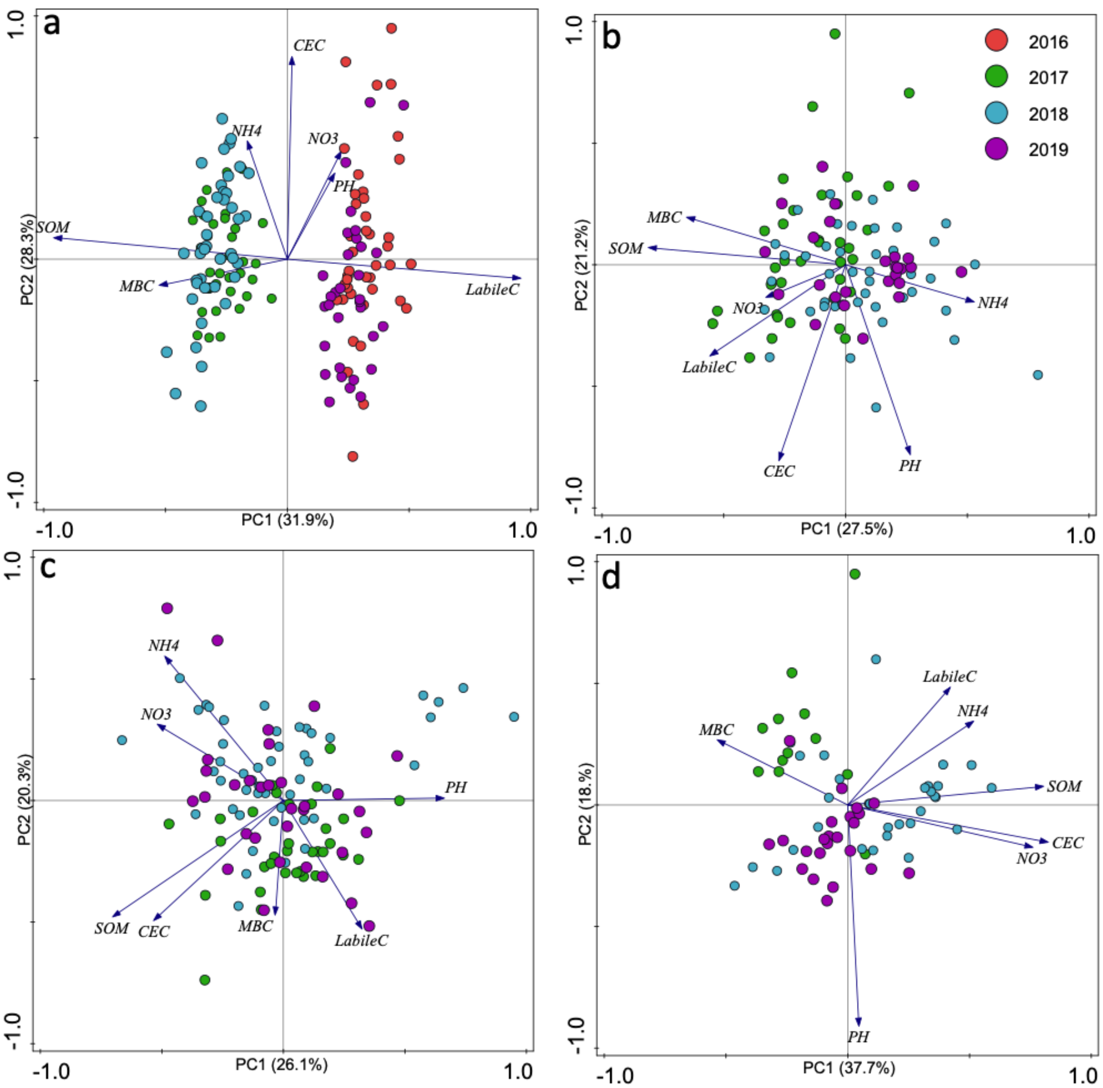

Figure 2.22. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables separated into individual analyses of each no-till and stubble and the conventional-till field, and scores with the explained variability for principal components 1 and 2. Plots a, b, c and d correspond to F1, F2, F3 and C1 edaphic variables-only analysis. Plots e, f, g and h correspond to environmental variables-only analysis. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable-ammonium (NH4), extractable-nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC).

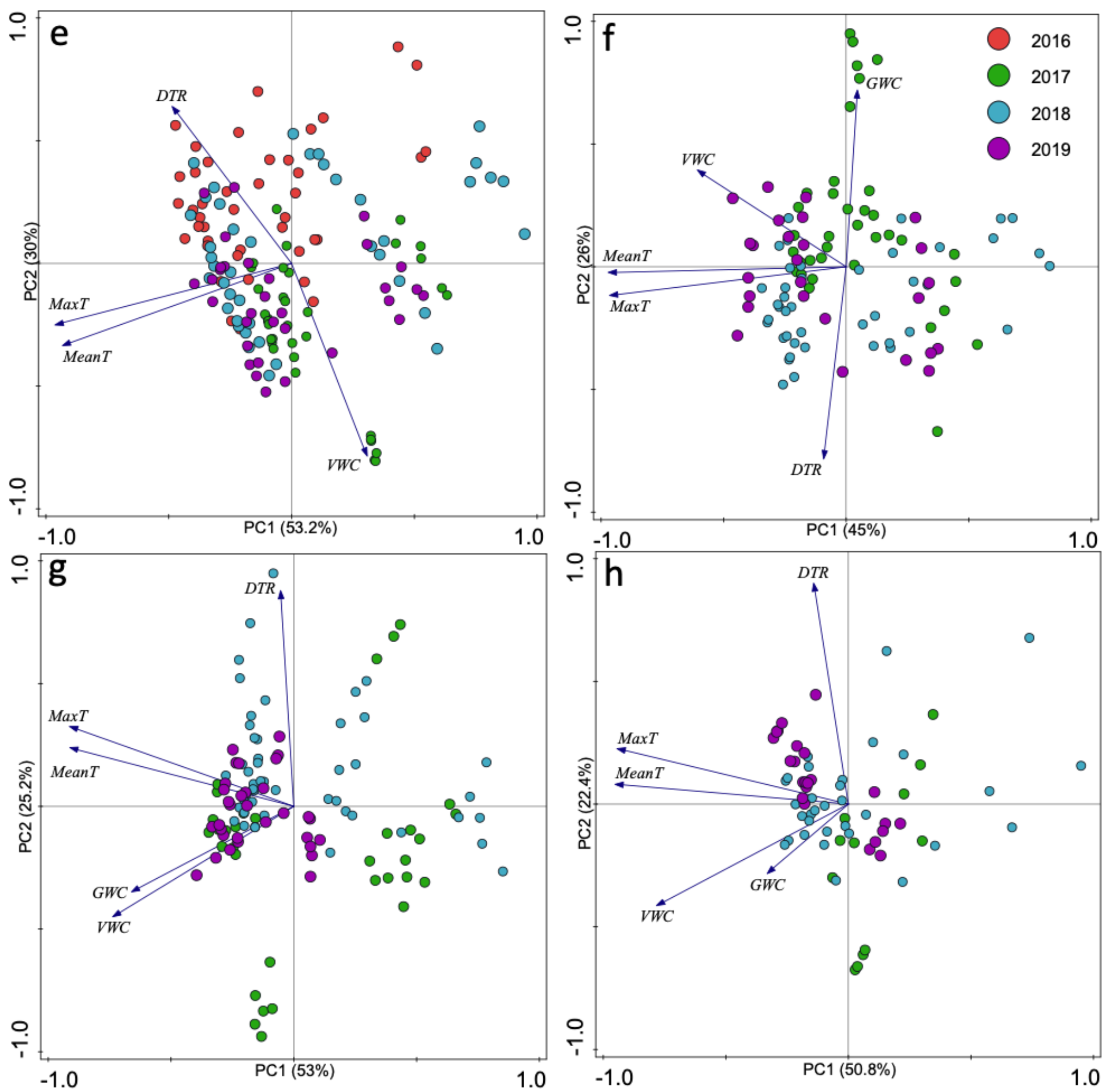

Figure 2.22. Continued. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables separated into individual analyses of each no-till and stubble and the conventional-till field, and scores with the explained variability for principal components 1 and 2. Plots a, b, c and d correspond to F1, F2, F3 and C1 edaphic variables-only analysis. Plots e, f, g and h correspond to environmental variables-only analysis. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable-ammonium (NH4), extractable-nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC).

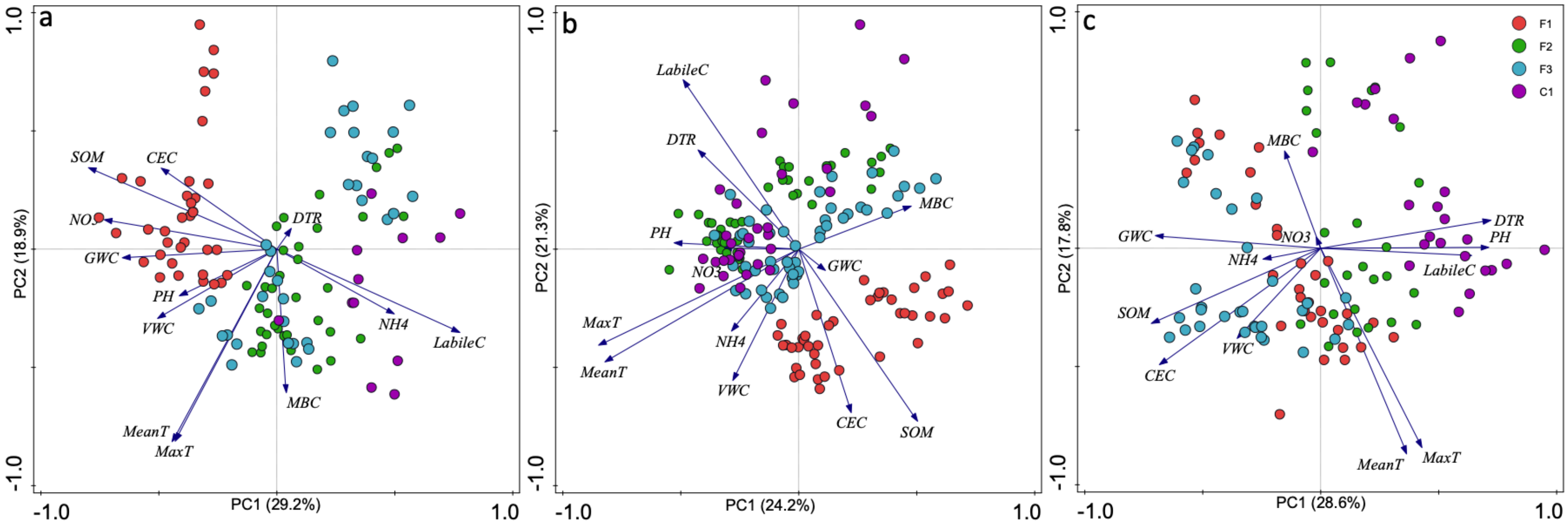

Figure 2.23. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables of no-till and stubble fields F1, F2, F3 and the conventional-till field C1 in years 2017 (a), 2018 (b) and 2019 (c), and scores with the explained variability for principal components 1 and 2. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable ammonium (NH4), extractable nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC).

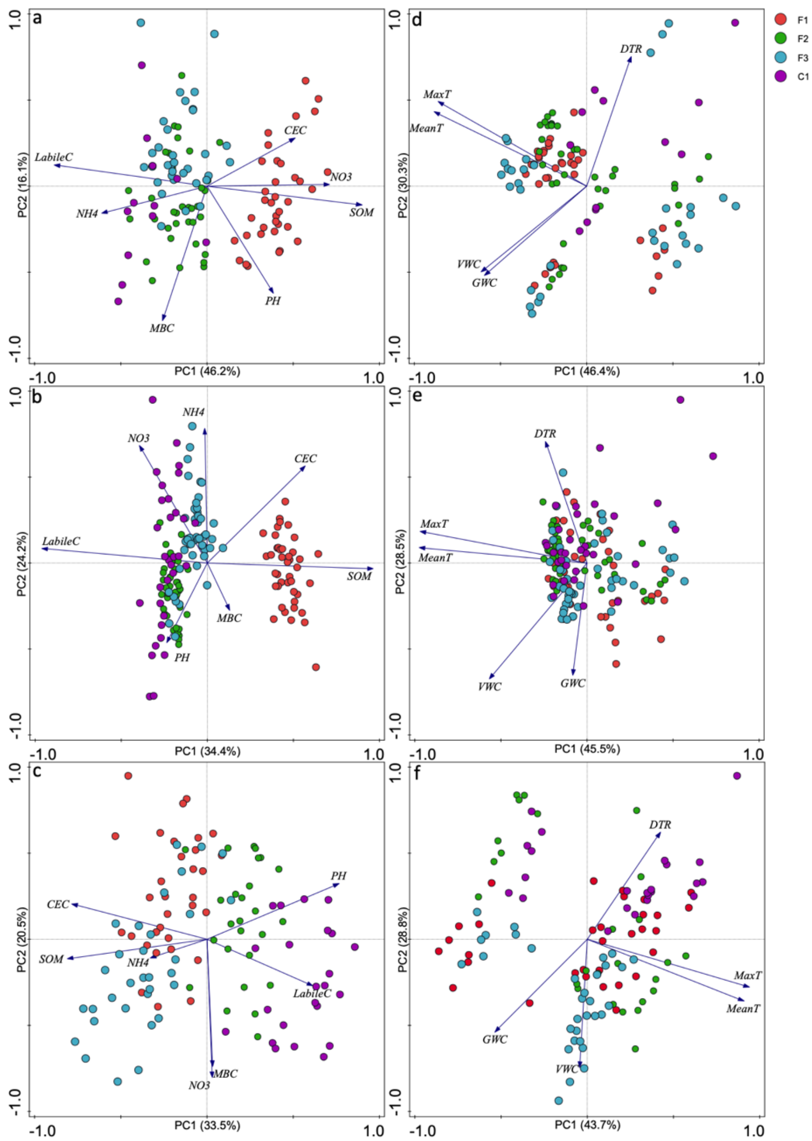

Figure 2.24. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables separated into individual analyses of no-till and stubble and the conventional-till field, and scores with the explained variability for principal components 1 and 2. Plots a, b, and c correspond to years 2017. 2018 and 2019 edaphic variables-only analysis. Plots d, e and f correspond to environmental variables-only analysis of the same years. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable-ammonium (NH4), extractable-nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC).

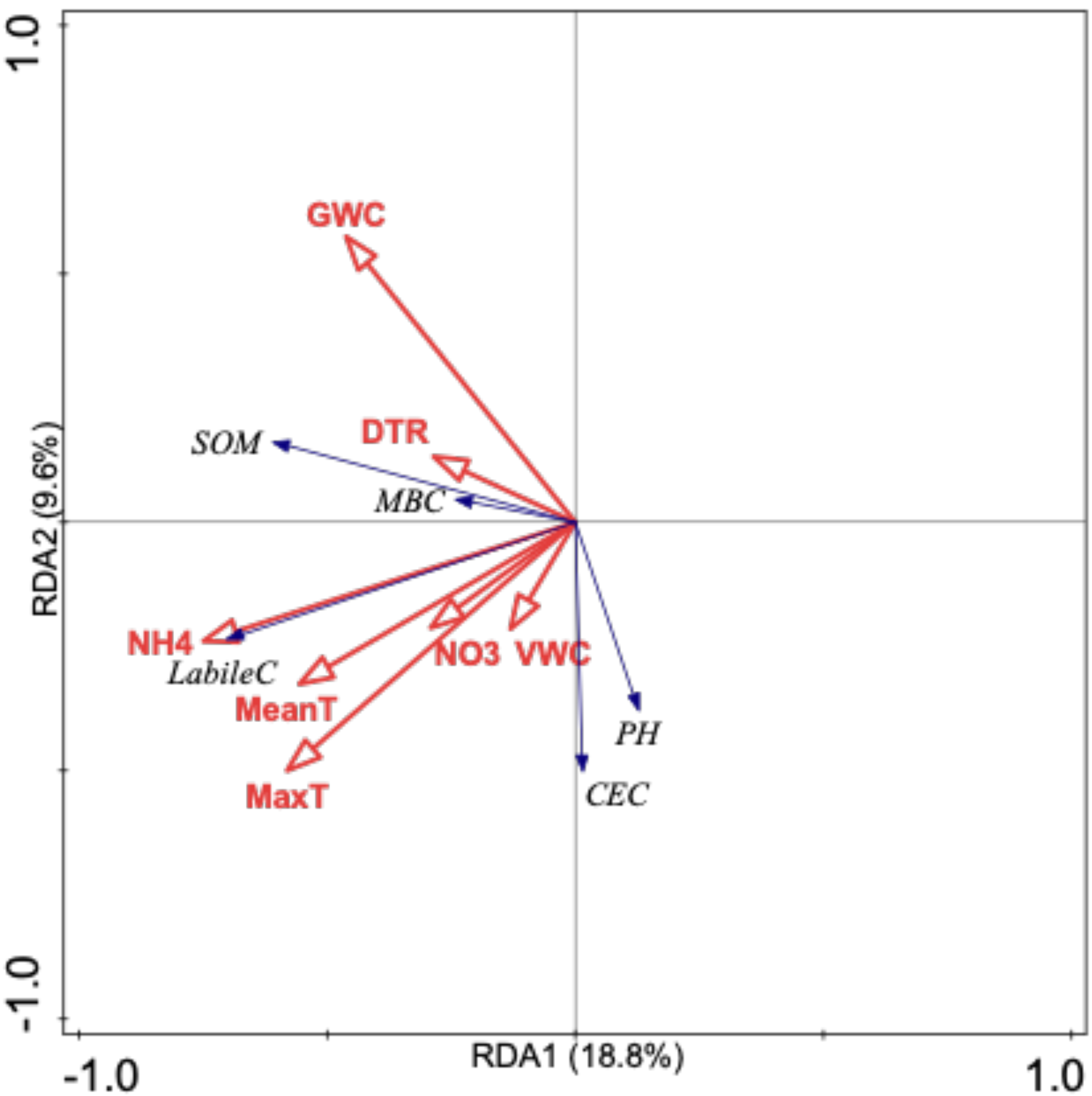

Figure 2.25. Redundancy analysis for no-till and stubble field F1for 2016. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3). The response variables are: cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

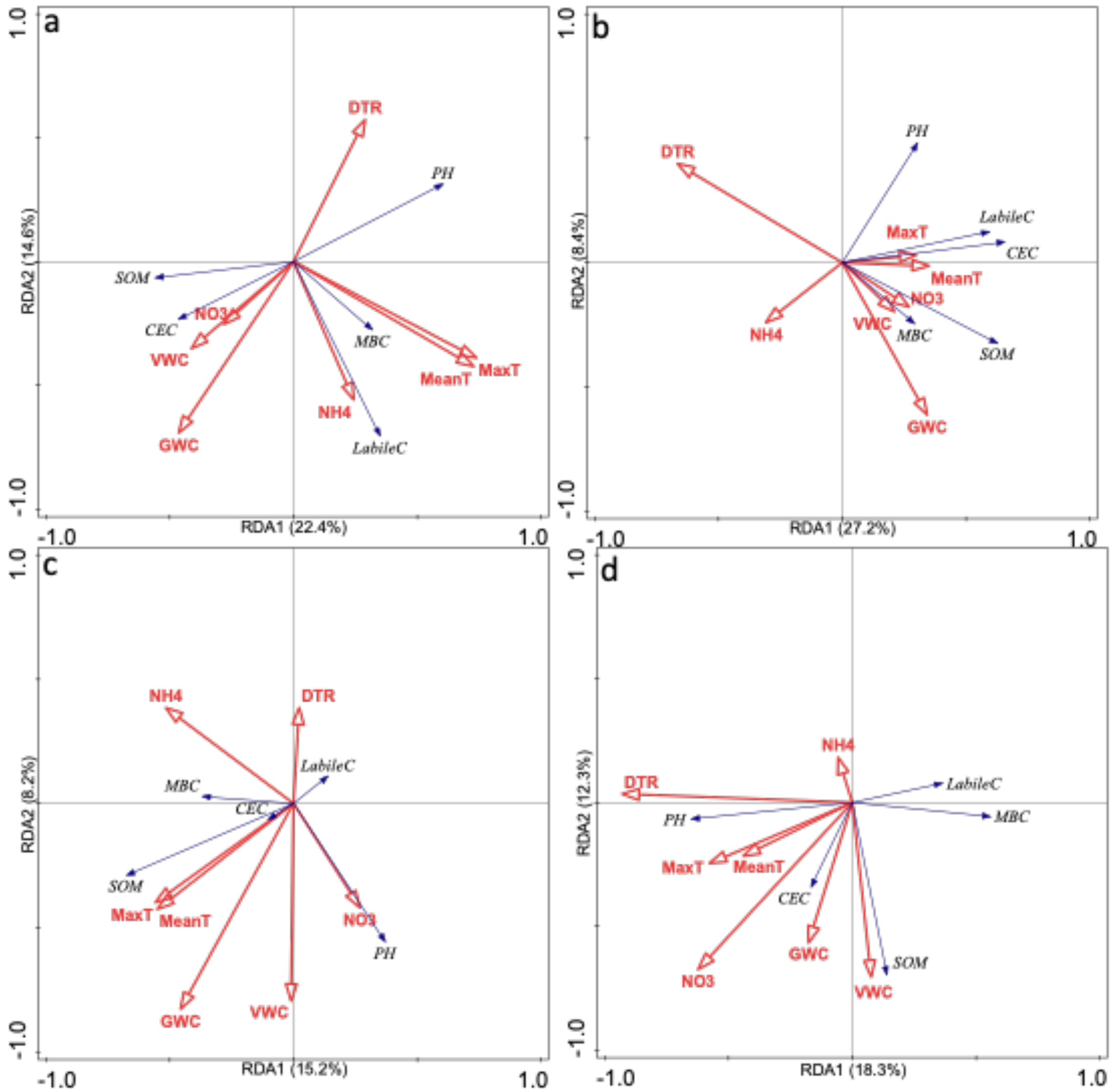

Figure 2.26. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for 2017. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3). The response variables are: cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

