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Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA

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ABSTRACT

The concept of soil health has attracted considerable attention during the past two decades, but few studies have focused on the effects on soil health of long-term soil management in arid irrigated environments. We investigated the effects of cover cropping and no-till management on soil physical and chemical properties during a 15-year experiment in California's San Joaquin Valley (SJV) USA. Our objective was to determine if soil health could be improved by these practices in an annual crop rotation. The impact of long-term no-tillage (NT) and cover cropping (CC) practices, alone and in combination, was measured and compared with standard tillage (ST) with and without cover crops (NO) in irrigated row crops after 15 years of management. Soil aggregation, rates of water infiltration, content of carbon, nitrogen, water extractable organic carbon (WEOC) and organic nitrogen (WEON), residue cover, and biological activity were all increased by NT and CC practices relative to STNO. However, effects varied by depth with NT increasing soil bulk density by 12% in the 0–15 cm depth and 10% in the 15–30 cm depth. Higher levels of WEOC were found in the CC surface (0–5 cm) depth in both spring and fall samplings in 2014. Surface layer (0–15 cm) WEON was higher in the CC systems for both samplings. Tillage did not affect WEON in the spring, but WEON was increased in the NT surface soil layer in the fall. Sampling depth, CC, and tillage affected 1-day soil respiration and a soil health index assessment, however the effects were seasonal, with higher levels found in the fall sampling than in the spring. Both respiration and the soil health index were increased by CC with higher levels found in the 0–5 cm depth than in the 5–15 and 15–30 cm depths. Results indicated that adoption of NT and CC in arid, irrigated cropping systems could benefit soil health by improving chemical, physical, and biological indicators of soil functions while maintaining similar crop yields as the ST system.

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1. Introduction

Soils are a finite natural resource that are nonrenewable under agricultural production without implementation of sustainable management practices (SSSA, 2015). Since the publication of '*Soil Quality, A Concept, Definition, and Framework for Evaluation (A Guest Editorial)*' by Karlen et al. (1997), and the pointed rebuttal, '*Reservations Regarding the Soil Quality Concept*,' by Sojka and Upchurch (1999), an energetic and at times acrimonious debate has been waged between proponents and critics of the concept of soil quality, or more recently, the related concept of soil health. Supporters point to the urgent needs, globally, to protect soils to ensure food security and ultimately human security (Wall and Six, 2015; Amundson et al., 2015). Skeptics argue, however, that relationships between soil attributes and how a given soil

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functions are poorly understood, that it is difficult to apply soil health practices broadly across diverse environments, and that the entire notion of soil health is abstract, particularly in regions like California where farmers achieve some of the highest crop yields, and yet soil quality assessments generally indicate low inherent quality (Andrews et al., 2002; Sojka and Upchurch, 1999).

Soil carbon (C) is one of the more important soil quality indicators that influence a variety of soil functions including nutrient and moisture retention (Hudson, 1994; Bettner, 2012). In California (Fig. 1), intensive tillage, irrigation practices, and a hot, arid environment limit the potential to accumulate organic C in soil. Intensive irrigation practices over the past 60 years have led to an average increase of 1–1.3% soil C in agricultural soils, likely through the increases in crops yields and associated residue inputs as well as changes in the types and variety of crops grown (DeClerck and Singer, 2003). Though challenging in hot, arid environments, increasing soil C above what can be gained through increased crop productivity due to irrigation practices can be achieved through increased crop residue inputs, particularly from cover crops (Clark et al., 1998; Mitchell et al., 2015). The benefits of cover crop (CC) practices include more productive soil, increased water use efficiency, reduced disease and pest pressure, and other ecosystem services (Follett, 2001; Alcantara et al., 2011; Ruiz-Colmenero et al., 2011; Schipanski et al., 2014).