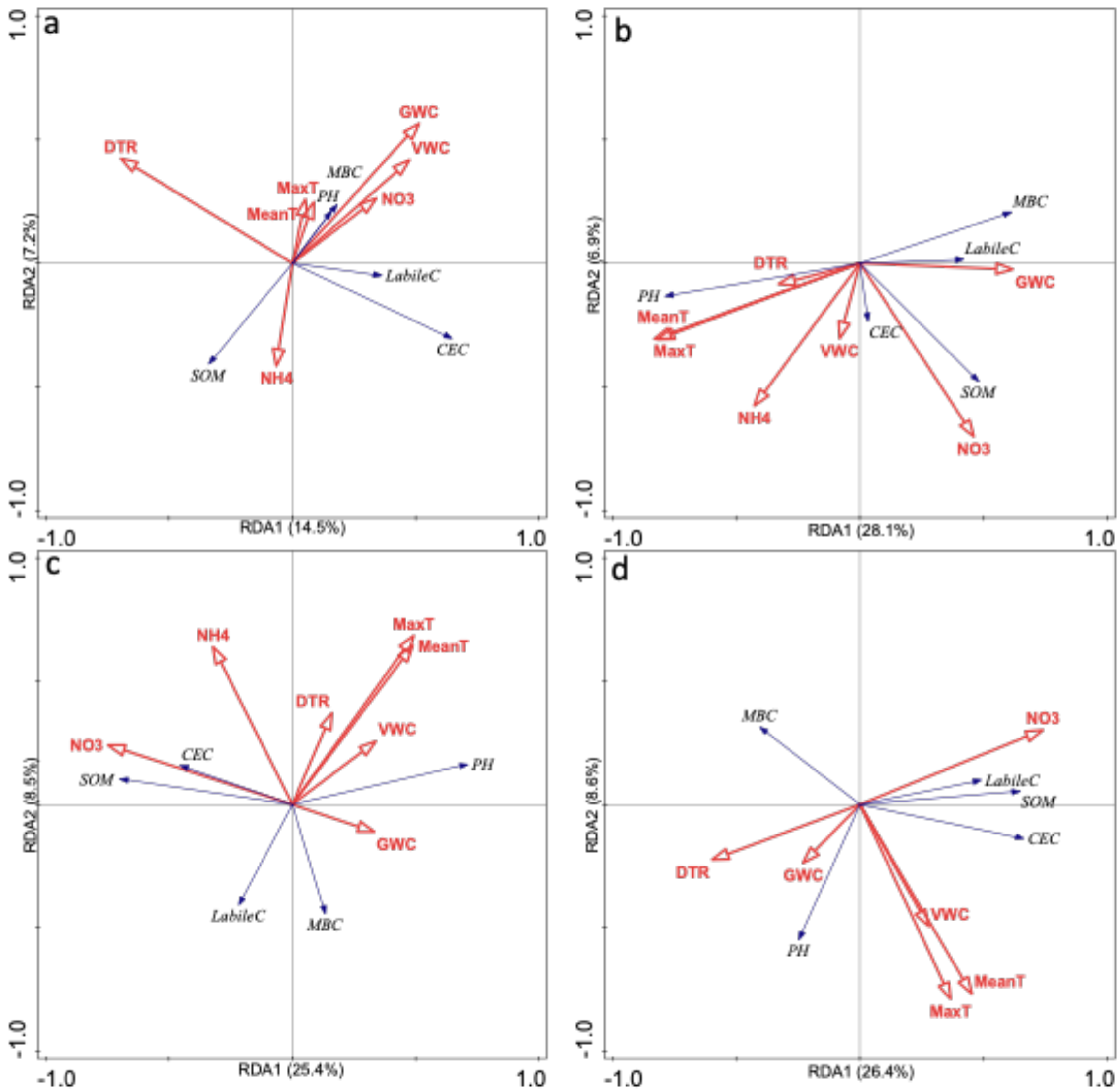

Figure 2.27. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for 2018. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3). The response variables are: cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

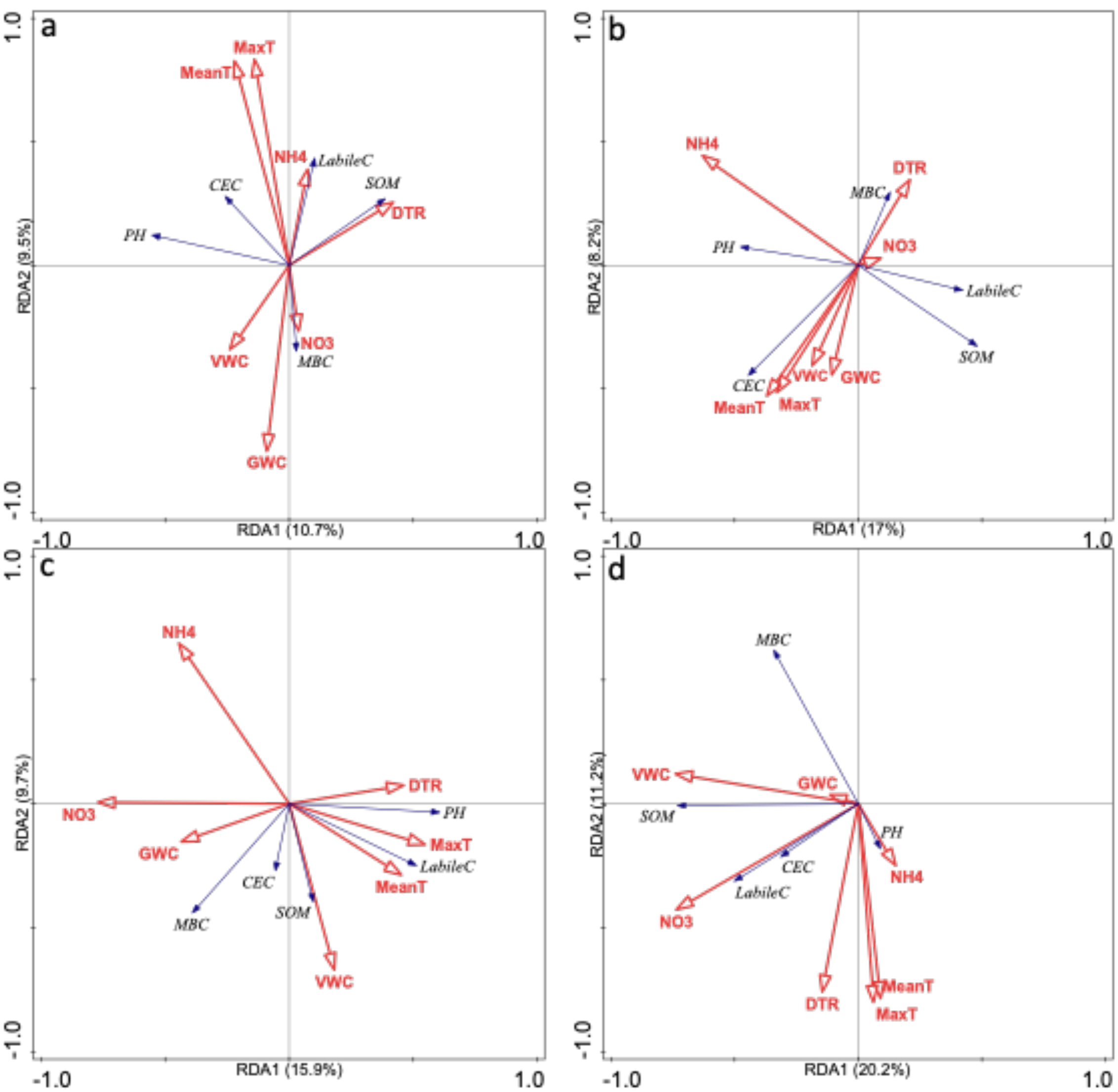

Figure 2.28. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for 2019. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3). The response variables are: cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

CHAPTER III

SOIL MICROBIAL COMMUNITIY DYNAMICS UNDER DIFFERENT LAND MANAGEMENT TYPES OF PIVOT IRRIGATED COTTON SYSTEMS IN THE SEMI-ARID SOUTHERN HIGH PLAINS OF TEXAS

Abstract

Diverse and functionally stable soil microbial communities are essential to carry out important processes that support plant growth and sustain soil health in both natural and managed ecosystems. In agriculture systems, land management strategies that support soil health are necessary to help agroecosystems respond to increasing climate variability. However, conventional agriculture systems that incorporate tillage are known to change soil conditions to levels where microbial communities become more affected by climate variability like high temperatures and drought, eventually affecting functions involving nutrient cycling and soil organic matter dynamics. This study evaluated four center pivot-irrigated cotton production systems in Petersburgh, TX in 2017 and 2018. Three fields had no-till and stubble management, while one field used conventional-tilling techniques. Soil microbial communities were evaluated via ester linked-fatty acid methyl ester (EL-FAME) profiles. Despite lack of strong differences in yearly averages of microbial markers between land management types, positive relations between FAMEs and soil health indicators like extractable nitrogen, soil organic matter (SOM) and labile carbon were more positive across the no-tilled fields than under conventional tillage. For irrigated semi-arid agroecosystems, moving towards a no-till and stubble management approach resulted in a better relationship between the microbial communities and carbon and nitrogen dynamics and developing a positive trajectory in soil health.

Introduction

The Southern High Plains of Texas (SHPT) consists predominantly of semiarid soils that are characterized for having low fertility, biological activity and soil organic matter (SOM) than soils from mesic regions (Hendricks, 1991; Maestre et al., 2012). These soil characteristics and their impacts on plant growth are exacerbated in semi-arid environments due to high air and soil temperatures, low humidity levels and high solar radiation, which contributes to a high evapotranspiration potential stress conditions for plants and microbes (Reynolds et al., 2007). Agriculture in the SHPT occurs mostly where irrigation is available, although a considerable acreage (40% of cropland) is used to grow dryland cotton (Texas A&M AgriLife Extension). Together, irrigated and dryland cotton contribute to approximately 25% of the cotton produced in the United States (LCC, 2021). Agriculture success in this area has been a consequence of consistent temperature and rainfall patterns that allow for a stable crop production (Rottler et al., 2019). However, continuous cropping and the use of conventional cropping strategies with high impact on soil physical properties, like tillage (Petermann et al., 2019), in addition to recent increase in climate variability (Modala et al., 2017; Steiner et al., 2017) in the SHPT threatens crop production and soil health by affecting soil dynamics regulated by microorganisms. Several decades of continuous tillage increases soil compaction by homogenizing aggregates, which in turn reduces soil water retention and infiltration (Abu-Hamdeh, 2004; Hamza and Anderson, 2005), and increases soil surface temperature fluctuation by leaving the surface exposed (Kladivko, 2001).

As soil structure changes, microbial communities shift due to the change of the soil conditions. Oxygen levels in the top 20 cm increase with tillage, allowing for aerobic bacteria to thrive (Six et al., 2006). Fungal communities are reduced and fungal biomass decreases as a consequence of tillage physically destroying mycelial networks (Helgason et al., 2009). Changes in the diversity and composition of the soil microbial community as a consequence of the combined impacts of tillage, high soil temperatures, and decreased soil moisture, results in a decrease in soil organic matter (SOM) levels resulting from their rapid degradation by aerobic bacteria (Six et al., 2006). Studies from dryland semiarid soils have also shown that nutrient cycling, mediated primarily via extracellular enzyme activity (EA) is affected by extreme environmental shifts such as droughts, which initially increase EA due to high temperatures, but ultimately decreases activity because of exhaustion of substrates drawn from the SOM (Acosta-Martinez et al., 2014a; Acosta-Martinez et al., 2014b; Acosta-Martinez et al., 2003) and a decline in production. Other studies have pointed out that decrease in EAs is due to reduced microbial biomass, decreased adsorption of enzymes to soil particles under drier conditions, and to limited enzyme encounter with substrates due to moisture limitation (Alster et al., 2013; Bowles et al., 2014; Steinweg et al., 2012).

Interest in adoption of land management techniques that mitigate soil degradation due to environmental and historical agriculture disturbances is increasing (Steiner et al., 2017). Increase in soil water retention, soil erosion mitigation, SOM build up and better nutrient cycling rates have been observed as positive effects of no-till agriculture and use of cover crops (Cates and Jackson, 2019; Dabney et al., 2001; Triplett Jr and Dick, 2008). These conditions generally support functional soil microbial communities with key roles in nutrient cycling (Habig and Swanepoel, 2015; Helgason et al., 2010; Helgason et al., 2009; Lupwayi et al., 2018; Stromberger et al., 2007; Tyler, 2019).

In this study, I observed and described the response of community ester-linked Fatty Acid Methyl Ester (EL-FAME) composition and total EAs under three no-till and stubble and one conventional-till cotton production fields across two growing seasons on the semiarid SHPT. In the FAME approach of characterizing microbial communities, biomarkers found in all microbial cell membranes are linked with essential functions like energy storage and signaling that provide profiles that allow to differentiate between functional groups of microbes (Veum et al., 2021; Zelles, 1999). The study was designed to determine the benefits of using conventional versus no-till and stubble management practices for center-pivot irrigated cotton production on soil health indicators and microbial communities, and to describe the dynamics on both an intraannual and interannual basis in a semi-arid environment. I hypothesized that no-till fields will support higher Total FAMEs, higher Fungal:Bacterial ratios, and higher total EAs at all points during the growing seasons. This outcome is expected assuming that fields that don't use any tilling regime and incorporate crop rotations and cover crops provide soil conditions capable of developing and maintaining healthy microbial communities under the SHPT climatic conditions. That is, does no-till and stubble management mitigate some of the stress from the climatic regime of the region to result in improved soil health? Secondly, will use soil enzymes and microbial community composition methods in addition to traditional soil microbial biomass carbon measurements to provide a more in-depth understanding of how soil management practices influence soil health for semi-arid regions.

Materials and Methods

Study sites

The study sites are located on the Southern High Plains in Hale County, near Petersburg, Texas. The area is traditionally used for row crops and some rangeland. Soils are relatively productive, and the flat topography supports irrigation and mechanization. Management problems include limitation of soil moisture, wind erosion and improper water management. This area is a leading producer of cotton, grain sorghums and wheat in the region. Mean annual precipitation was 457 mm (range 188-931) for the 20-year period 2001-2020 according to the closest West Texas Mesonet weather station (Schroeder et al., 2005) located in Abernathy, TX. Precipitation mostly occurs at the beginning of the growing season in May and June and there is usually a second rainfall event during August and September (See Table 2.1 in chapter 2).

For this study, four center pivot irrigated fields were used as the locations for data collection. Three of the fields are located 5 km North of Petersburg and belong to producer Mr. RN Hopper (designed as RN-fields). These three fields will be henceforth known as F1 (Lat 33.9350 Lon -101.5793), F2 (Lat 33.9288 Lon -101.5716) and F3 (Lat 33.9356 Lon -101.5619). The fourth field is located 2 km West of Petersburg and is a conventional tilled cotton production system operated by Mr. Tom Gregory. This field will be designated as C1 (Lat 33.8729 Lon -101.6259).

No-till and Stubble Managed (RN) system

Soils in the RN farm are classified as deep, well drained, and slowly permeable Pullman Clay loams (See Table 2.2 in chapter 2). These fields have been under no-till management for approximately 11 years at the first year of observations. Each field is part of a three-step rotation system where a different crop is being grown at a given time (See Table 2.3 in chapter 2). This rotation system includes cotton as the main commodity crop and corn. A mixed no-cash crop / cover-crop using grass, legume, radish, was introduced to the easternmost field (F3) in summer of 2017. In 2018 season, F1 was subjected to fallow after winter wheat. Black eyed peas were used as cover crop after winter wheat, on F2 in 2019 growing season. Crop per year and field area can be observed in table 2.3 in chapter 2. Each field is a center pivot irrigated system with irrigation and are 124 (F1), 184 (F2) and 116 (F3) acres.

Conventional tillage system

Soil in this field is categorized as Estacado Loam, which is described as a deep, well drained, moderately slowly permeable soil. This farm is a conventional cotton growing system subjected to tilling. The centerfield used for this investigation was divided in a half growing cotton and the other half growing corn. Each half was rotated to grow the other crop every growing season, and observations were taken from the half growing cotton. In 2019, a hailstorm destroyed the cotton seedlings early on the growing season. Because of this, the farmer decided to grow corn and the observations for that year were made on soil growing corn instead of cotton. This field is a center pivot irrigated system and is 122 acres.

Belowground measurements

Sampling for the longer study (see Chapter 2) began in June 2016 after cotton was planted on field F1. In May 2017, F2 and F3 were incorporated in addition to F1, and in August of the same year, observations started on C1. Six random sites were selected for each field at the beginning of each growing season moving from a field edge to the center of the field. Decagon Em50 data loggers with 5TM probes just below the soil surface and at 15 cm (designated as root depth) to record soil temperature and volumetric water content every 60 minutes for the extent of the growing season. Data loggers were occasionally removed for a few days or weeks depending on the farmer's needs. Loggers were set back in their original site once it was allowed. Average, minimum, and maximum temperatures were calculated for each day of data collection. Daily temperature range (DTR) was calculated by subtracting minimum daily temperature from maximum daily temperature.

Composite soil samples of approximately 300 g were collected from the upper 15 cm of soil near each data logger site for this study from May to November in 2017 and from February to September in 2018. Soils were kept cold during transit from the field to the lab, after which they were transferred to a 4 °C cold room until analyzed.

Soil microbial biomass carbon (MBC) was measured using field-moist soil within one week of collection following the chloroform-fumigation extraction technique (Brookes et al., 1985; Vance et al., 1987). Two 5 g dry weight equivalent replicates of each soil sample were fumigated with chloroform while two more replicates were kept unfumigated for 48 hours at 4 °C until extraction. Chloroform fumigations lyse the living cells of the microbial community, which release C and increase extractable C levels in the soil replicate compared to the unfumigated replicate. The four replicates were then shaken in 50 mL of 0.5M K_2SO_4 to extract soluble C compounds and filtered using Whatman Grade 43 filter paper. The filtered solution was measured spectrophotometrically at 280 nm to obtain the concentration of organic C compounds. Microbial biomass C (MBC) was calculated using the difference of the absorbance between the fumigated and the unfumigated replicates (Nunan et al., 1998). Labile organic C amounts were obtained from carbon levels obtained from the nonfumigated replicates. Extractable ammonium (NH_4^+), nitrate (NO_3^-), soil organic matter (SOM) and soil texture were measured by Waters Agricultural laboratories (Owensboro, KY, USA) within one week of sample collection. Gravimetric water content (GWC) was evaluated within one day of collection by oven-drying soils at 60 °C for 48 h to determine soil moisture conditions at the moment of sampling and to calculate the dry-weight equivalent amount of soil to be used for microbial biomass assessments and FAME levels.

Microbial community composition

Fatty acid methyl esters (FAMEs) were extracted from soil samples with the Ester-linked (EL) Extraction method. FAME analysis was carried out within two weeks of soil collection. A sub sample consisting of 3 g of dry weight equivalent was added to a glass centrifuge tube. The soil was mixed with 15 ml of 0.2 M KOH and was incubated at 37 °C for 1 hour, vortexing every 15 minutes. 3 ml of 1.0 M acetic acid were added to neutralize the pH. In order to extract the FAMEs from the acidic phase into the organic phase, 10 ml of hexane were added to the tube before centrifuging at 480 x g for 10 minutes. The hexane layer was then transferred to a clean glass tube and was evaporated under a stream of N_2. Dried FAMEs were then re-dissolved in 0.5 ml of 1:1 hexane: methyl-*tert* butyl ether and hexane containing methyl nonadecanoate (19:0) as an internal standard (0.5 mg ml – 1) (Schutter and Dick, 2000). The samples were then vortexed and transferred to a 250-µl glass insert in a 2-ml GC vial. FAME analysis was done using an Agilent 6890 N gas chromatograph with a 25 m x 0.32 mm x 0.25 µm (5 % phenyl)-methylpolysiloane Agilent HP-5 fused silica capillary column (Agilent, Santa Clara, CA) and flame ionization detector (Hewlett Packard, Palo Alto, CA) with ultra-high purity hydrogen as the carrier gas. The temperature program ramped from 170 °C to 270 °C at 5 °C min $^{-1}$, the ramped to 300 °C for 2 min to clear the column. TSBA6 aerobe program from MIDI (Microbial ID, Inc., Newark, DE) was used to perform peak identification and area calculation. Particular FAMEs were used as microbial markers. Included identified markers are for Gram-positive (GP) bacteria (*i*14:0, *a*14:0, *i*15:0, *a*15:0, *i*16:0, *a*16:0, *i*17:0, *a*17:0, *i*19:0, *a*19:0), Gram-negative (GN) bacteria (*cy*17:0 ω7c, *i*17:0 3OH, *cy* 19:0 ω7c) and Actinomycetes (10Me 16:0, 10Me 17:1 ω7c, 10Me 17:0, 10Me 18:1 ω7c, 10Me 18:0, 10Me 19:1 ω 7c). Fungal markers for Saprophytic Fungi (SF) included (18:3 ω6c, *i*18:0, 18:4 ω3c, 18:2 ω6c, 18:1 ω1c, 18:1 ω7c, 18:1 ω6c, 18:1

ω5c) and Arbuscular Mycorrhizal Fungi (AMF) (16:1 ω5c). Absolute amounts of FAMEs (nmol g $^{-1}$ soil) were calculated following (Zelles, 1999) using the 19:0 internal standard and these values were afterward used to calculate mol percent.

Enzyme activities

Enzyme activities were measured for four enzymes (β-glucosidase, β-glucosaminidase, acid phosphatase and arylsulphatase) using a combined assay for simultaneous determination following (Acosta-Martínez et al., 2019) procedure. In order to perform the experiment, 0.5 g of field-moist soil were incubated in 0.5 mL of 0.5M acetate buffer pH 5.5 with 0.5 mL of each of the four substrates prepared in the same buffer for 1 hour at 37 °C. Each sample was assessed in duplicate with a control, to which all substrates were added after incubation. After incubation, 0.5 mL of 1.0M $CaCl_2$ was added in order to have a clear filtrate. To stop the reaction, 2 mL of 0.1M THAM pH 12.0 was added. The final volume of 5 mL was filtered using a Whatman No. 2v filter and PNP released was determined colorimetrically at 400nm. Values resulting from the control duplicates were subtracted from the sample value.

Statistical analyses

Violin plots using yearly means within fields and within years for each land management approach were generated using *ggplot2* (Wickham, 2009) in RStudio (Team, 2015) to visualize the distribution of soil edaphic and microbial data for each field and across growing seasons. Data were log-transformed to homogenize the variances to perform multivariate analysis of variance (MANOVA) and determine if there were significant differences in the soil health indicators among fields per year, and for each field across time. Subsequent post hoc analyses were conducted using Tukey's honestly significant difference (HSD) with confidence interval of 95% in IBM SPSS Statistics for Windows, Version 26.

Ordinations were performed to better understand the relations between environmental and edaphic factors of each field. Discriminant function analysis (DFA) was performed on soil and environmental variables within fields across growing seasons, and between fields per year to test the probability of the observations from a given field to be classified as belonging to a different field. This analysis was done in IBM SPSS Statistics for Windows, Version 26. Principal components analysis (PCA) was also performed on soil microbial responses and environmental variables with the software Canoco 5 (ter Braak and Smilauer, 2012) using monthly means for each field per year. This allowed to compare the relationships between the indicators, and the type of land management that a field was under at a given year. In both ordination analyses, plots were generated using all variables to describe the general outcome involving all factors. However, ordinations were also done separating environmental variables from the measured soil health indicators to observe effects that may have been washed out due to confounding effects.

Results

Yearly Patterns for Environmental Parameters

For the two-year in-depth study, 2017 was one of the highest precipitation years since 2010 for the area (545 mm) while 2018 was typical of a dry year (369mm). The precipitation amount for 2018 was 37% lower than the previous year. However, irrigation would have been applied to make up this deficit for all fields as need for the specific crop. These differences in total rainfall amounts are reflected in the VWC patterns at the surface and at root-depths for the four fields. According to the two-way MANOVA, significant interaction effects at $P < 0.05$ of field and year on the environmental parameters were observed only in VWC at surface measurements (Table 3.1). Comparisons of main effects were conducted using Tukey's HSD posterior tests establishing differences at $P < 0.05$ to describe broad patterns of each environmental variable among years for each field, and to compare each environmental variable mean among fields. At the surface, only no-tilled fields F1 and F3 decreased VWC significantly from 2017 to 2018 ($P = 0.012$ for F1 and $P = 0.019$ for F3) (Figure 3.1a). Volumetric water content only decreased significantly in F1 ($P = 0.05$) at root depth (Figure 3.1b). Between field comparisons of VWC showed significant differences among all no-till fields and the conventionally managed field at surface ($P < 0.001$ with F1 and F2, and $P = 0.001$ with F3) (Figure 3.2a). The conventional-tilled field showed similar levels of VWC to most no-till fields in 2018.

Surface and root depth DTR were significantly lower in all no-till and stubble managed fields in 2017 than in 2018 ($P < 0.001$ in all fields) (Figures 3.1c and d), while no strong differences were observed at for 2017 and 2018 in the conventionally managed field. Daily temperature range comparisons showed no strong differences between the no-till fields and the conventionally managed field at any level in 2017 or 2018 (Figures 3.2c and d). Surface and Mean Temperatures were significantly lower in 2017 than in 2018 for F1 ($P = 0.041$) and F2 ($P < 0.001$), but similar levels were observed for the same years in F3 and C1 (Figure 3.1e). At rot depth, only Mean temperature of field F2 increased significantly ($P = 0.02$) (Figure 3.1f). Maximum Temperatures were significantly lower at the surface of all no-till fields in 2017 than in 2018 ($P < 0.001$ in F1 and F2, $P = 0.001$ in F3) but remained similar in the conventional managed field (Figures 3.1g). Root depth Maximum temperatures were similar from 2017 to 2018 in all fields except in F2 where levels increased significantly ($P < 0.001$) (Figure 3.1h).

Maximum and Mean Temperatures in the tilled field were similar to the no-tilled fields at all levels during the growing season (Figure 3.2g and h).

Yearly means and standard error for each environmental variable per year and field can be found in Table 3.2.

Soil Edaphic Factors Across Years

According to the two-way MANOVA, significant interaction effects at $P < 0.05$ of field and year on the edaphic parameters were observed in GWC, CEC, NO_3^--N, SOM and Labile C measurements (Table 3.1). Comparisons of main effects were conducted using Tukey's HSD posterior tests establishing differences at $P < 0.05$ to describe broad patterns of each edaphic variable and FAME indicator among years for each field, and to compare each edaphic variable and FAME indicator mean among fields. Only GWC levels of F3 and C1 increased significantly ($P = 0.002$ in F3 and $P = 0.001$ in C1) from 2017 to 2018 (Figure 3.3a). Among field comparisons showed no-tilled fields with statistically strong higher levels of GWC than C1 in both years ($P < 0.001$ in all fields in 2017 and 2018) (Figure 3.3b).

Within field comparisons across years showed no differences of Cation exchange capacity (CEC) in the no-tilled fields but indicated strong increase ($P = 0.001$) from 2017 to 2018 in C1 (Figure 3.4a). Between field comparisons of CEC showed C1 with the lowest levels in 2017 ($P < 0.001$ for all fields). In 2018, conventional-tilled field CEC had similar levels with F2, but lower levels than F1 ($P < 0.001$) and F3 ($P < 0.001$) (Figure 3.4b).

In F1 and F3, NH_4^+ increased significantly from 2017 to 2018 ($P < 0.001$ in F1 and $P = 0.011$ in F3), while F2 and C1 NH_4^+ levels remained similar from in those years (Figure 3.5a). Between field comparisons of NH_4^+ levels were similar between no-till managed fields and the conventional-till managed field in both 2017 and 2018 (Figure 3.5b). Nitrate (NO_3^-) levels increased significantly in F3 and C1 from 2017 to 2018 ($P < 0.001$ for both fields) and remained stable in F1 and F2 on the same years (Figure 3.6a). Between fields comparisons showed F1 with significantly higher NO_3^- levels than the rest of the fields in 2017 ($P < 0.001$ for F3 and C1, $P = 0.03$ for F2), while in 2018 conventional-till field and F3 had the highest levels of this nutrient (Figure 3.6b).

Soil organic matter (SOM) in the no-tilled fields was at highest levels in 2017 and decreased significantly ($P = 0.036$ in F1, $P = 0.004$ in F2, $P = 0.031$ in F3) towards 2018 (Figure 3.7a). In contrast, SOM levels in C1 were the lowest in 2017 and increased strongly ($P = 0.016$) in 2018. Between field comparisons showed that SOM levels in the conventional-tilled field were significantly lower than levels of all the no-tilled fields in 2017 ($P < 0.001$ for all fields). Similar levels were observed between C1 and F2 in 2018, both fields having significantly lower SOM levels than F1 ($P < 0.001$ for F2 and C1) and F3 ($P < 0.001$ for F2 and C1) (Figure 3.7b).

Labile carbon levels were highest in 2017 and decreased significantly in 2018 in both no-tilled and conventional-tilled fields ($P < 0.001$ for F1 and F3, $P = 0.017$ for C1) except for F2 (Figure 3.8a). Between field comparisons showed C1 Labile carbon levels had similar levels with F1 and higher levels than F2 ($P = 0.004$) and F3 ($P < 0.001$) in 2017. In 2018, the conventional-tilled field had significantly higher levels of Labile carbon ($P < 0.001$ for all fields) than every no-tilled field (Figure 3.8b).

Within field comparisons across years showed a strong decrease in Microbial Biomass Carbon (MBC) levels from 2017 to 2018 in F2 ($P < 0.001$) and C1 ($P = 0.002$), while F1 and F3 MBC levels remained similar (Figure 3.9a). Between field comparisons showed higher levels of MBC in C1 than in F1 ($P = 0.03$) and F3 ($P = 0.04$) in 2017. No significant differences were observed in levels of MBC across fields in 2018 (Figure 3.9b). Yearly means and standard error for each edaphic parameter per year and field can be found in Table 3.2. Monthly dynamics from years 2017 and 2018 for each edaphic parameter for each field can be seen in Figures 2.11 to 2.17 in chapter 2.

Enzyme activity (EA) decreased significantly from 2017 to 2019 ($P < 0.001$ in F2, $P = 0.029$ in F3 and $P = 0.045$ in C1) at each field except for F1 (Figure 3.10a) (Table 3.3). When compared among the crops for a given year, EA did not show any significant variation in any year (Figure 3.10b) (Table 3.3).

For all fields, no significant differences were observed between average microbial composition markers (FAME) and for the F:B ratios from 2017 to 2018 (Figure 3.11a to i) except for AMF in C1, in which 2017 levels where significantly higher ($P = 0.020$) than in 2018 (Figure 3.11f). Between field comparisons showed that the C1 field did have microbial levels in every FAME marker similar to one or more of the no-tilled and stubble managed fields, and that no-tilled fields shared similar levels of most FAME markers in 2017 and 2018 (Figure 3.12a to i).

All fields shared a significant increase ($P = 0.003$ in F1, $P = 0.038$ in F2, $P = 0.002$ in F3, $P = 0.012$ in C1) in the relative abundance of Actinomycetes from 2017 to 2018 (Figure 3.13 a to d). Among the no-tilled fields, Actinomycetes abundance grew from 1% to 2%, while in the conventional-tilled field the increase was 1.5%. Relative abundance of GN changed significantly only in F1 ($P = 0.027$) were it decreased 1.5% from 2017 to 2018 (Figure 3.13a). Gram-Positive bacteria relative abundance remained with no strong changes in all no-tilled fields from 2017 to 2018 but in the conventional-tilled field had a 2% significant increase ($P = 0.034$) (Figure 3.13d). Significant changes in the relative abundance of AMF were only present in F3 ($P = 0.010$) and C1 ($P = 0.004$), where levels in 2018 decreased 2% compared to 2017 (Figure 3.13c and d).

Saprophytic fungi relative abundance remained consistent with only small differences across all fields and years (Table 3.3 and Figures 3.13 to 3.22)

Microbial community relative abundances remained similar from 2017 to 2018 except in F1 where a significant decrease was observed in GN markers ($P = 0.027$) (Figure 3.23a) and in C1 where AMF markers decreased significantly ($P = 0.02$) (Figure 3.23d). Between-field comparisons in 2017 showed that all fields shared similar Actinomycete relative abundance (Figure 3.24a). In the same year, the conventional-tilled field GN relative abundance levels were significantly larger than F2 ($P = 0.013$) and F3 ($P = 0.012$) with approximately 3.5% more GN abundance than F2 and F3, but no differences were observed with F1 (Figure 3.24a). Relative abundance of GP markers was similar among the no-tilled fields while the no-tilled fields had 4.2% more GP levels higher levels of GP markers than in the conventional field. Relative abundance of AMF markers in 2017 was significantly higher in F3 ($P < 0.001$) than for all other fields indicting the positive impacts of the mixed cover crop (5 % increase) that was planted in 2017 (see table 2.3). The highest relative abundance of Saprophytic fungi was observed in C1, with no strong differences between F1 and F2, but significantly higher levels than F3 ($P < 0.001$) with 6% more relative abundance. In 2018, all fields shared similar relative abundance of GN and GP. Actinomycete relative abundances was significantly higher in F1 ($P < 0.001$) and F2 ($P = 0.003$) than in the conventional-tilled field, having 3.3% more (Figure 3.24b). Arbuscular Mycorrhizal Fungi relative abundance was significantly higher in fields F2 ($P < 0.001$) and F3 ($P = 0.001$), while levels of saprophytic fungal relative abundance were significantly higher ($P < 0.001$ for all fields) in the conventional-till field than in the no-tilled fields (Figure 3.24b).

Discriminant Function Analyses

Misclassification of year was low as indicated by DFA using environmental, edaphic parameters and FAME markers datasets in each field. Highest misclassification (5.2%) was observed in F2, while lowest misclassification was seen in F3 (1.2%) (Table 3.4). Discriminant function analysis done between fields per year showed lower misclassification in 2017 (8.7%) than in 2018 (14.4%), which emphasizes the impact of rainfall on soil microbial parameters (Figures 3.25a and b) (Table 3.5). In the wet year (2017) no-tilled fields were misclassified as another no-tilled field and not as the conventional field. In the dry year (2018) misclassification of C1 was highest among all fields indicating that the conventional field had the most variable responses.

Principal Component Analyses

Principal component analysis showed no defined structure to the impacts of crop management practices for 2017 and 2018 observations when every field was included in the analysis using all edaphic, environmental, and microbial parameters (Figure 3.26a to d). Total explained variation ranged between 41.3% and 47.1% in the no-till fields and was 46.7% in the conventional-tilled field. Between-fields PCA in 2017 showed slight segregation between no-till fields F1 and F3 across the second component (Figure 3.27a). This segregation showed F3 with positive associations with all FAME markers while generally having a negative interaction with NO_3^-. In 2018, field separation was observed between F2 and F3 across the Y axis, while F1 and C1 overlapped with all fields (Figure 3.27b). No strong interactions were observed between FAME markers and any of the fields. Total explained variation in was 49.4% in 2017, and 45.5% in 2018. In both years, FAME markers contributed most strongly to the first component. In 2017, Maximum and Mean temperature, GWC and VWC contributed most to the second component, while in 2018, the second component was mostly influenced by CEC and SOM.

Redundancy Analyses

Redundancy analysis was used to describe the response of FAMEs to the soil biotic and abiotic factors observed during 2017 and 2018. In 2017, FAME markers of all no-tilled fields were negatively related to Mean and Max Temperature (F1 and F3) or DTR (F2) (Figure 3.28a, b and c). The same fields were observed to have positive relations between FAMEs and Labile C and MBC in 2017. Soil Organic Matter and FAMEs were observed with strong positive relations only in F2 during the same year. In the conventional-till field, all FAME markers had a strong negative relation with NO_3^-, pH and CEC (Figure 3.28d). Gram Negative bacteria (GN) and AMF also had negative relations with DTR and Labile C, while being positively affected by MBC and VWC for the conventional-till field (Figure 3.28d). In 2018, FAME markers from all no-tilled fields were negatively related to Max and Mean Temperature as would be expected during a hot and dry year (Figure 3.29a, b and c)). In fields F2 and F3, FAME markers also had negative interactions with pH, NH_4^+ and VWC. The conventional-till field showed FAME markers of Actinomycetes, GP and SF with strong negative relations with DTR, while AMF and GN was negatively related to CEC, Maximum and Mean Temperature (Figure 3.29d).

Across both years, FAMEs in the no-tilled systems were negatively affected by Maximum and Mean temperature, except for AMF in F1 (Figure 3.30a, b and c). In the same fields, positive relations were consistently observed between FAME markers and Labile C and MBC. FAMEs from the conventional-tilled system that were negatively affected by Maximum and Mean Temperature and DTR were GN and AMF, also with strong negative associations with

CEC and NO_3^- (Figure 3.30d). Actinomycetes, GP, and SF were observed with positive associations to Labile C and NH_4^+.

Discussion

Seasonal comparisons of microbial community structure linked with microbial functionality (MBC, FAMEs, and enzyme activity) to soil management approaches used in growing cotton on the semi-arid SHP showed no substantial differences in responses among the no-till stubble managed fields and the conventional-till field during two years of observations. These outcomes indicate that adding a more detailed assessment of microbial community structure (FAME) in addition to the widely used measurements of microbial biomass carbon did not provide greater resolution of impacts of the two soil management approaches under center pivot irrigation. Even when enzyme activity was included (microbial function) the yearly levels were similar between the conventional tilled and no-till and stubble managed systems despite major soil disturbance within the conventional production system. Thus, for these irrigated cotton production systems for the two years of the study, these additional microbial characteristics of detailed structure and function did not provide greater resolution to understanding differences in microbial benefits to soil health from using no-till and stubble management over conventional tillage under cotton. While a more detailed resolution of soil microbial structure is crucial for assessing how the microbial community is changing, FAME analysis on its own may not be informative enough to be able to link soil health changes from year to year over the short-term. For understanding large scale impacts on soil health in a semi-arid environment moisture availability is likely a key driver of the capacity to build a positive trajectory in soil health when moving from conventional tillage practices to non-till and stubble management.

Previous studies have shown that microbial community composition is influenced strongly by soil water content in semi-arid soils (Clark et al., 2009; Cregger et al., 2012), and changes in the microbial community are likely to be observed when water stress is present. Detailed descriptions of soil microbial communities during a record drought on the SHPT found that while fungal and bacterial communities and EAs decreased through the extent of the drought, fungal communities were able to recover faster than bacterial communities (Acosta-Martinez et al., 2014a). Moreover, the study found that fungal and bacterial assemblages that were more resilient after the drought period were associated with greater individual EAs related to C, N, P and S cycling in fields with crop rotation regimes. This suggests that management strategies that incorporate plant diversity like crop rotation or the use of cover crops benefits diversification of microbial communities not only structurally but also functionally.

Crop type, environment and age of the field used all have been shown to have a substantial role in determining the bacterial community associated with a crop's rhizosphere in the mesic system (Walters et al., 2018). Not surprisingly, among the no-till fields, strong differences were observed between F3, and F1 and F2 FAMEs indicating the influences of crop type and soil structure even under a semi-arid environment. From early to mid-2017 F3 was planted with winter wheat. During the summer the farmer planted a mix cover crop composed of grasses, legumes, and radish. Plant diversity benefits microbial communities because diversity in rhizodeposition and detritus becomes available as resources for a wider variety of microbes (Zak et al., 2003). Winter wheat followed by the mixed cover crop created a prolonged period of time in which a variety plant inputs from litter and rhizodeposition supported a diverse and active microbial communities (Garland et al., 2021) while reinforcing conditions that promoted soil health, such as buffering soil temperature variability and enhancing soil water retention capability through surface shading. Studies point directly at crop diversity as the factor affecting microbial community shifts (Tiemann et al., 2015; Yao et al., 2006). However a recent large-spatial scale study across environmental gradients observed that variation appears and disappears with changes in environmental factors, indicating that effect of crop diversity on the subsequent level of soil microbial biodiversity may be regulated by large scale environmental control (Garland et al., 2021). Although the rest of the fields in this study did not grow prolonged cover crops like F3 during 2017, soil temperature variation and water content did not differ drastically; maintaining a relatively similar soil environment despite tillage and different crops were grown, and therefore, maintaining similar microbial communities and EAs.

While differences in microbial community structure, composition, and functionality were modest at best to soil management strategies under center pivot irrigation of cotton production systems, the DFAs and RDAs of the detailed microbial data and environmental parameters showed a more significant and long-term trajectory toward a positive outcome for the no-till and stubble managed soils. Low misclassification of no-till observations as compared with the conventional-till observations in the DFAs indicates that variation of soil factors thorough the growing seasons allowed ecological dynamics to behave differently enough so that observations did not overlap frequently. That is, the conventional system had a more chaotic microbial response across the growing season and years to changing environmental conditions than did the no-tilled and stubbled managed fields. These negative outcomes under the conventional management systems were also expressed in the nitrogen dynamics within this field. The strong negative relationship between FAME levels and levels of extractable NO_3^- -N and NH_4^+ -N in the conventional-tilled field may represent an uncoupling of crucial aspects of soil nitrogen dynamics from microbial control (Berthrong et al., 2013) and linking rates of nitrogen mineralization to abiotic control. The steady levels of extractable nitrogen observed in the no-tilled fields, even with fertilization would suggests that nitrogen dynamics are regulated by immobilization/mineralization processes mediated by the microbial community across the growing season irrespective of abiotic conditions. FAME levels in the no-tilled fields were also positively associated with Labile C indicating that the availability of adequate carbon may be one aspect of soil health that is necessary to stabilize crucial soil processes, which is a benefit from no-till and stubble managed systems and which does not happen with high soil disturbance. This positive association, not observed in the conventional-tilled field, also suggests better conditions in the no-tilled fields because availability of labile substrates may lead to increase in microbial biomass and higher stabilization of soil organic matter that will allow for increase mineralized N available for plants through higher microbial turnover (Dijkstra et al., 2009; Hamilton III and Frank, 2001). Understanding the intertwined C and N dynamics is essential to better tailor land management recommendations to farmers switching from conventional agriculture methods, emphasizing that on the long-term, these adjustments in management practices may lead to systems that can rely on a local N supply with reduced fertilizer applications and reduce fertilizer demands. For irrigated systems in a semi-arid environment of the SHPT, the measure of the capacity to build soil health using no-till and stubble management may be more effectively evaluated using aspects of the C and N dynamics as they are linked to the traditional metrics of MBC, community structure or enzyme production and the regulation of these process by environmental constraints. Ultimately, you would want to see a positive trajectory of these outcomes as was shown in the RDAs from this investigation.

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Tables

Table 3.1. Mean and the standard error of environmental and edaphic variables and FAME indicators under field irrespective of year, year irrespective of field, and P value from a two-way MANOVA. Values in bold are significant at P < 0.05.

Variables	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	2017 (Mean ± SE)	2018 (Mean ± SE)	Field *P* value	Year *P* value	Field x Year *P* value
VWC 0 cm (°C)	17.1 ± 0.7	20.7 ± 0.5	16.7 ± 0.7	13.5 ± 1.2	18.4 ± 0.6	16.8 ± 0.4	**<0.001**	0.171	**<0.001**
VWC 15 cm (°C)	24.5 ± 0.4	23.7 ± 0.2	22.0 ± 0.8	18.0 ± 1.3	22.7 ± 0.6	22.5 ± 0.4	**0.002**	0.243	0.857
DTR 0 cm (°C)	5.9 ± 0.4	6.8 ± 0.5	5.3 ± 0.5	7.8 ± 0.8	3.5 ± 0.2	8.9 ± 0.3	**<0.001**	**<0.001**	0.105
DTR 15 cm (°C)	2.0 ± 0.1	3.1 ± 0.4	2.3 ± 0.2	3.3 ± 0.3	1.6 ± 0.08	3.5 ± 0.1	**0.004**	**<0.001**	0.126
Max T 0 cm (°C)	22.1 ± 0.9	22.9 ± 0.9	20.8 ± 0.9	21.7 ± 1.2	18.6 ± 0.5	25.1 ± 0.7	**0.027**	**<0.001**	0.45
Max T 15 cm (°C)	19.5 ± 0.7	20.5 ± 0.2	19.1 ± 0.8	20.0 ± 1.1	18.0 ± 0.5	21.4 ± 0.6	**0.043**	0.462	0.343
Mean T 0 cm (°C)	18.4 ± 0.8	18.6 ± 0.7	17.6 ± 0.7	16.7 ± 1.2	16.3 ± 0.5	19.6 ± 0.6	**0.028**	**<0.001**	0.547
Mean T 15 cm (°C)	18.4 ± 0.7	18.8 ± 0.7	17.7 ± 0.7	18.0 ± 1.1	17.0 ± 0.5	19.5 ± 0.5	0.088	0.808	0.413
GWC (%)	15.9 ± 0.3	14.8 ± 0.2	16.3 ± 0.3	11.6 ± 0.5	14.9 ± 0.2	15.2 ± 0.2	**<0.001**	0.775	**<0.001**
CEC (meq/100g)	25.9 ± 0.1	21.1 ± 0.1	25.8 ± 0.2	20.5 ± 0.6	23.4 ± 0.3	24.0 ± 0.2	**<0.001**	**<0.001**	**<0.001**
NH4 (µg/g)	1.8 ± 0.06	1.9 ± 0.08	2.2 ± 0.07	2.4 ± 0.2	1.7 ± 0.05	2.3 ± 0.09	**<0.001**	**<0.001**	0.09
NO3 (µg/g)	9.2 ± 0.7	7.8 ± 0.4	9.3 ± 0.7	20.7 ± 4.0	7.3 ± 0.4	13.1 ± 1.1	0.688	**<0.001**	**<0.001**
SOM (%)	1.5 ± 0.03	1.2 ± 0.02	1.6 ± 0.03	1.07 ± 0.04	1.4 ± 0.02	1.3 ± 0.03	**<0.001**	**0.015**	**<0.001**
Labile C (µg/g)	1095.3 ± 34.7	1137.1 ± 29.9	959.7 ± 25.4	1423.7 ± 41.2	1240.1 ± 27.2	1023.8 ± 21.3	**<0.001**	**<0.001**	**0.044**
MBC (µg/g)	313.8 ± 23.1	343.0 ± 26.2	317.4 ± 23.2	366.2 ± 35.1	390.2 ± 20.5	286.5 ± 16.0	0.555	**<0.001**	0.122
Total FAMEs (nmol/g)	86.9 ± 3.2	96.5 ± 0.7	122.4 ± 4.5	102.4 ± 3.5	17.0 ± 0.6	19.5 ± 0.6	**<0.001**	0.804	0.721
Total Bacteria (nmol/g)	54.4 ± 1.9	58.0 ± 4.5	72.6 ± 2.6	61.3 ± 0.7	17.0 ± 0.7	19.5 ± 0.7	**<0.001**	0.755	0.599
Total Fungi	31.5 ± 1.3	36.3 ± 1.9	47.3 ± 1.9	39.6 ± 2.5	17.0 ± 0.8	19.5 ± 0.8	**<0.001**	0.979	0.898
Fungal:Bacterial Ratio	0.5 ± 0.01	0.61 ± 0.01	0.65 ± 0.01	0.65 ± 0.01	17.0 ± 0.9	19.5 ± 0.9	**0.003**	0.687	0.31
Saprophytic Fungi (nmol/g)	24.0 ± 1.1	25.4 ± 1.5	30.5 ± 1.5	31.7 ± 1.2	17.0 ± 0.10	19.5 ± 0.10	**<0.001**	0.783	0.526
AMF (nmol/g)	7.4 ± 0.1	10.9 ± 0.5	16.8 ± 0.7	7.9 ± 0.5	17.0 ± 0.11	19.5 ± 0.11	**<0.001**	0.406	0.235
Gram Positive (nmol/g)	21.9 ± 0.8	23.4 ± 1.0	29.4 ± 1.1	23.5 ± 0.7	17.0 ± 0.12	19.5 ± 0.12	**<0.001**	0.713	0.465
Gram negative (nmol/g)	19.5 ± 0.7	21.7 ± 1.0	27.6 ± 1.0	25.4 ± 1.9	17.0 ± 0.13	19.5 ± 0.13	**<0.001**	0.56	0.566
Actinomycetes (nmol/g)	12.9 ± 0.4	12.7 ± 0.4	15.5 ± 0.5	12.3 ± 0.3	17.0 ± 0.14	19.5 ± 0.14	**<0.001**	**0.044**	0.523

Table 3.2. Yearly means (± Standard Error) of soil variables from 2017 and 2018 growing season from a no-till and stubble system (F1, F2 and F3) and a conventional-tilled (C1) cotton production systems in semi-arid west Texas.