Adoption of cover crops and no-tillage (NT) to increase soil quality and health has been difficult to promote in the California agricultural community (Mitchell et al., 2007, 2015). Crop yields in the state are on an ever-increasing trajectory due to sustained breeding and genetic improvement efforts, a number of parallel advances in production technology including particularly the adoption of precision micro-irrigation systems, giving little incentive to consider indicators of soil health (Mitchell et al., 2012; Phene, 2010). For example, tomato yields have increased by 50–80% with the adoption of subsurface drip irrigation (Hartz and Bottoms, 2009). Regardless of the demonstrated and perceived benefits of cover crops, the majority of growers do not adopt them due to costs of establishment and management, risk associated with timing of planting of cash crops, and other issues related to their compatibility with residue management and irrigation practices. Further, many people are concerned that practices currently endorsed to promote soil health are not relevant to the climate and crops of California because these practices were developed for rainfed, commodity crop farming systems with a winter fallow period and with typically higher soil organic matter (SOM) levels (Personal communication, T.K. Hartz). With the state's diverse base of high-value crops (CDFA, 2012) and given high yields achieved with existing management practices over the past century, there has been little incentive to explore or adopt soil health principles in California crop production. Furthermore, the value of the concept of soil quality or soil health in guiding soil research and conservation policy has been questioned (Sojka and Upchurch, 1999). If these practices are ever to be adopted, they need to be shown to have value and also be achievable (Pannell et al., 2006).

Fig. 1. Map of California' San Joaquin Valley in western United States. indicates approximate location of Five Points, CA.

Progress to identify general and unifying concepts linking specific agricultural management practices and soil function continues to advance (Ferris and Tuomisto, 2015) as does our ability to monitor and assess changes in soil health (SQI, 2001; Doran and Jones, 1996; Haney et al., 2008; Haney, 2010). Obade and Lal (2016), however, point out that "a universal model that quantifies soil quality remains elusive" because it cannot be directly measured and is only inferable by determining soil physical, chemical, and biological properties. Various minimum data sets (Franzluebbers, 2010) and measurement techniques (Obade and Lal, 2016) have been proposed as means for achieving sensitive, easy to measure, and cost-effective indicators of soil health. Comparisons of these assessment tools with commonly-reported, traditional, volume-based assays of total soil C and N are needed (Franzluebbers, 2010). Over the past 20 years, a number of techniques or methods have been developed and used in a variety of formal assessments of various aspects of what was initially termed "soil quality," (Karlen et al., 1997), and is now generally defined as "soil health." Field monitoring procedures for water infiltration (Stamatiadis et al., 1999; Liebig et al., 1996), soil aggregate stability (Herrick et al., 2001), slaking (Seybold et al., 2002), and respiration (Liebig et al., 1996) were developed. Studies comparing these field tests to standard laboratory analyses have indicated that they have sufficient accuracy and precision to be of value in providing useful information (Liebig et al., 1996; Herrick et al., 2001). Several of these field assessment tools have been combined by the USDA NRCS (2001) and have been used in a variety of evaluation contexts (Franco-Vizcaino, 1996; Parkin et al., 1996). Given that roughly 36–40% of our planet consists of arid lands and many of these soils support critical food production (White et al., 2009), it is particularly important to develop practices and assessment tools for improving soil function in these areas (Neary et al., 2002; Ladoni et al., 2010) and for providing reliable, inexpensive techniques for monitoring the performance of management efforts aimed at this goal.

The long-term University of California Conservation Agriculture (CA) Systems Project (UCCASP) was initiated in the fall of 1999 by a group of San Joaquin Valley (SJV) farmers, USDA Natural Resource Conservation Service (NRCS), private sector, and university partners to measure changes in soil and crop productivity with implementation of cover crops and NT in California's arid SJV. The original intent was to investigate farming practices that would reduce particulate matter emissions and increase soil C relative to the historically high soil disturbance practices that had been used in the region for over 80 years (Mitchell et al., 2015). At that time, NT practices were used on less than 2% of annual crop acreage in the SJV (Mitchell et al., 2007) and informal estimates indicated that the extent of cover cropping was at similar low levels of adoption. Results from the project demonstrated that cover crop inputs and reduced tillage resulted in much lower soil disturbance and increases in SOM (Mitchell et al., 2006, 2008, 2009; Veenstra et al.,