	2017				2018			
Variables	**F1 (Mean ± SE)**	**F2 (Mean ± SE)**	**F3 (Mean ± SE)**	**C1 (Mean ± SE)**	**F1 (Mean ± SE)**	**F2 (Mean ± SE)**	**F3 (Mean ± SE)**	**C1 (Mean ± SE)**
MBC (µg/g)	345.5 ± 36.2	462.6 ± 45.6	321.0 ± 28.5	525.1 ± 54.1	289.2 ± 29.8	249.9 ± 24.0	314.2 ± 36.1	295.6 ± 39.6
Labile C (µg/g)	1310.0 ± 53.3	1228.4 ± 50.5	1075.9 ± 35.9	1579.4 ± 50.0	928.4 ± 30.6	1066.1 ± 33.1	856.4 ± 29.6	1354.5 ± 51.4
NH4(µg/g)	1.5 ± 0.07	1.8 ± 0.1	1.9 ± 0.07	1.8 ± 0.1	2.1 ± 0.08	2.0 ± 0.1	2.4 ± 0.1	2.7 ± 0.4
NO3(µg/g)	10.8 ± 1.2	6.8 ± 0.4	5.5 ± 0.4	4.4 ± 0.8	8.07 ± 0.7	8.6 ± 0.5	12.6 ± 1.2	27.9 ± 5.3
SOM (%)	1.6 ± 0.03	1.3 ± 0.02	1.7 ± 0.03	0.8 ± 0.07	1.4 ± 0.04	1.1 ± 0.04	1.5 ± 0.06	1.1 ± 0.05
CEC (meq/100g)	25.5 ± 0.2	20.8 ± 0.3	26.0 ± 0.4	17.1 ± 0.9	26.2 ± 0.2	21.4 ± 0.2	25.7 ± 0.3	22.1 ± 0.7
pH	8.1 ± 0.02	8.1 ± 0.04	7.9 ± 0.03	7.9 ± 0.1	8.0 ± 0.02	8.2 ± 0.02	7.8 ± 0.02	8.2 ± 0.03
GWC (%)	16.7 ± 0.4	14.6 ± 0.4	15.5 ± 0.4	9.3 ± 0.7	15.3 ± 0.4	15.1 ± 0.3	17.1 ± 0.4	12.6 ± 0.6
VWC 0 cm (°C)	19.7 ± 1.0	21.8 ± 0.9	20.7 ± 1.2	19.3 ± 2.1	14.3 ± 0.9	20.1 ± 0.5	16.2 ± 0.7	18.7 ± 1.3
VWC 15 cm (°C)	25.3 ± 0.5	24.3 ± 0.7	26.3 ± 1.5	21.3 ± 2.3	22.1 ± 0.7	24.9 ± 0.6	23.6 ± 0.9	23.2 ± 1.4
DTR 0 cm (°C)	3.0 ± 0.2	2.9 ± 0.3	2.4 ± 0.3	3.7 ± 1.0	10.2 ± 0.7	10.9 ± 0.5	8.1 ± 0.7	9.2 ± 1.1
DTR 15 cm (°C)	1.2 ± 0.09	1.6 ± 0.1	1.2 ± 0.1	1.5 ± 0.5	2.9 ± 0.2	4.8 ± 0.3	3.6 ± 0.3	3.4 ± 0.4
Max T 0 cm (°C)	22.2 ± 1.1	20.8 ± 1.1	21.2 ± 1.2	22.5 ± 1.4	30.8 ± 1.3	31.2 ± 1.1	27.4 ± 1.0	29.0 ± 1.5
Max T 15 cm (°C)	21.3 ± 1.6	20.3 ± 0.9	21.5 ± 0.9	21.0 ± 1.8	25.1 ± 1.3	26.4 ± 1.1	23.8 ± 0.9	25.0 ± 1.3
Mean T 0 cm (°C)	20.0 ± 1.0	18.8 ± 1.0	19.5 ± 1.2	19.6 ± 1.6	24.3 ± 1.3	24.4 ± 1.1	22.5 ± 1.0	23.5 ± 1.5
Mean T 15 cm (°C)	20.5 ± 0.9	19.3 ± 0.9	20.3 ± 1.2	20.0 ± 1.7	23.4 ± 1.3	23.9 ± 1.1	21.8 ± 0.9	22.9 ± 1.3

Table 3.3. Yearly means (± Standard Error) of total enzyme activities from 2017, 2018 and 2019 growing season from a no-till and stubble system (F1, F2 and F3) and a conventional-tilled (C1) cotton production systems in semi-arid west Texas.

	2017				2018				2019			
	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)	F1 (Mean ± SE)	F2 (Mean ± SE)	F3 (Mean ± SE)	C1 (Mean ± SE)
Enzyme Avtivity (mg PNP kg−1 soil h−1)	207.1 ± 23.4	297.7 ± 43.7	298.7 ± 24.3	206.6 ± 18.5	186.7 ± 27.9	224.0 ± 19.4	258.0 ± 23.6	166.1 ± 16.8	139.8 ± 23.9	98.5 ± 7.8	194.0 ± 43.3	126.7 ± 24.1

Table 3.4. Yearly means (± Standard Error) of FAME markers and relative abundance from 2017 and 2018 growing season from a no-till and stubble system (F1, F2 and F3) and a conventional-tilled (C1) cotton production systems in semi-arid west Texas.

	2017				2018			
Variables	**F1 (Mean ± SE)**	**F2 (Mean ± SE)**	**F3 (Mean ± SE)**	**C1 (Mean ± SE)**	**F1 (Mean ± SE)**	**F2 (Mean ± SE)**	**F3 (Mean ± SE)**	**C1 (Mean ± SE)**
Total FAME (nmol/g)	85.1 ± 5.9	97.0 ± 6.6	120.3 ± 5.7	103.4 ± 5.5	88.2 ± 3.7	96.2 ± 6.2	124.4 ± 7.1	102.1 ± 4.3
Bacteria (nmol/g)	53.0 ± 3.3	58.1 ± 3.6	69.9 ± 3.3	60.8 ± 3.4	55.3 ± 2.2	57.9 ± 3.4	75.3 ± 4.2	61.5 ± 3.1
Fungi (nmol/g)	31.5 ± 2.3	36.5 ± 2.9	47.8 ± 2.5	40.7 ± 2.1	31.4 ± 1.6	36.2 ± 2.6	46.9 ± 3.0	39.2 ± 1.9
Fungi:Bacteria	0.5 ± 0.01	0.6 ± 0.02	0.6 ± 0.02	0.6 ± 0.01	0.5 ± 0.01	0.6 ± 0.01	0.6 ± 0.02	0.6 ± 0.02
Saprophytic (nmol/g)	23.9 ± 1.9	26.2 ± 2.2	29.2 ± 1.8	30.8 ± 1.4	24.2 ± 1.5	24.8 ± 2.1	31.7 ± 2.4	31.9 ± 1.6
AMF (nmol/g)	7.5 ± 0.5	10.3 ± 0.8	18.5 ± 1.2	9.8 ± 1.0	7.2 ± 0.4	11.3 ± 0.7	15.1 ± 0.9	7.2 ± 0.5
Gram P (nmol/g)	21.6 ± 1.5	23.8 ± 1.5	28.2 ± 1.4	22.2 ± 1.1	22.1 ± 0.9	23.2 ± 1.4	30.7 ± 1.8	23.9 ± 0.9
Gram N (nmol/g)	19.5 ± 1.2	21.9 ± 1.6	27.0 ± 1.3	27.2 ± 2.2	19.5 ± 0.8	21.6 ± 1.4	28.2 ± 1.6	24.9 ± 2.5
Actinomycetes (nmol/g)	11.7 ± 0.7	12.3 ± 0.6	14.6 ± 0.6	11.3 ± 0.5	13.6 ± 0.4	13.0 ± 0.5	16.3 ± 0.7	12.6 ± 0.4
RA Actinomycetes (%)	13.9 ± 0.4	13.3 ± 0.3	12.4 ± 0.2	11.1 ± 0.4	15.9 ± 0.3	14.2 ± 0.2	13.5 ± 0.2	12.6 ± 0.3
RA GN (%)	23.4 ± 0.6	22.4 ± 0.4	22.3 ± 0.2	25.9 ± 1.1	22.0 ± 0.2	22.3 ± 0.2	22.8 ± 0.3	23.9 ± 1.2
RA GP (%)	25.8 ± 0.7	24.8 ± 0.3	23.4 ± 0.4	21.5 ± 0.5	25.1 ± 0.2	24.3 ± 0.3	24.6 ± 0.3	23.6 ± 0.4
RA AMF (%)	9.4 ± 0.6	10.5 ± 0.5	15.5 ± 0.8	9.3 ± 0.6	8.4 ± 0.4	12.1 ± 0.6	12.5 ± 0.5	7.0 ± 0.3
RA Saprophytic (%)	28.4 ± 1.2	26.4 ± 0.6	23.9 ± 0.4	30.1 ± 0.8	26.8 ± 0.5	25.0 ± 0.3	24.7 ± 0.8	31.3 ± 0.8

Table 3.5. Discriminant function analysis outcomes for the classification of no-till fields (F1, F2, F3) and conventional tilled fields (C1) using edaphic and environmental variables, and FAME markers within fields for each growing season and across years. Percentage of cases that kept original classification per field: F1: 97.1%, F2: 94.8%, F3: 98.8% and C1: 97.1%.

	F1		F2		F3		C1	
	Predicted membership (%)		Predicted membership (%)		Predicted membership (%)		Predicted membership (%)	
Year	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
2017	97.1	2.9	94.4	5.6	97.3	2.7	85.7	14.3
2018	2.9	97.1	4.9	95.1	0	100	0	100

Table 3.6. Discriminant function analysis outcomes for the classification of crop management types (no-till = F1, F2, & F3) and Conventional tillage (C1) within years, (2017 and 2018) using edaphic and environmental variables, and FAME markers. Percentage of cases that kept original classification for 2017: 91.3% and 2018: 88.8%.

	2017				2018			
	Predicted membership (%)				Predicted membership (%)			
Field	**F1**	**F2**	**F3**	**C1**	**F1**	**F2**	**F3**	**C1**
F1	88.6	8.6	2.9	0	85.7	5.7	5.7	2.9
F2	5.6	94.4	0	0	0	100	0	0
F3	10.8	0	89.2	0	9.3	4.7	83.7	2.3
C1	0	0	0	100	4.2	12.5	0	83.3

Figures

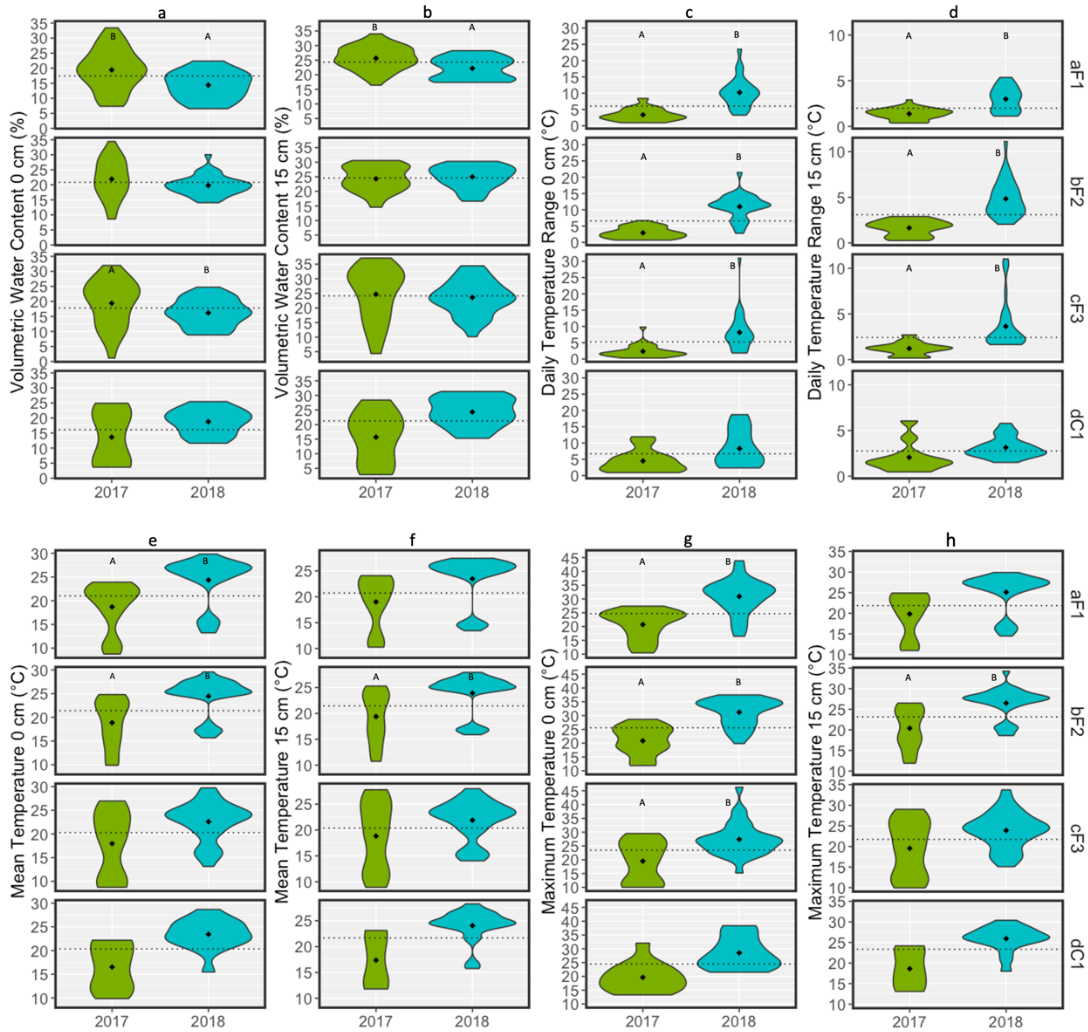

Figure 3.1. Among-year comparisons of each field's yearly mean measurements of: volumetric water content (a and b), daily temperature range (c and d), mean temperature (e and f), and maximum temperature (g and h) just below the soil surface (1 cm) and root depth (15 cm) across years 2017 and 2018 in F1, F2, F3 and C1. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences. No-till and stubble managed fields = F1, F2, and F3. Conventional Field = C1.

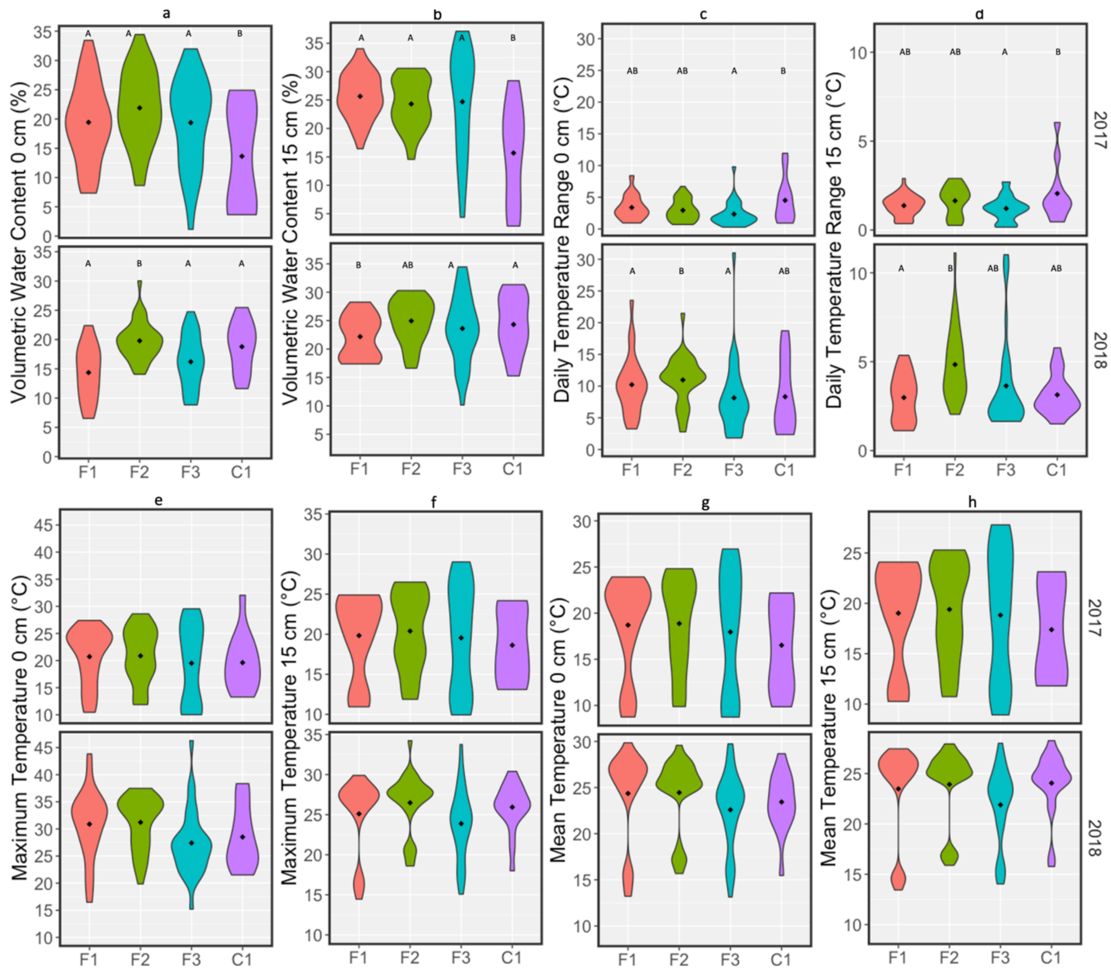

Figure 3.2 Among-fields comparisons of yearly mean measurements of: volumetric water content (a and b), daily temperature range (c and d), mean temperature (e and f), and maximum temperature (g and h) just below the surface (1 cm) and root depth (15 cm) for 2017 and 2018. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences. Field designations are presented in Figure 3.1.

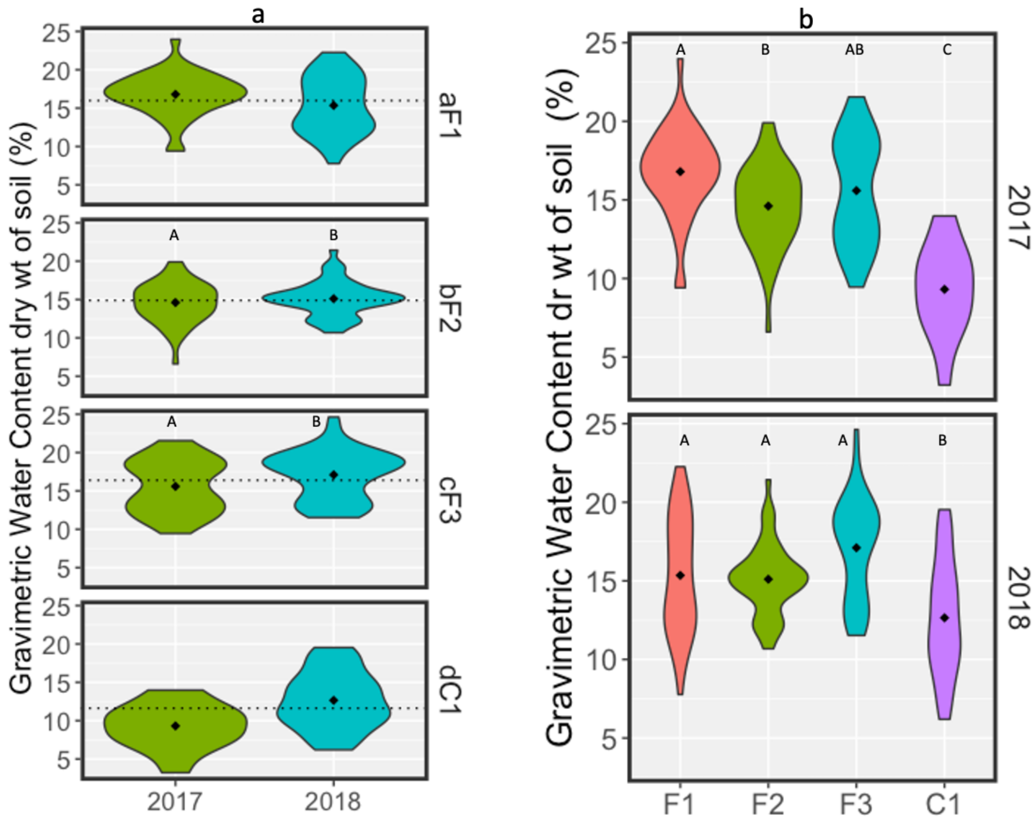

Figure 3.3. Gravimetric water content comparisons of each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

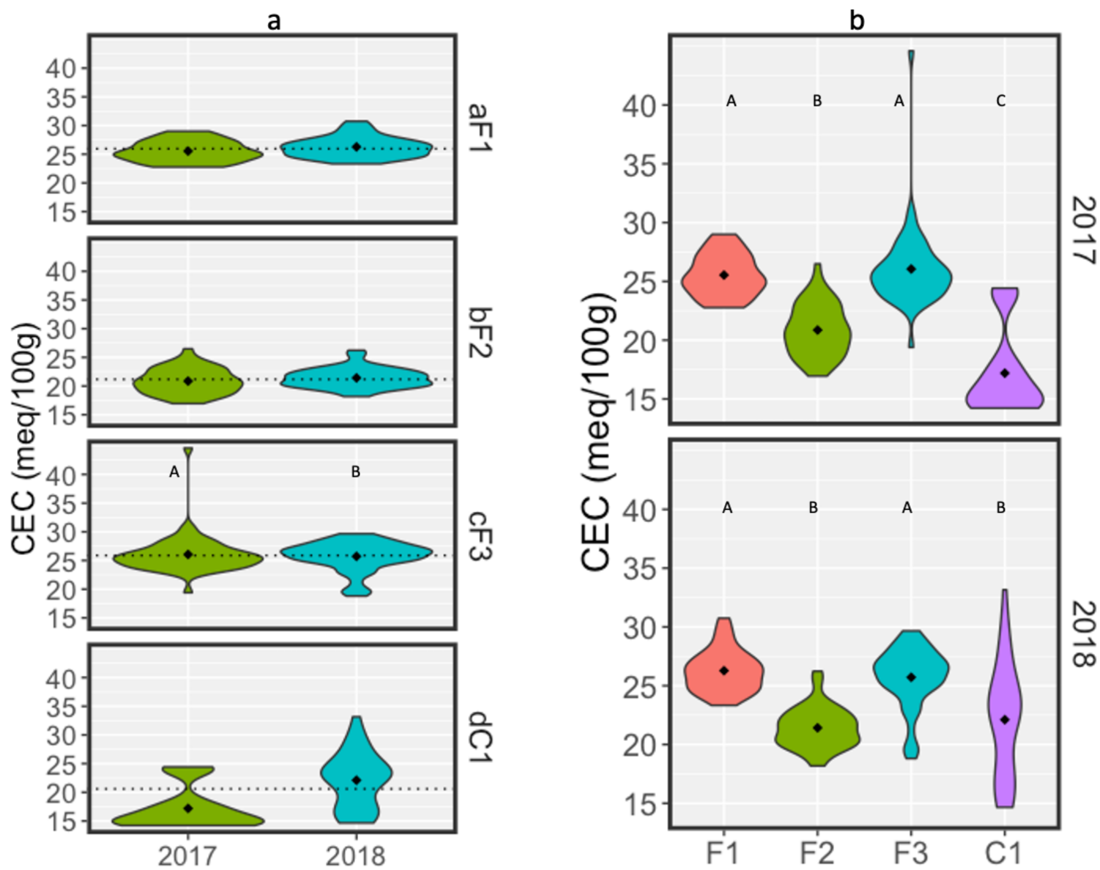

Figure 3.4. Cation exchange capacity of each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

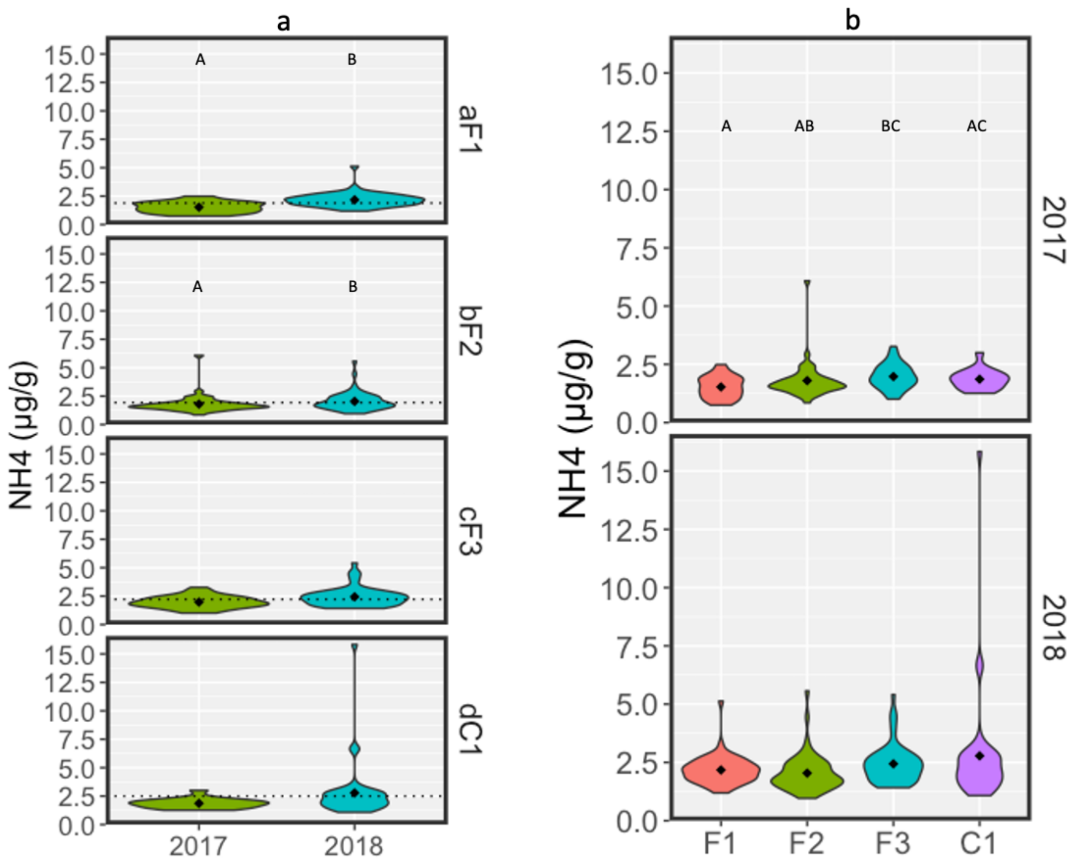

Figure 3.5. Extractable levels of NH_4^+-N for each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field C1 in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

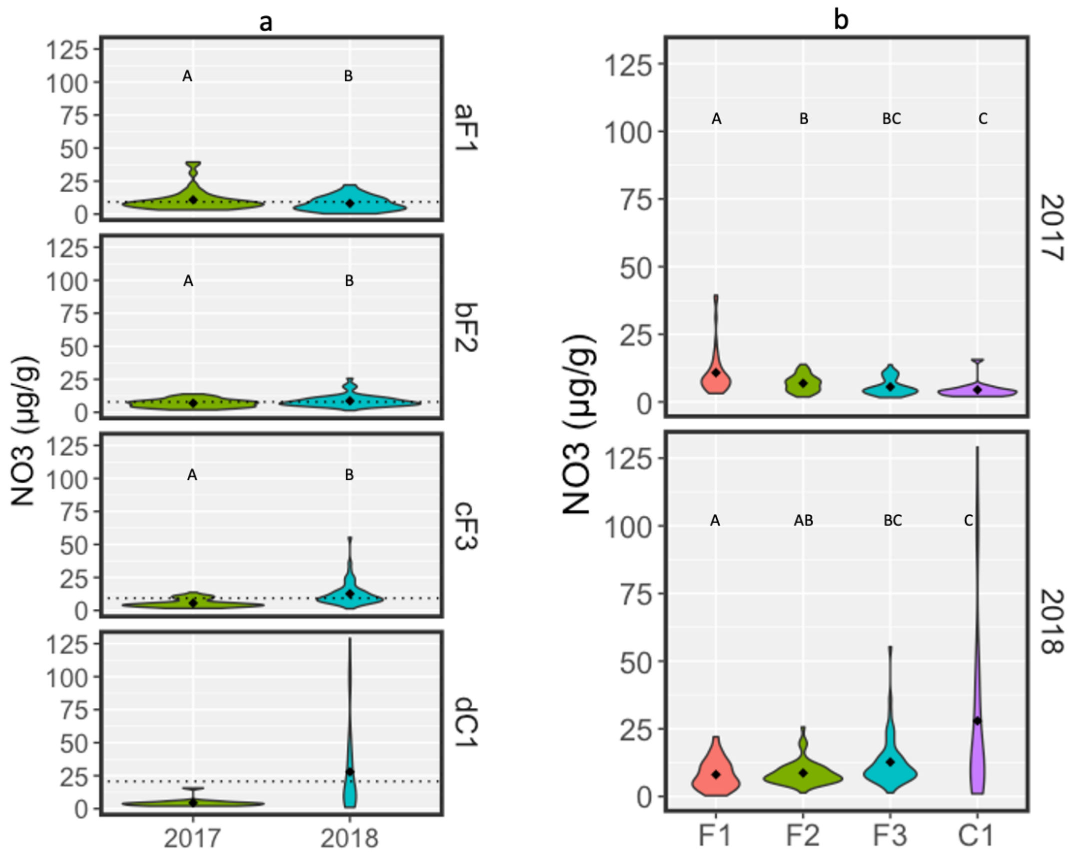

Figure 3.6. Extractable levels of NO_3^--N for each field across years (a) and among fields on a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

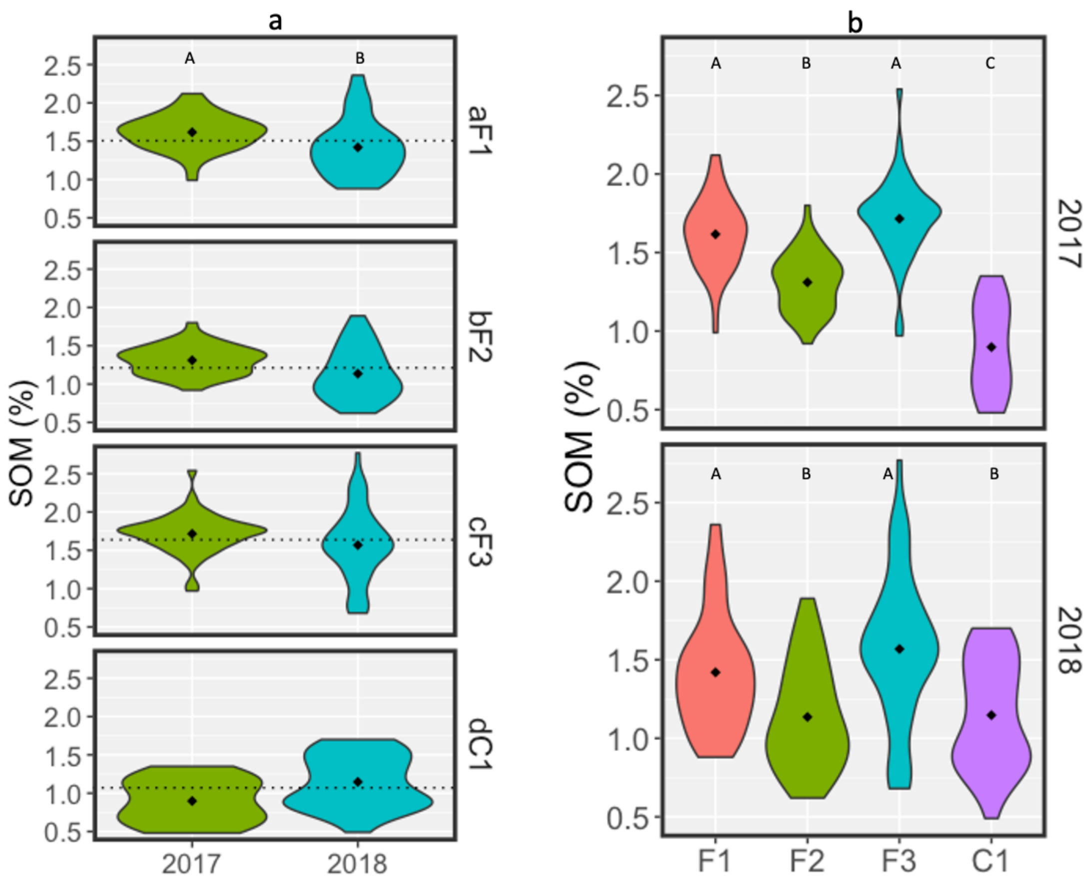

Figure 3.7. Soil organic matter levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

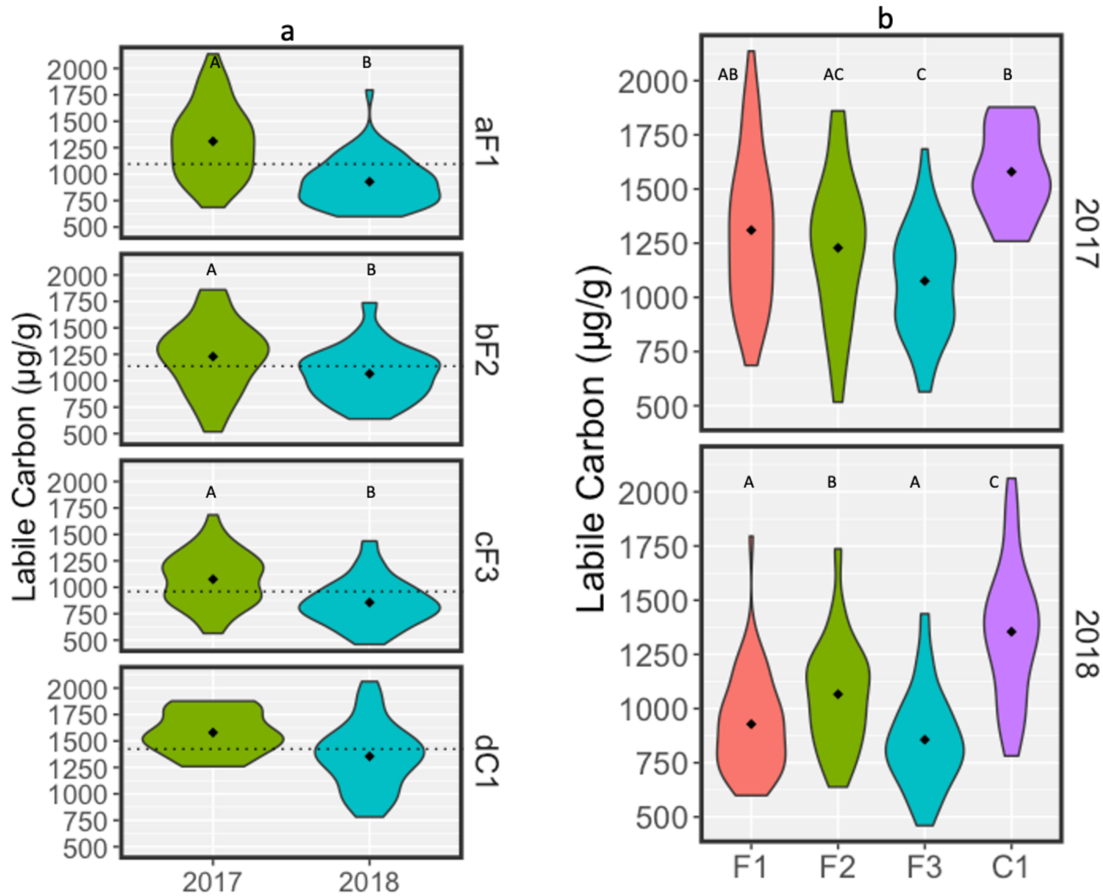

Figure 3.8. Labile carbon levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F)3, and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

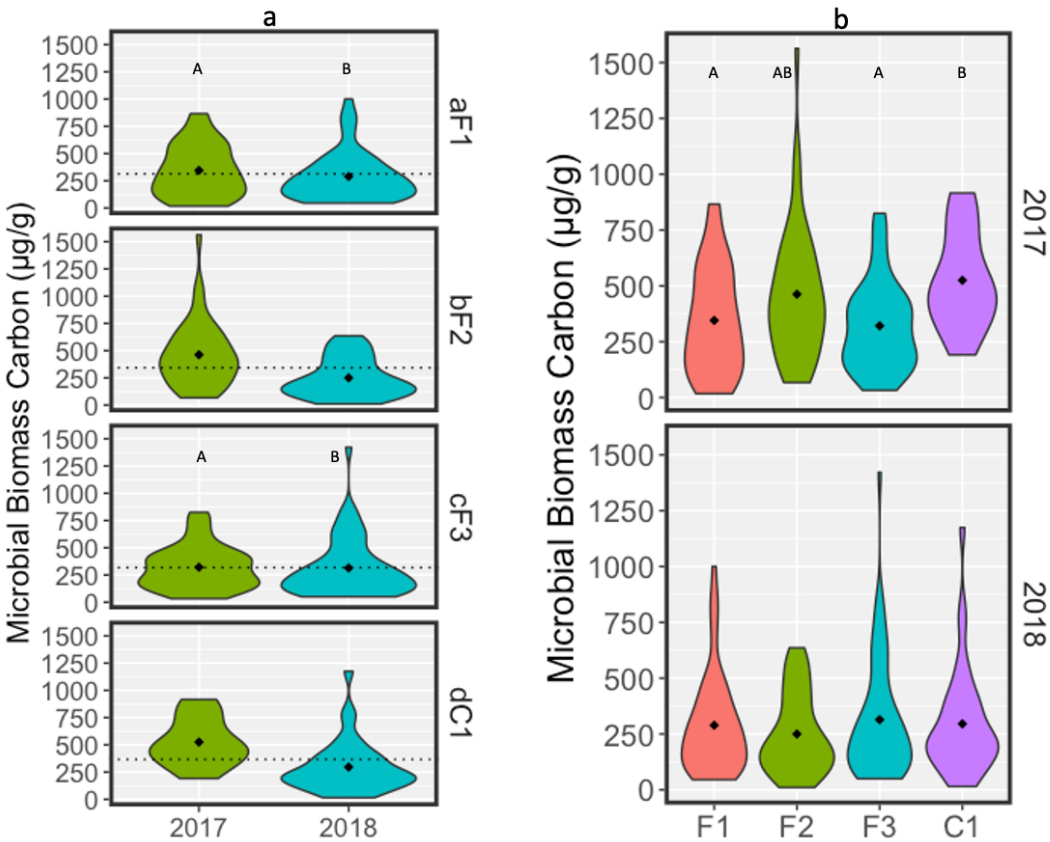

Figure 3.9. Microbial biomass carbon levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

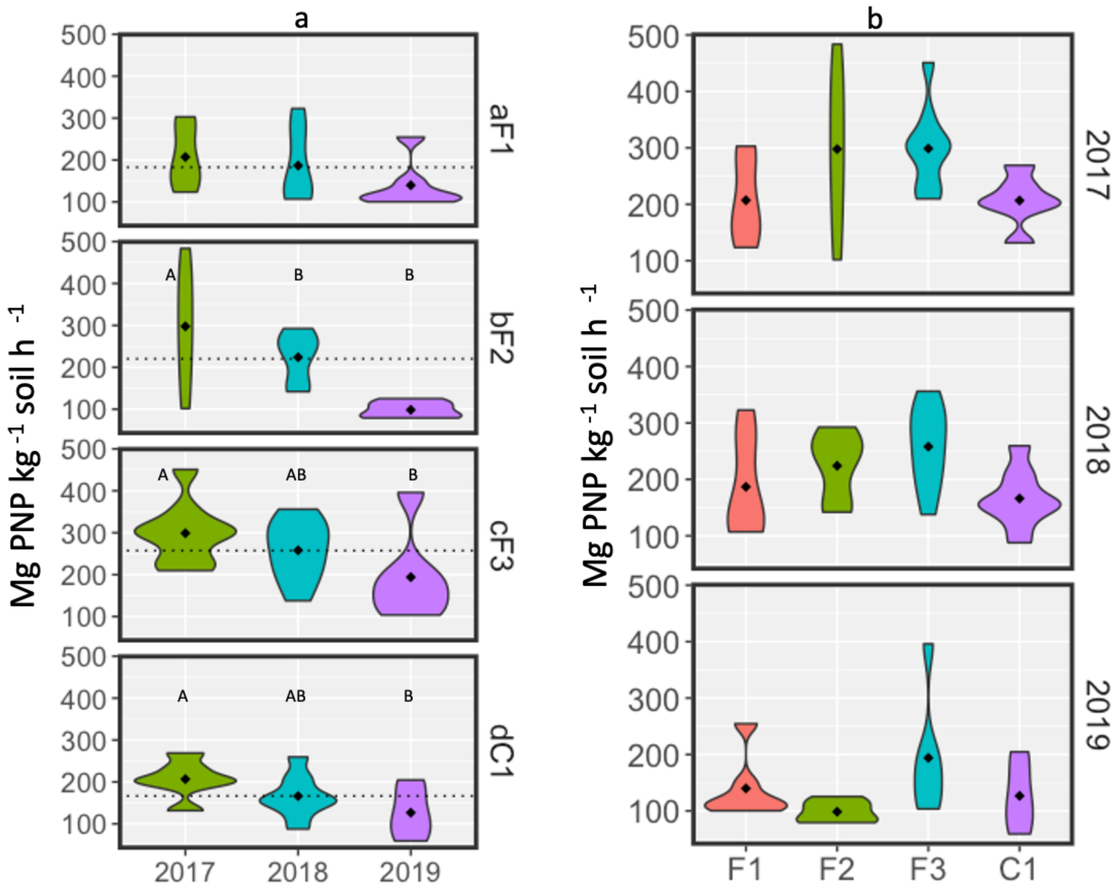

Figure 3.10. Enzyme activity levels of each field across years (a) and among fields in a given year (b) of no-till and stubble fields (F1, F2, F3), and conventional-till field (C1) in semi-arid west Texas. Values represent the mean of: no-till fields 2017 n = 9, 2018 n = 9, 2019 n = 9; conventional-till field 2017 n = 9, 2018 n = 9, 2019 n = 6. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

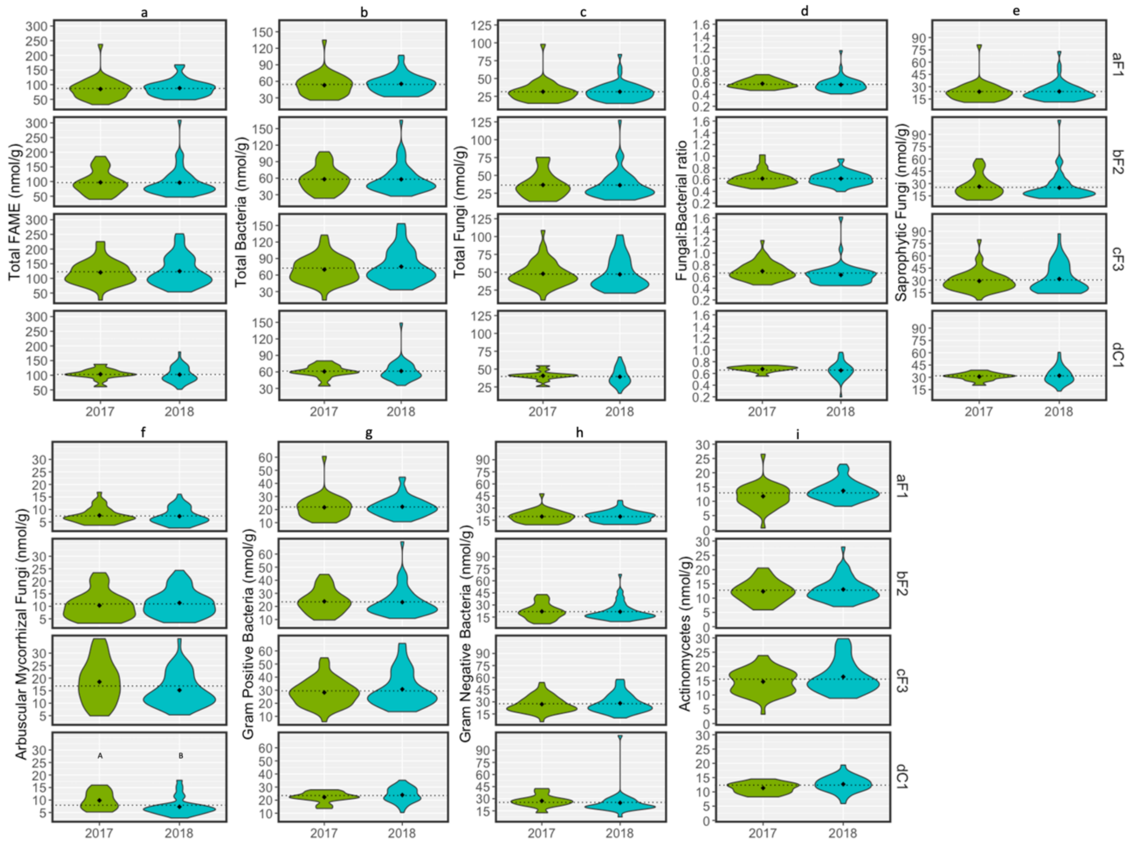

Figure 3.11. Among-year comparisons of each field's yearly mean measurements of: Total FAME (a), total bacteria (b), total fungi (c), fungal:bacterial ratio (d), saprophytic fungi (e), arbuscular mycorrhizal fungi (f), gram positive bacteria (g), gram negative bacteria (h) and actinomycetes (i) in years 2017 to 2018 in F1, F2, F3 and C1. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 22018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

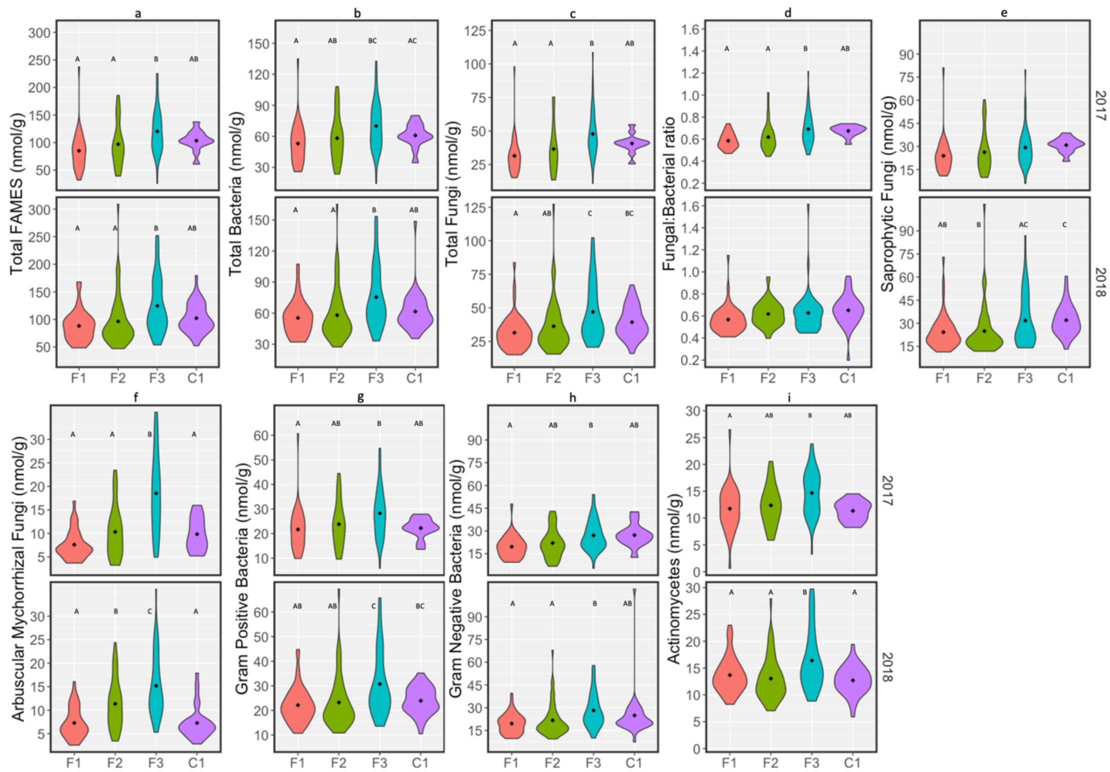

Figure 3.12. Among-fields comparisons of yearly mean measurements of: Total FAME (a), total bacteria (b), total fungi (c), fungal:bacterial ratio (d), saprophytic fungi (e), arbuscular mycorrhizal fungi (f), gram positive bacteria (g), gram negative bacteria (h) and actinomycetes (i) in years 2017 to 2018 in F1, F2, F3 and C1. Values represent the mean of: no-till fields 2017 n = 42, 2018 n = 54; conventional-till field 2017 n = 16, 2018 n = 36. Different letters above each violin indicate significant differences at P < 0.05 calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

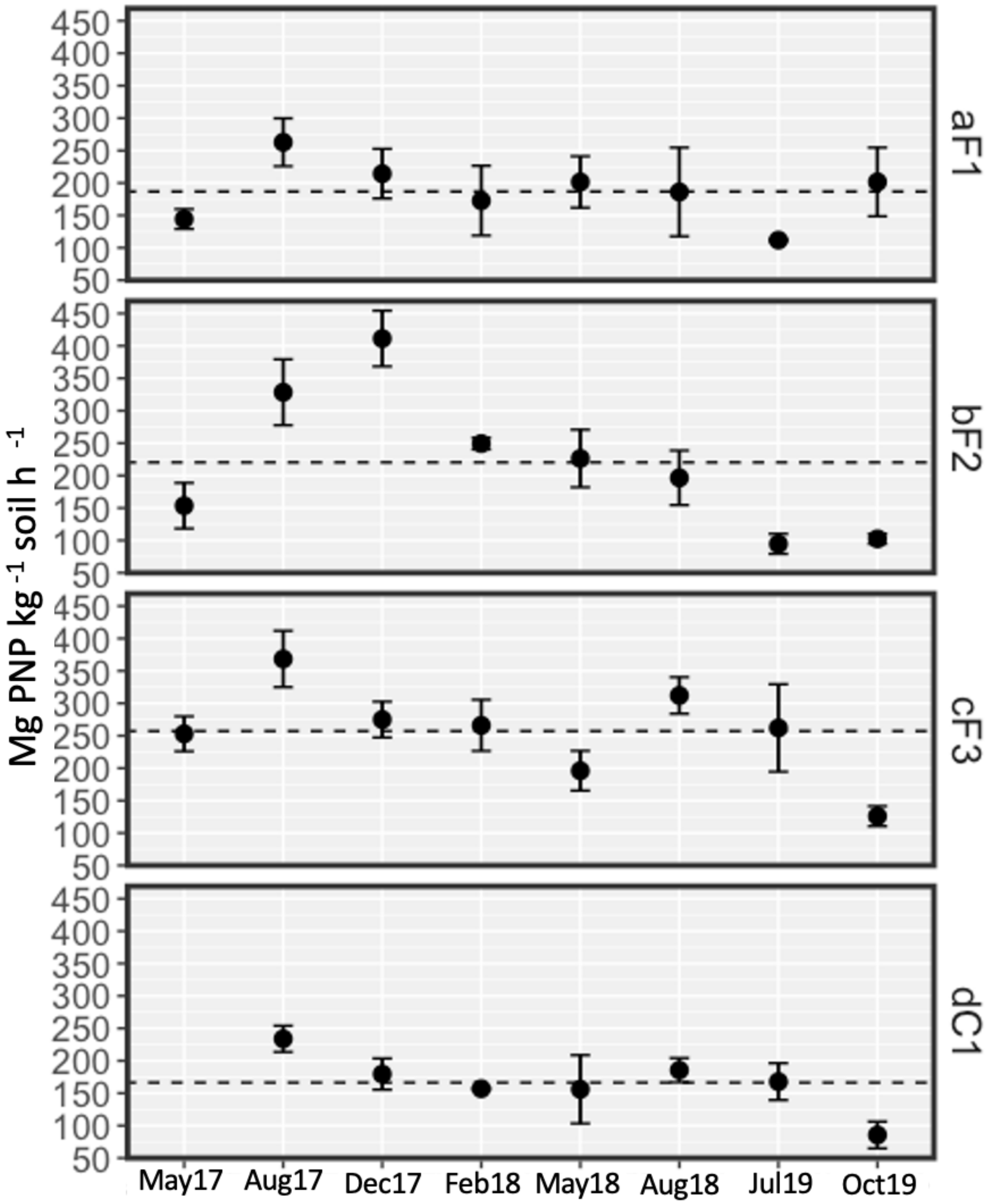

Figure 3.13. Monthly levels of enzyme activity within each field per year of no-till and stubble fields F1, F2, F3, and conventional-till field C1 in semi-arid west Texas. Values represent the mean ± S.E n = 3.

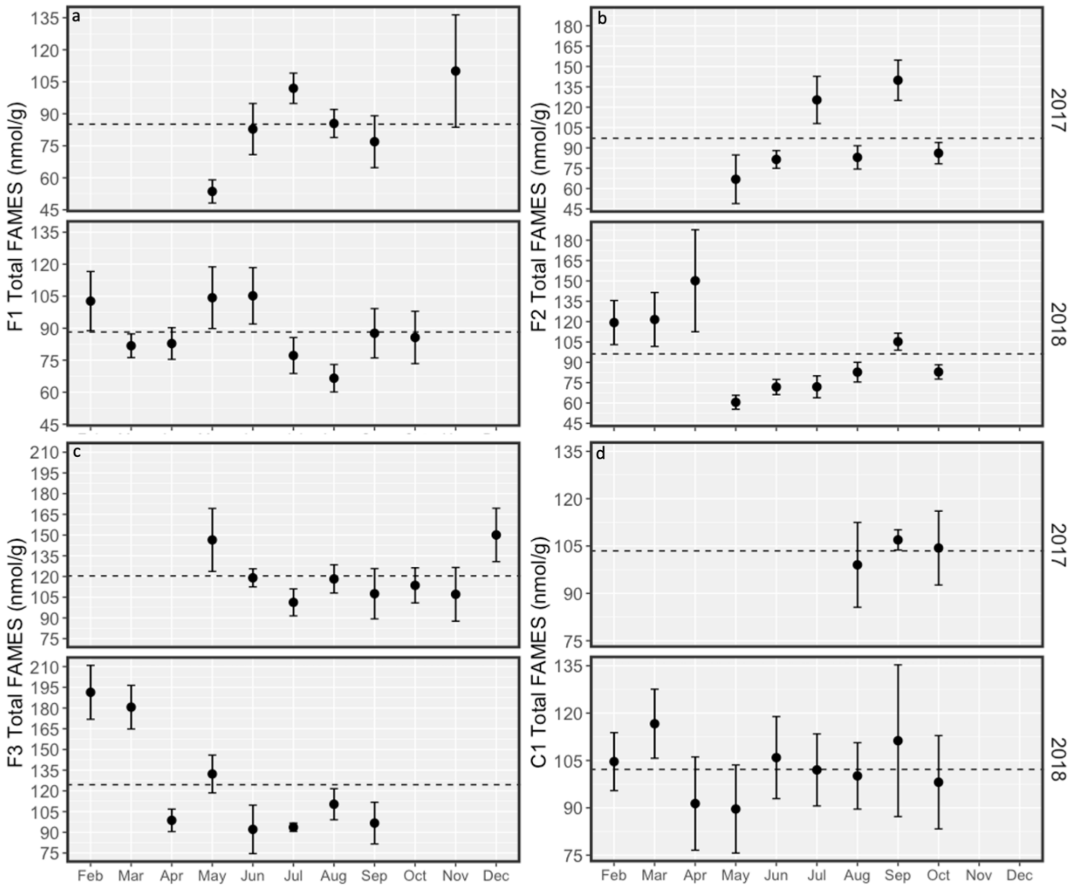

Figure 3.14. Monthly levels of total FAMEs within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

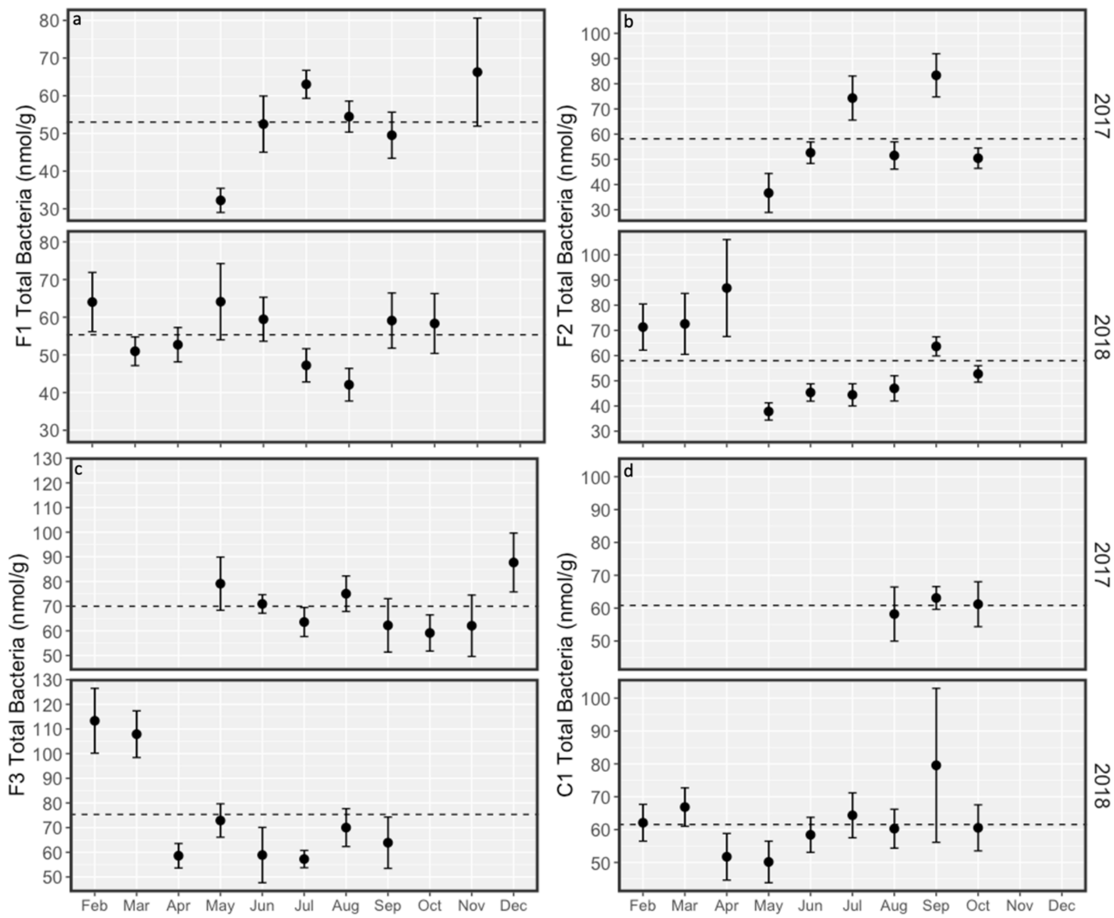

Figure 3.15. Monthly levels of total bacteria within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

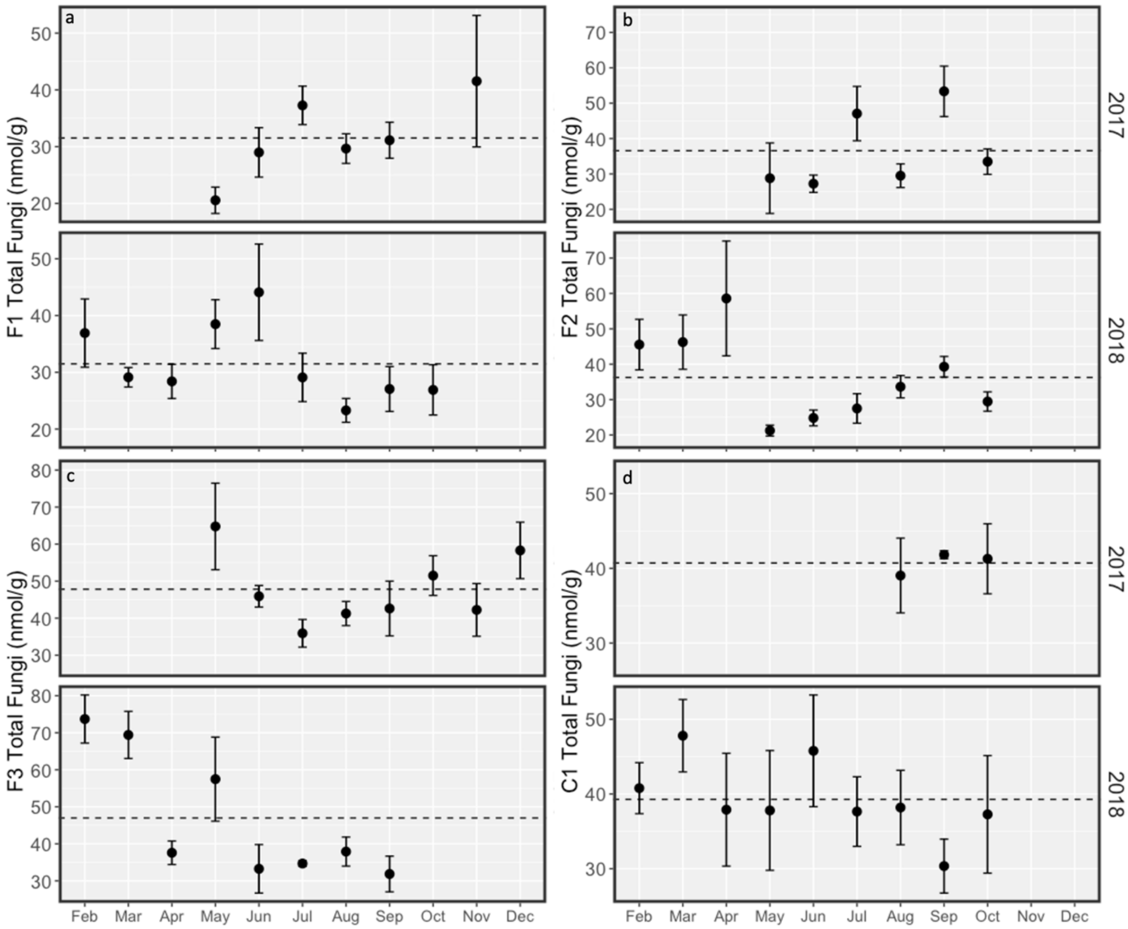

Figure 3.16. Monthly levels of total fungi within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

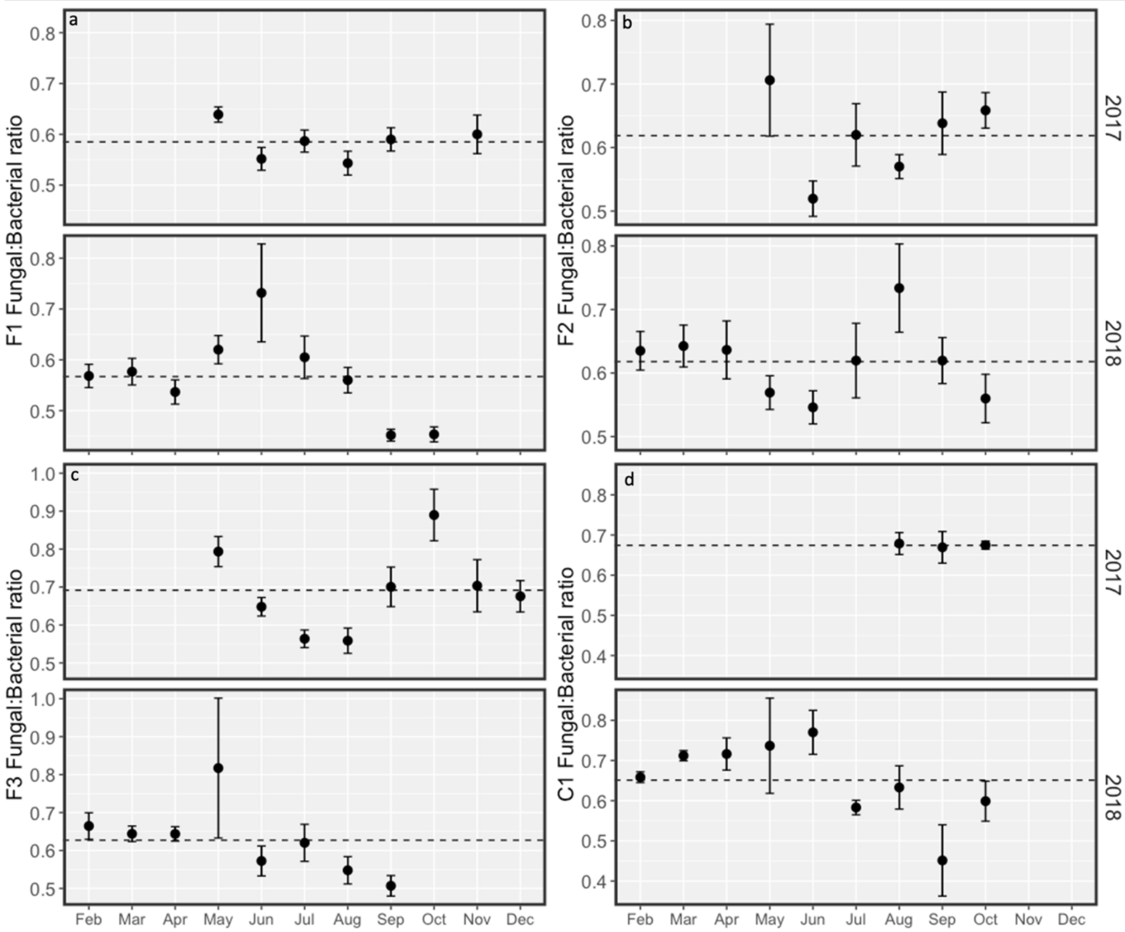

Figure 3.17. Monthly fungal:bacterial ratio within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

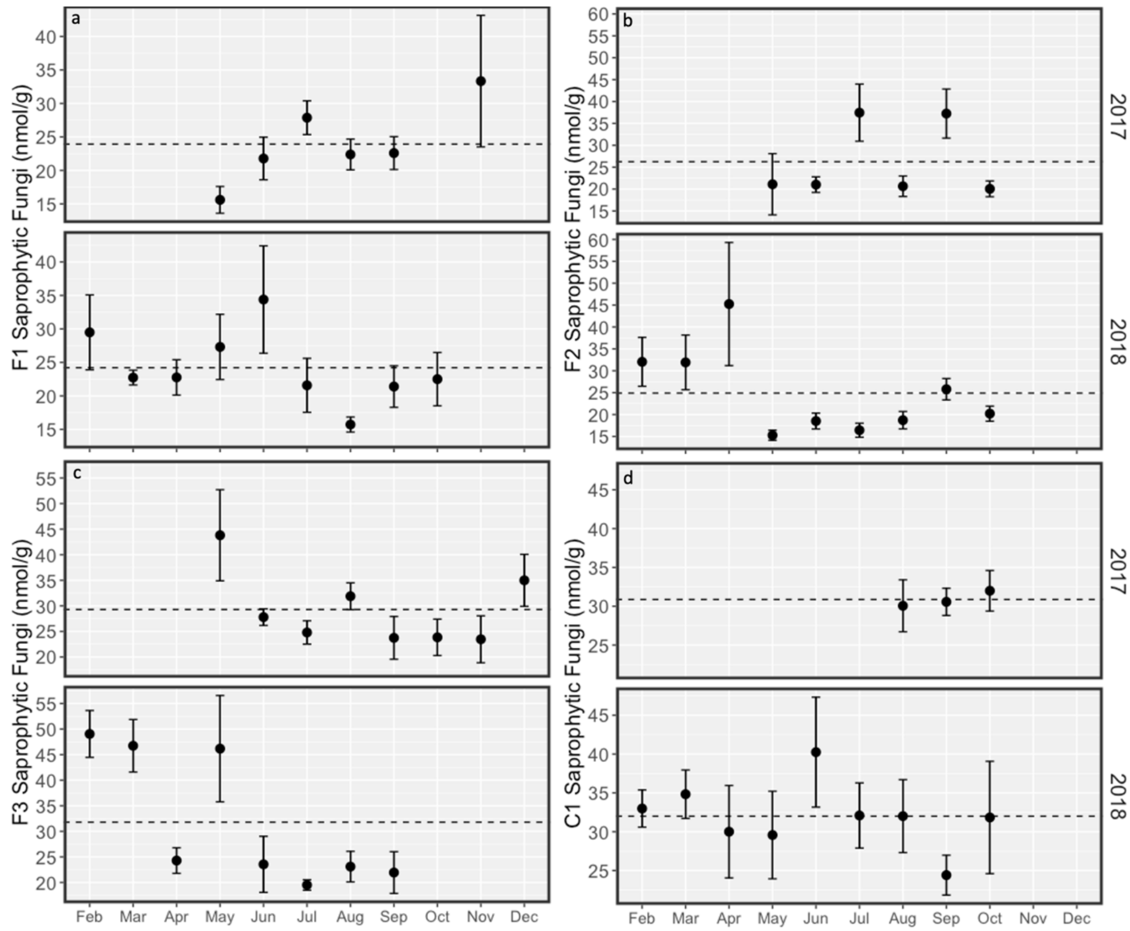

Figure 3.18. Monthly levels of saprophytic fungi within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

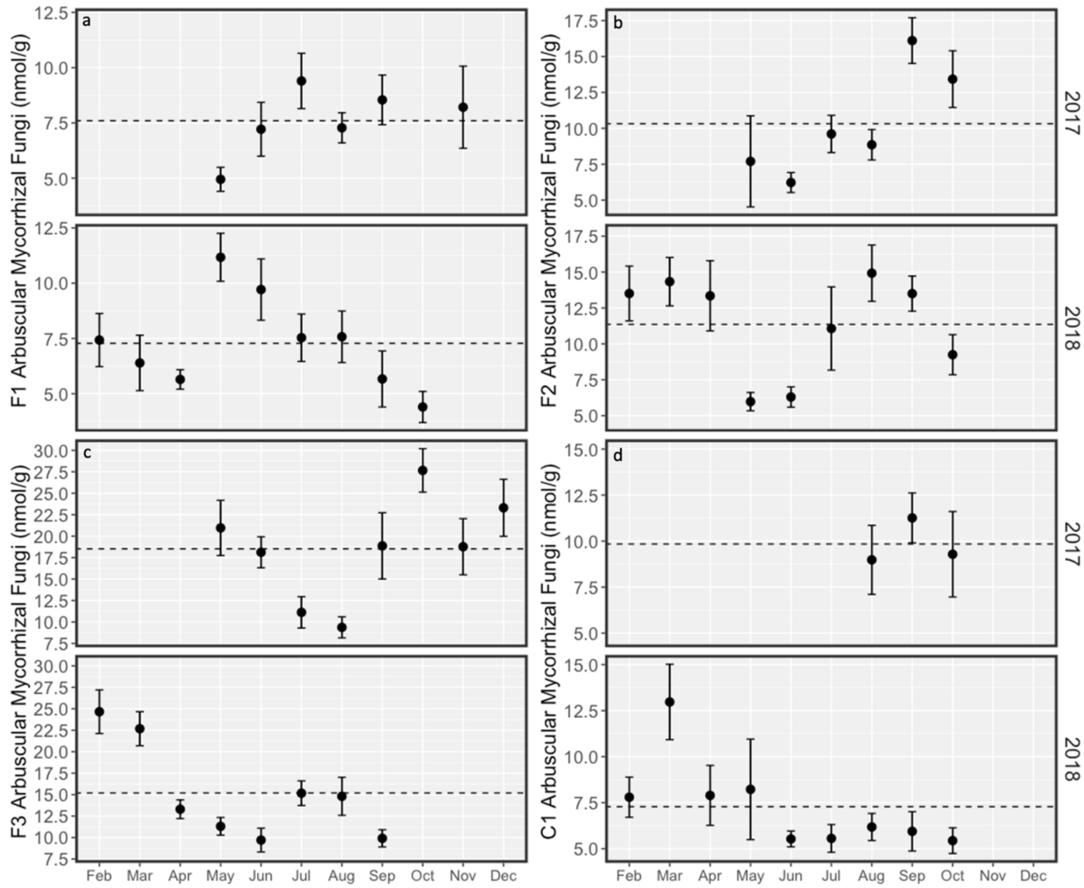

Figure 3.19. Monthly levels of arbuscular mycorrhizal fungi within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

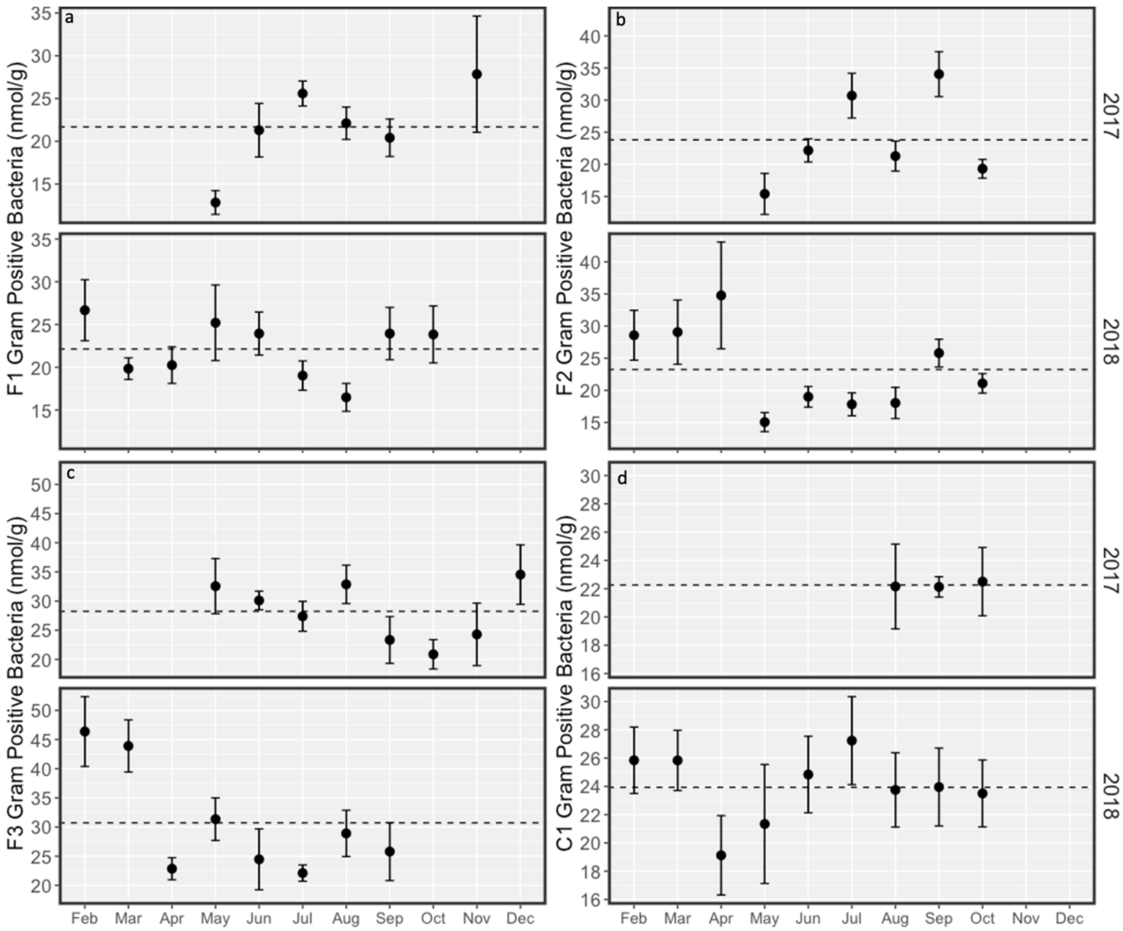

Figure 3.20. Monthly levels of Gram positive bacteria within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

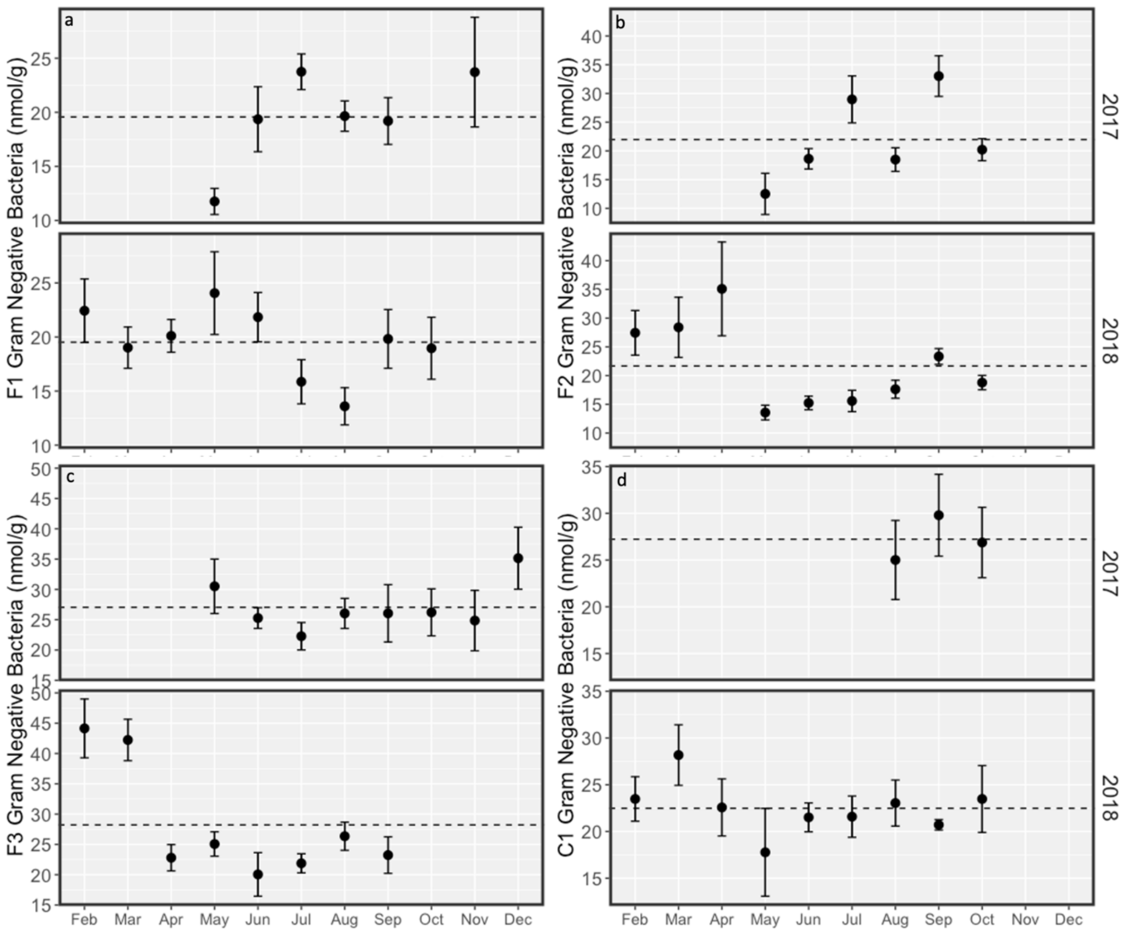

Figure 3.21. Monthly levels of Gram negative bacteria within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

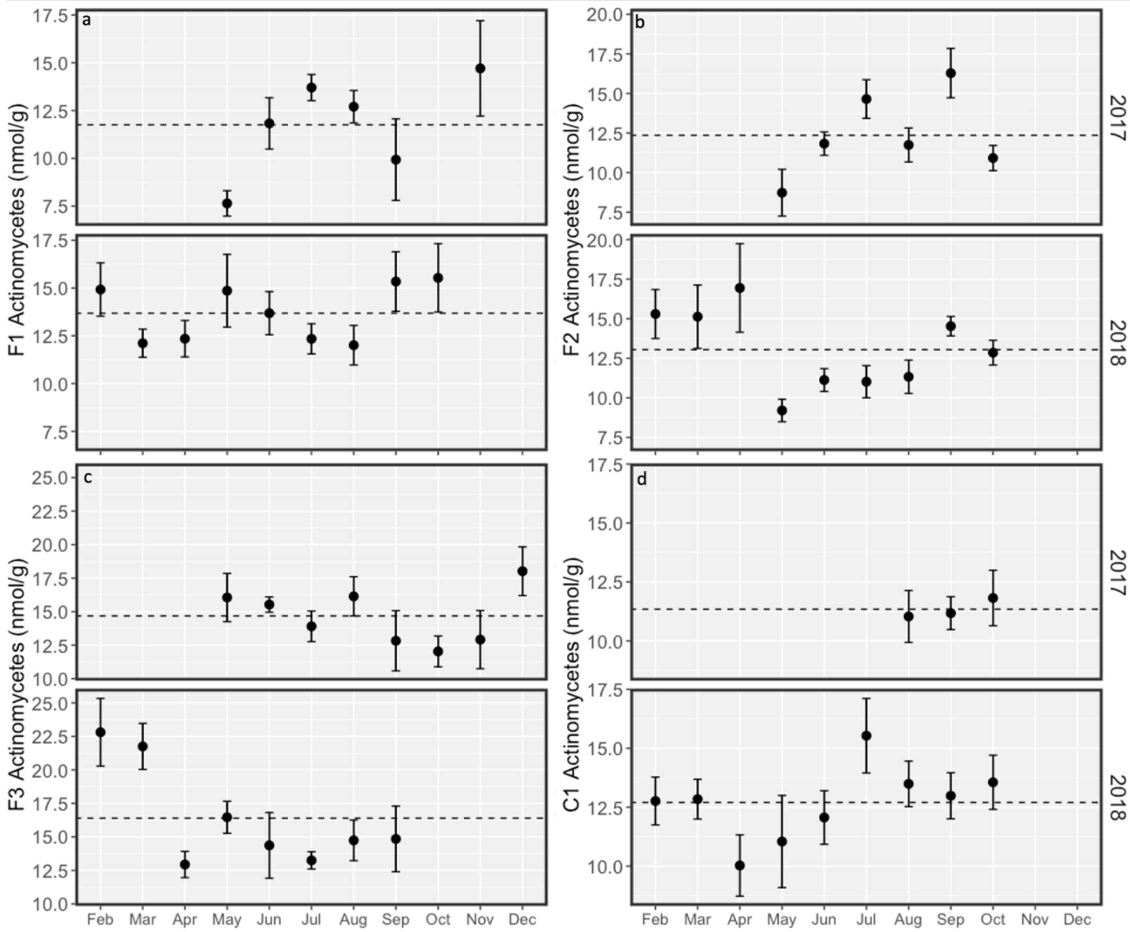

Figure 3.22. Monthly levels of actinomycetes bacteria within each field per year of no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (d) in semi-arid west Texas. Values represent the mean ± S.E of: no-till fields n = 6 and conventional-till field n = 4.

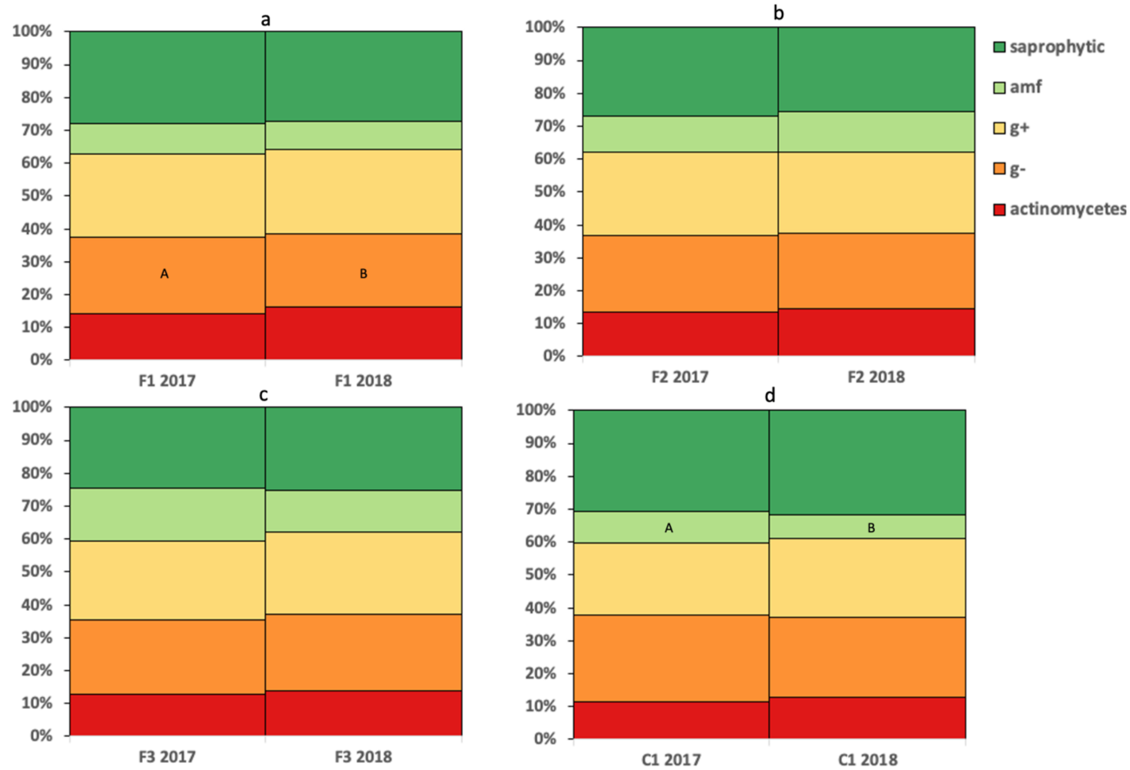

Figure 3.23. Relative abundance of microbial markers of each no-till and stubble field F1 (a), F2 (b), F3 (c) and conventional till-field C1 (d) in 2017 and 2018 in semi-arid west Texas. Different letters in the categories indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

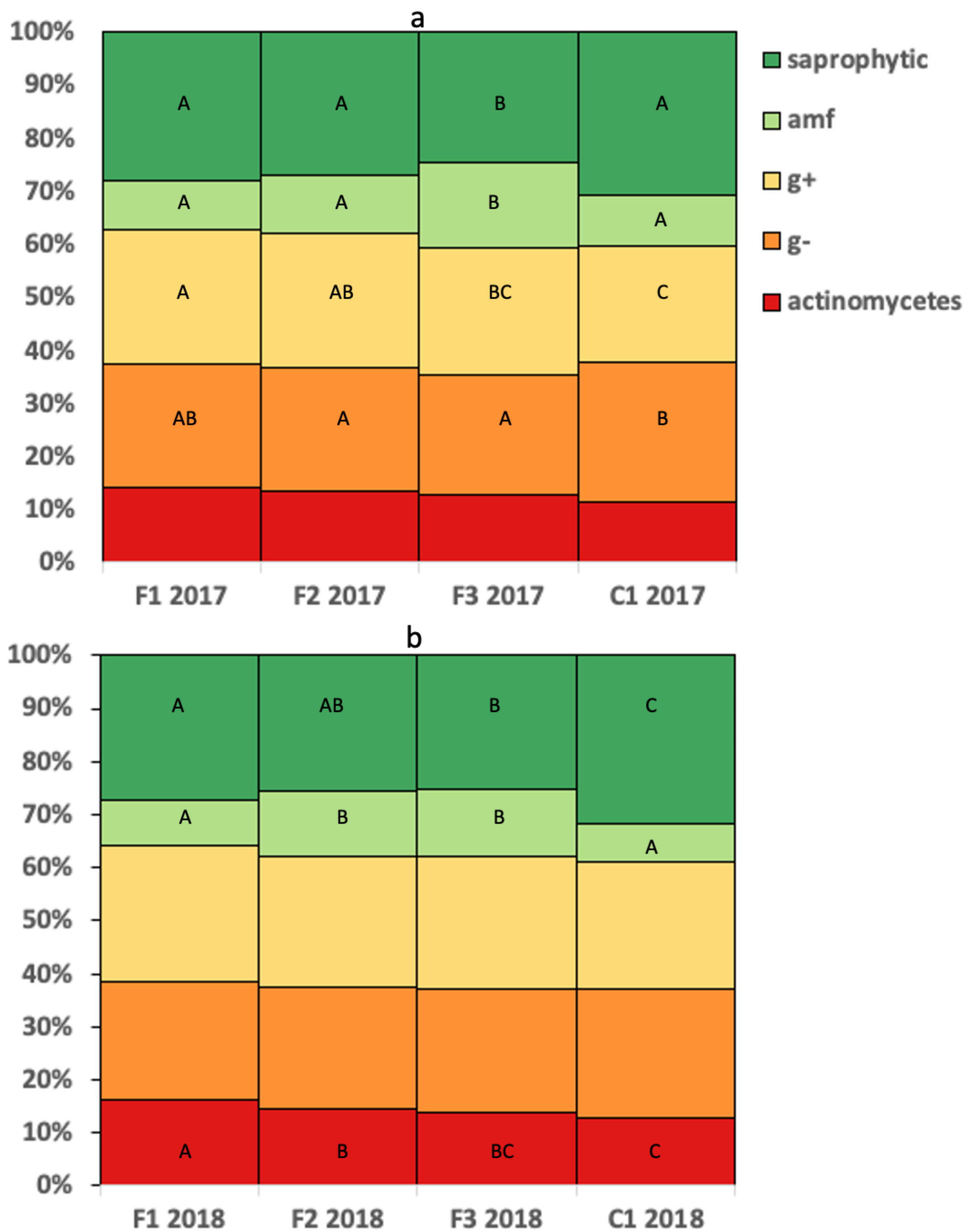

Figure 3.24. Relative abundance of microbial markers among no-till and stubble fields F1, F2, F3 and conventional till-field C1 in 2017 (a) and 2018 (b) in semi-arid west Texas. Different letters in the categories indicate significant differences at $P < 0.05$ calculated using Tukey's HSD posterior tests. Equal and no presence of letters indicate no significant differences.

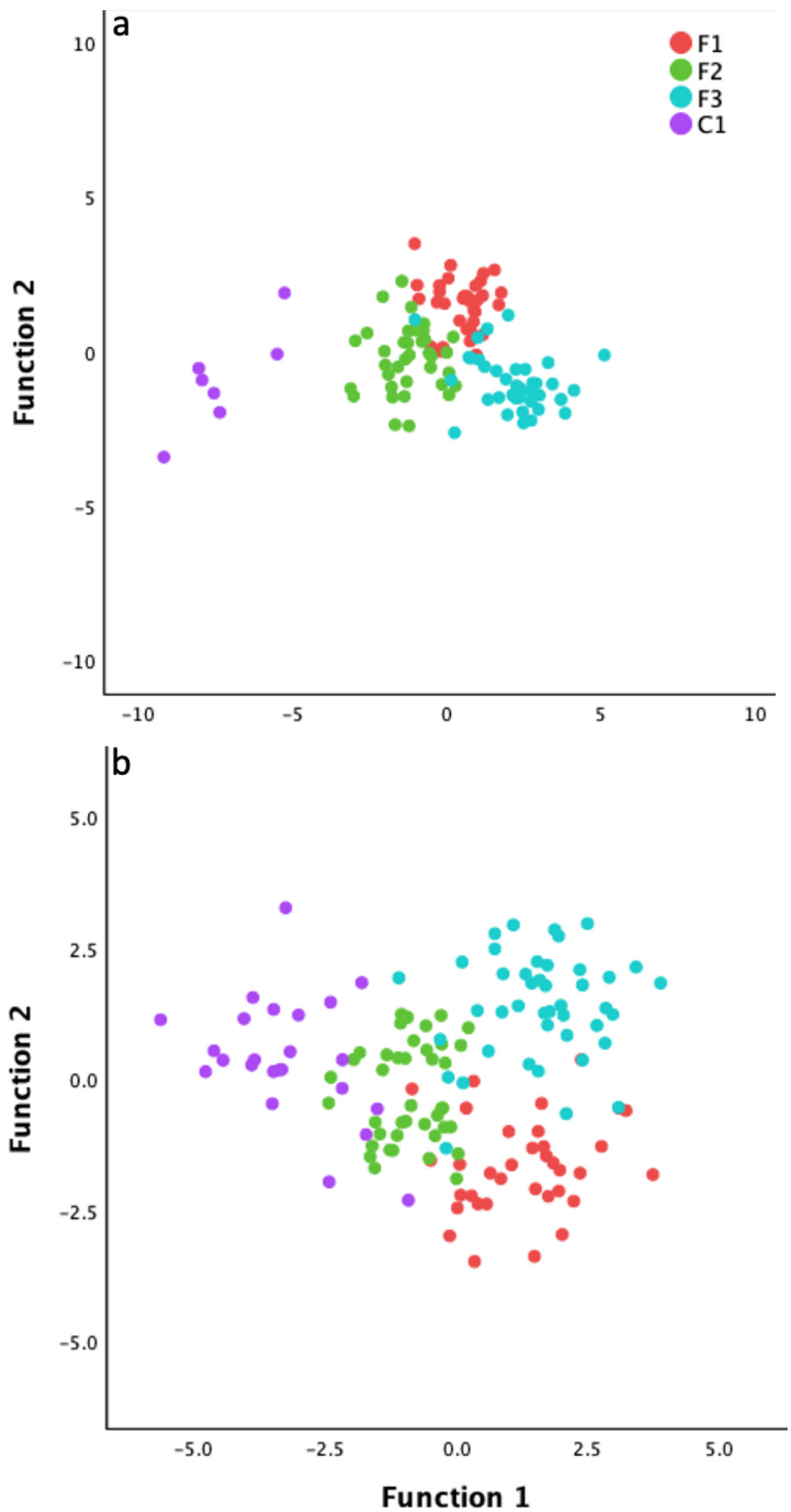

Figure 3.25. Graphical representation of a discriminant function analysis (DFA) with environmental and edaphic variables, and FAME markers for no-till and stubble fields (F1, F2, F3) and conventional-till field (C1) in years 2017 (a), 2018(b) in semi-arid west Texas among-fields per year.

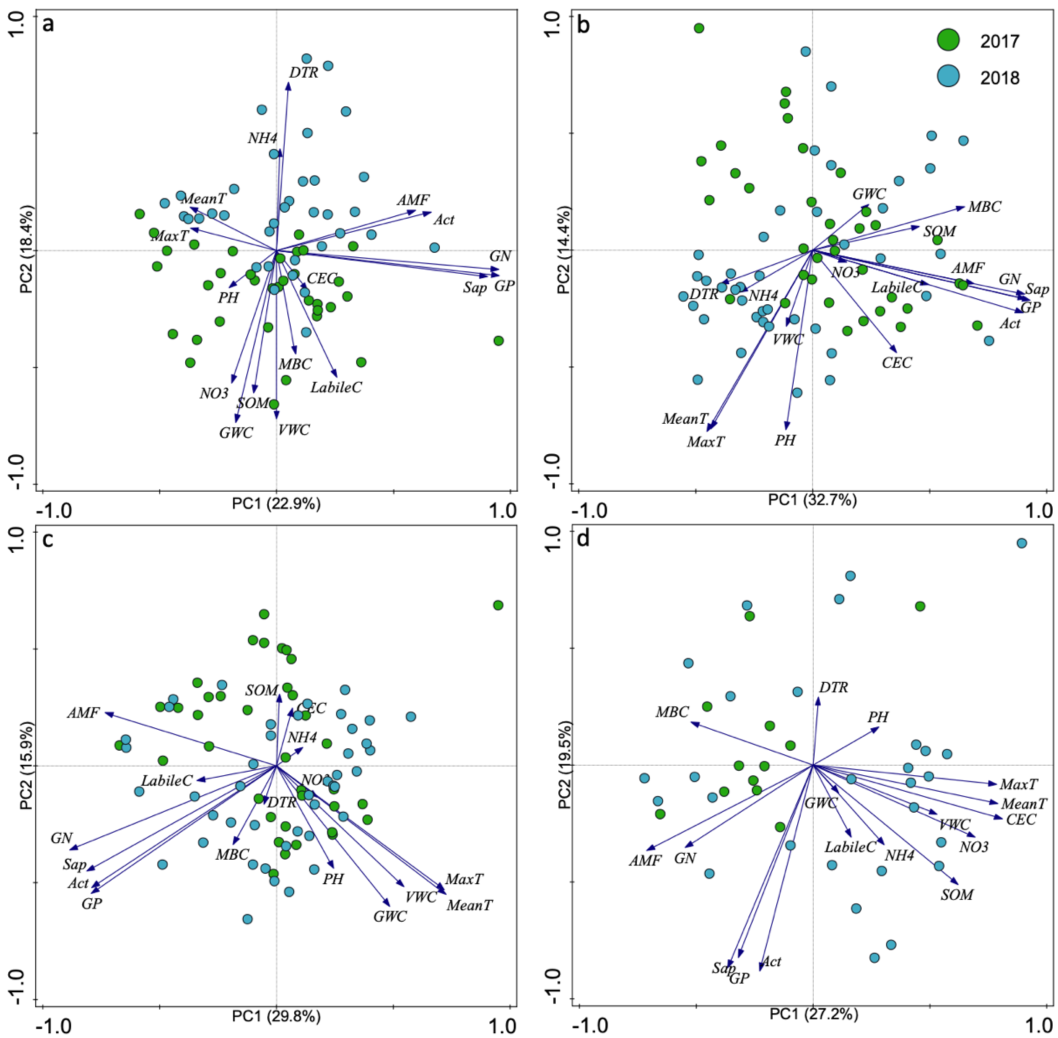

Figure 3.26. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables, and FAME markers of each no-till and stubble field F1 (a), F2 (b), F3 (c) and the conventional-till field C1 (d), and scores with the explained variability for principal components 1 and 2. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable-ammonium (NH4), extractable-nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC). FAME markers are: Gram positive bacteria (GP), Gram negative bacteria (GN), actinomycetes (Act), saprophytic fungi (Sap) and arbuscular mycorrhizal fungi (AMF).

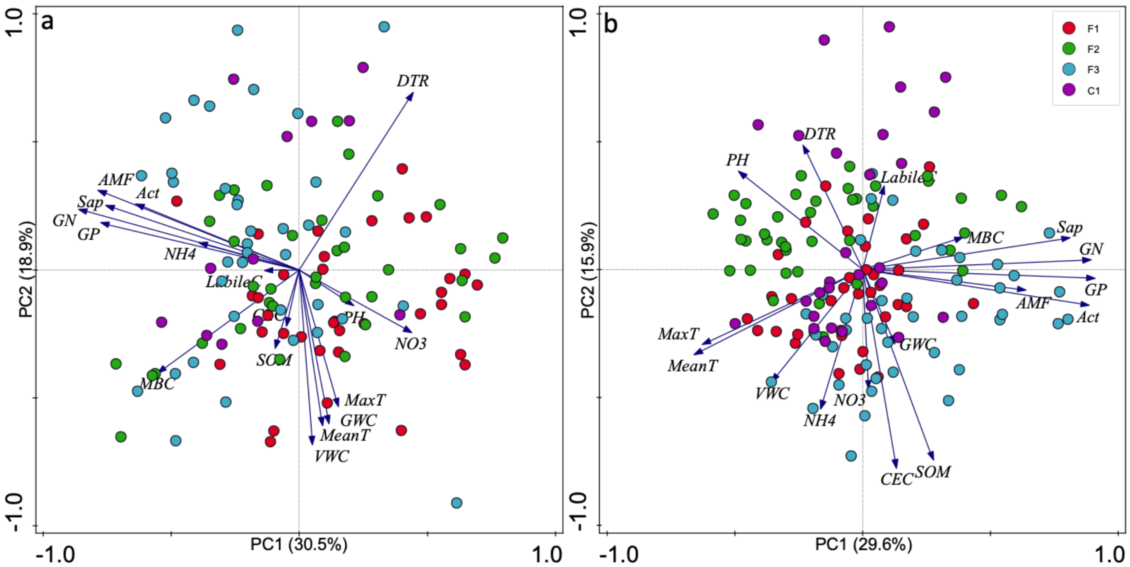

Figure 3.27. Graphical representation of principal component analysis (PCA) with loadings from edaphic and environmental variables of no-till and stubble fields F1, F2, F3 and the conventional-till field C1 in years 2017 (a) and 2018 (b), and scores with the explained variability for principal components 1 and 2. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. Environmental variables measured at 15 cm depth are: volumetric water content (VWC), daily temperature range (DTR), mean temperature (MeanT) and maximum temperature (MaxT). Edaphic variables are: gravimetric water content (GWC), cation exchange capacity (CEC), extractable ammonium (NH4), extractable nitrate (NO3), labile carbon (LabileC) and microbial biomass carbon (MBC). FAME markers are: Gram positive bacteria (GP), Gram negative bacteria (GN), actinomycetes (Act), saprophytic fungi (Sap) and arbuscular mycorrhizal fungi (AMF).

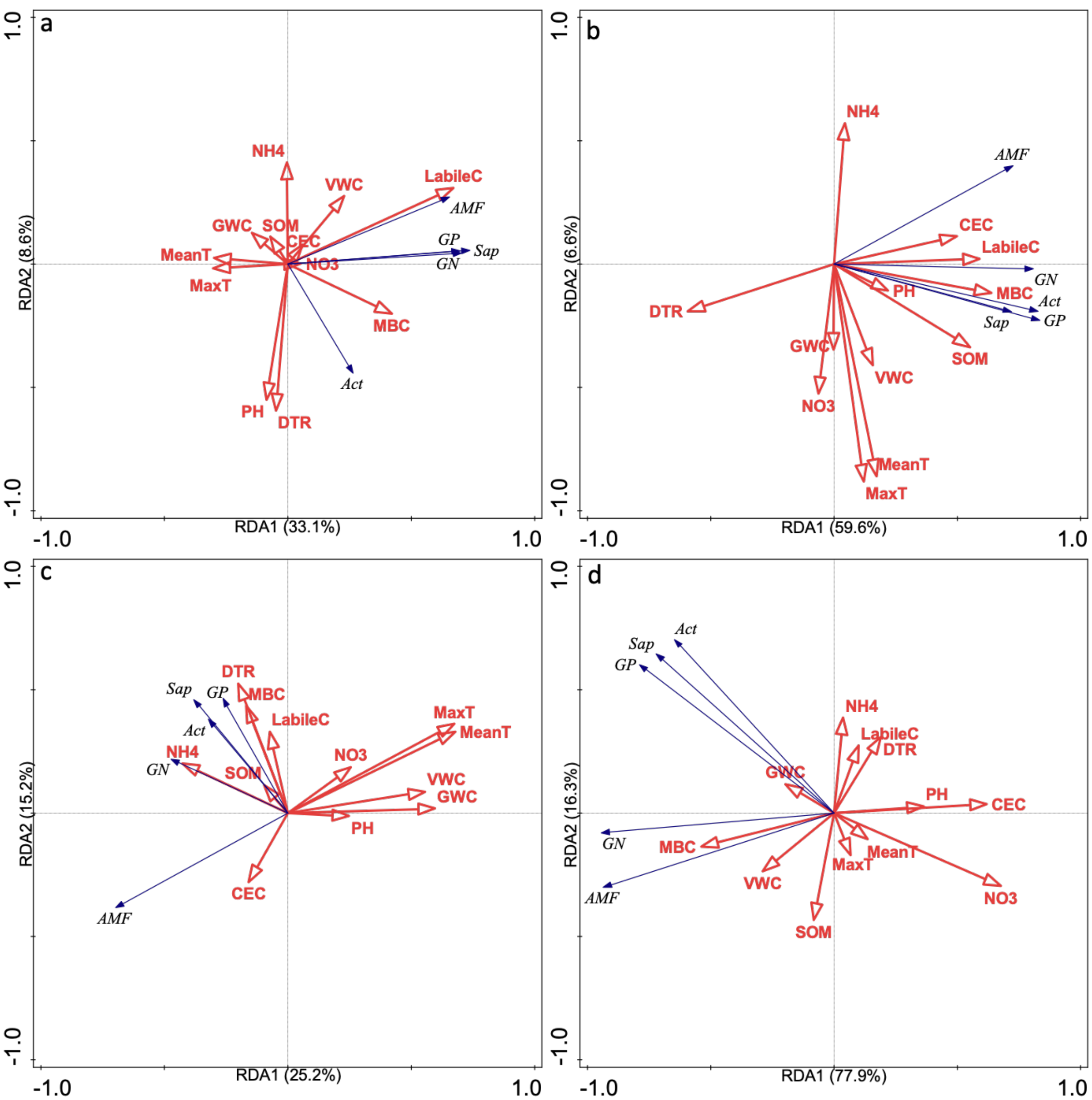

Figure 3.28. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for 2017. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3), cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). The response variables are FAME markers: gram positive bacteria (GP), gram negative bacteria (GN), actinomycetes (Act), saprophytic fungi (Sap) and arbuscular mycorrhizal fungi (AMF). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

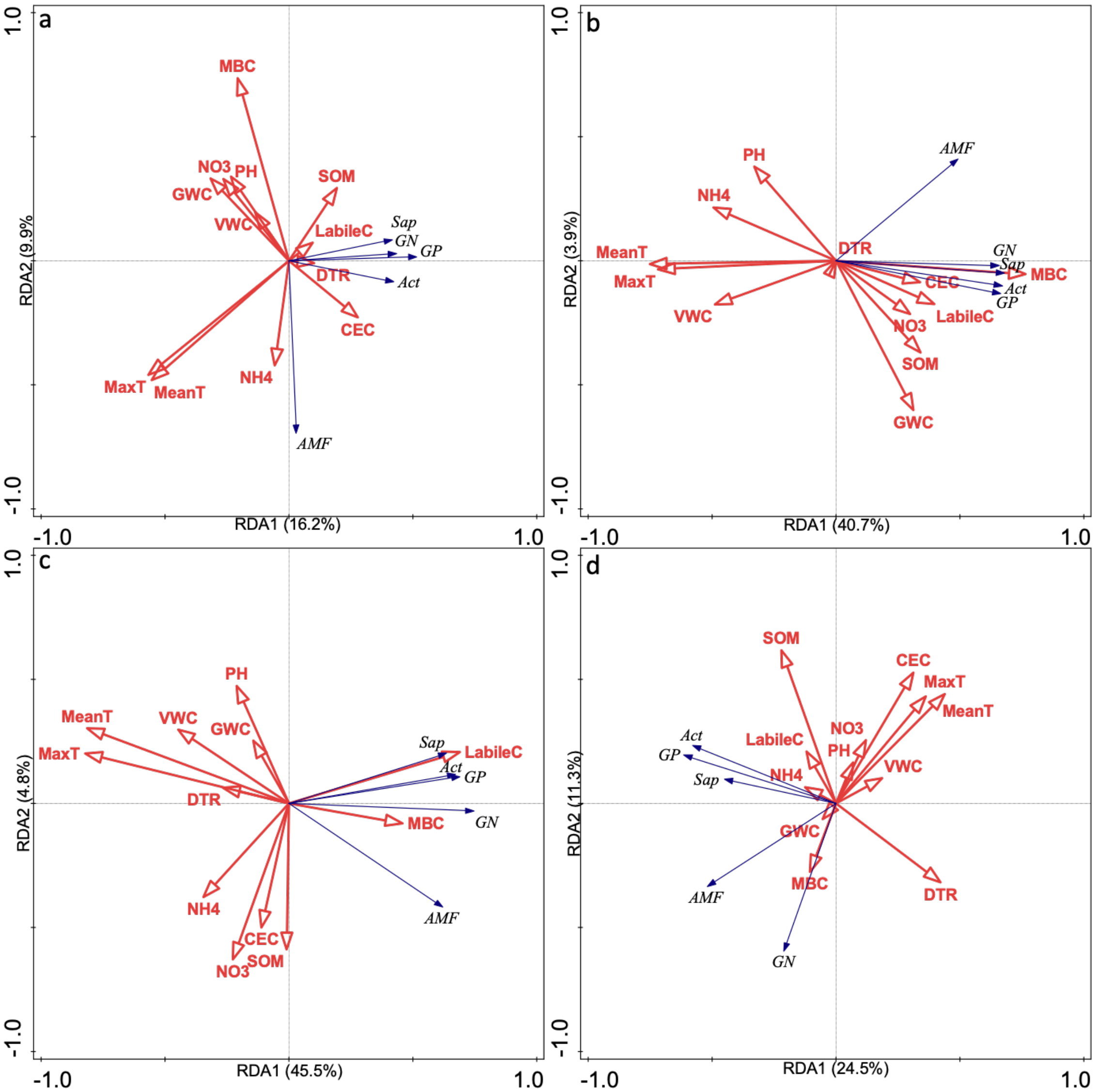

Figure 3.29. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for 2018. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3), cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). The response variables are FAME markers: Gram positive bacteria (GP), Gram negative bacteria (GN), actinomycetes (Act), saprophytic fungi (Sap) and arbuscular mycorrhizal fungi (AMF). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.

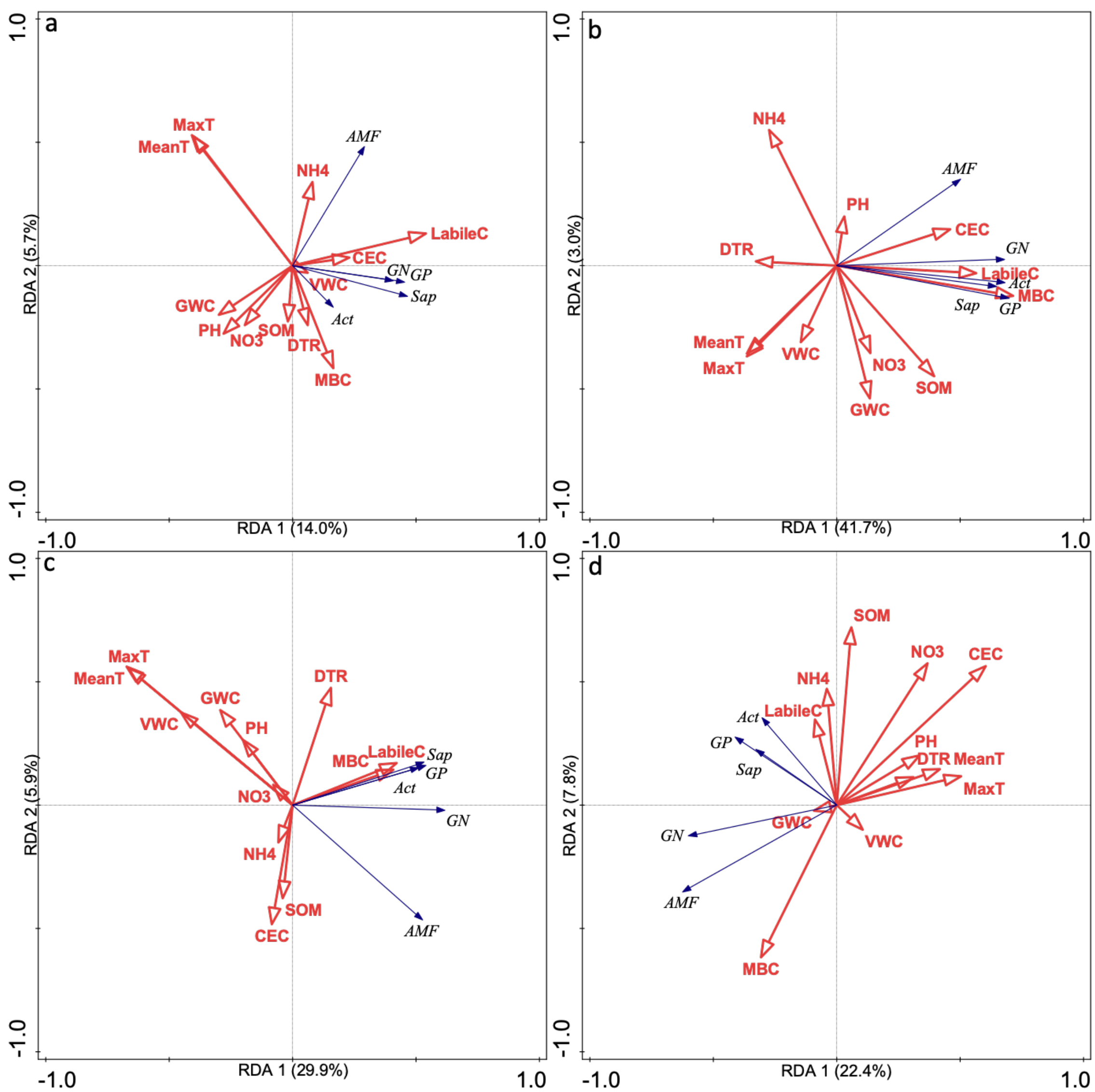

Figure 3.30. Redundancy analysis for no-till and stubble fields F1 (a), F2 (b), F3 (c), and conventional-till field C1 (c) for combined data of 2017 and 2018. The direction of the vector represents the direction of the relationship, and the length represents the strength of the relationship. The explanatory variables are: volumetric water content at 15 cm depth (VWC), daily range temperature at 15 cm depth (DTR), mean temperature at 15 cm depth (MeanT), maximum temperature at 15 cm depth (MaxT), gravimetric water content (GWC), extractable-ammonium (NH4) and extractable-nitrate (NO3), cation exchange capacity (CEC), soil organic matter (SOM), labile carbon (LabileC) and microbial biomass carbon (MBC). The response variables are FAME markers: Gram positive bacteria (GP), Gram negative bacteria (GN), actinomycetes (Act), saprophytic fungi (Sap) and arbuscular mycorrhizal fungi (AMF). RDA1 and RDA2 are the first two components describing maximum variance in parathesis.