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Strategic tillage may sustain the benefits of long-term no-till in a Vertisol under Mediterranean climate

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ABSTRACT

Long-term no-till or reduced tillage may decline functioning ability of soils due to surface/subsurface compaction and/or stratification of plant nutrients. A long-term (ten years) field experiment was established in 2006 in the Çukurova region of Turkey to evaluate the impact of tillage on the physical properties of a soil under a Mediterranean climate. The tillage systems investigated included two conventional (CT-1 and CT-2), three reduced (RT-1, RT-2 and RT-3) and two no-till (NT and ST), including strategic/occasional tillage. Nine-year old undisturbed no-till plots were divided into two categories and half of these plots were plowed by a moldboard plow in November 2015, and this practice was defined as strategic tillage (ST), while remaining half of the plots left undisturbed. Soil samples were collected from disturbed and undisturbed plots of NT as well as plots under other tillage systems from three soil depths (i.e., 0–10, 10–20 and 20–30 cm) in November 2016. The crop rotation at the experimental areas was winter wheat (*Triticum aestivum* L.), soybean (*Glycine max.* L.) – grain maize (*Zea mays* L.) – winter wheat. Soil samples were analyzed for aggregate stability (AS), mean weight diameter (MWD), bulk density (BD), water filled pore space (WFPS), water content at field capacity (FC), permanent wilting point (PWP), available water content (PAW), micropores (MiP), macropores (MaP), total porosity (TP), and penetration resistance (PR). The ST decreased MWD of surface soil compared to NT by 7.2%, while MWD under ST was higher than NT by 78.0% and 103.6% for 10–20 and 20–30 cm depths, respectively. The NT and RT resulted higher BD and PR, and lower MaP and TP than CT and ST in all three depths, though the values were generally not limiting for crop growth. The ST significantly ($P < 0.01$) decreased BD and PR within 30 cm of soil surface. However, water content at FC, PWP and also PAW in 0–10 and 10–20 cm depths were significantly reduced with ST compared to NT. The ST significantly ($P < 0.01$) increased the MaP and TP compared to NT which favors better aeration and water movement. The mean WFPS under NT, RT-2 and RT-3 systems in 0–10 cm and with all tillage systems (except ST in 10–20 cm) in subsurface layers were higher than 60%, which is considered a threshold for nitrogen losses as N_2O fluxes. Implementation of ST into conservational practices under Mediterranean climate could be a viable management option to overcome some of the disadvantages of long-term conservation tillage and thereby to improve physical soil conditions for crop growth, air and water movement.

1. Introduction

Conservation tillage systems (no-till or zero tillage and reduced tillage) have been increasingly adopted worldwide since last several decades due to their positive impacts on soil structure, soil organic carbon concentration, erosion, nutrient cycling, productivity and biodiversity (Lal, 2015). Despite the worldwide recognition of conservation tillage practices as the best sustainable management alternative to conventional practices (Verhulst et al., 2010), conventional tillage with moldboard plough, subsequent disking and floating for seedbed preparation and weed management is commonly practiced by farmers in Turkey (Celik et al., 2012). Intensive conventional tillage practices are the main cause of soil organic matter depletion and structural degradation in Mediterranean region (Martín-Lammerding

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et al., 2013), which threaten the sustainability of agricultural production by reducing fertility and productivity.

Long-term no-till (NT) or reduced tillage (RT) minimize negative effects of intensive conventional tillage practices (Stavi et al., 2011), and increase organic matter, improve aggregate stability and enhance soil fertility (Pareja-Sánchez et al., 2017). However, due to intense machinery traffic, NT or RT systems lead to excessive compaction of surface layers in long run with undesirable impacts on air, water and solute transport and penetration of roots (Bogunovic et al., 2018; Nunes et al., 2015). Water retention of soils and water use efficiency of crops are also impaired (Hamza and Anderson, 2005), and eventually crop yield is reduced during dry years (Bogunovic et al., 2018; Lopez-Garrido et al., 2014). In addition to compaction, increasing herbicide-resistant weed populations, difficulties in controlling soil and stubble-borne diseases and accumulation of nutrients and organic matter in soil surface are the major concerns for long-term sustainability of conservative tillage systems (Dang et al., 2015).

Compacted soil layers caused by continuous implementation of conservation tillage should be removed to sustain the benefits of conservative tillage systems. Therefore, in some cases, deep tillage, known as strategic tillage (ST), one-time tillage or occasional tillage of long term NT fields has been considered a potential management option, which helps removing compaction, dispersing the nutrients accumulated near soil surface and controlling weeds (Norton et al., 2014; Stavi et al., 2011). However, the reports on the effects of ST on physical properties of soils in NT and RT systems are contradictory. The ST may have non-significant effect on aggregate stability and water content of silty loam and silty clay loam soils (Wortmann et al., 2010), negative effects on soil aggregation of coarse and fine loamy soils (Grandy and Robertson, 2006). It also exerts negative effects on resistance to water, sediment and nutrient losses after heavy rainfall (Melland et al., 2016), little and/or short-term positive effect on soil functional physical properties (Reichert et al., 2017), and positive effect on soil compaction (Kuhwald et al., 2017). Dang et al. (2018) investigated the short and long-term impacts of ST on crop productivity, soil and environmental health in a range of soil types and found contradictory results for different soil types. They reported no influence in Veritsols, though Sodosols and Dermasols were negatively affected, and became vulnerable to runoff and associated sediment and nutrient losses during intense rainfall.

The contrasting reports and mixed effects of ST on soil physical properties mostly arise due to differences in soil types, duration of NT management, equipment's used in tillage operations, frequency of occasional tillage, tillage depth, soil sampling depths, climate and other environmental factors (Blanco-Canqui et al., 2017; Crawford et al., 2015; Dang et al., 2018; Reichert et al., 2017; Zhang et al., 2017). Tillage using a chisel plow is defined subsoiling, in which compacted layer is broken-up without disturbing the soil structure. In contrast to chisel plow, moldboard plow works as deep ploughing and destroys compacted layer, while bringing subsurface soil to surface (Sun et al., 2018). Although moldboard and chisel plough are the commonly used equipment's in ST operations, the depths and frequency of tillage are not the same in different studies. For example, Stavi et al. (2011) reported the use of disk plow every 3–4 years, while Wortmann et al. (2008) used moldboard plow to 20 cm followed by tandem disk. Similarly, moldboard plow to 30 cm and disc harrowing to 15 cm was used in the studies conducted by Lopez-Garrido et al. (2011). Likewise, Kuhwald et al. (2017) used moldboard plow to 30 cm. Liu et al. (2016) performed tillage with chisel plow to 10 cm and offset disc tillage to 10 cm, whereas chisel plow to 25–30 cm and 3-disk plow to 20 cm was used by Reichert et al. (2017).

Increasing population pressure and decreasing land area per person in Turkey inevitably lead agricultural intensification in different regions of the country, especially Çukurova region. Burning of crop residues prior to conventional tillage is a very common practice in Turkey (Celik et al., 2011), and unfortunately increased with intensive crop rotation in many regions of the country (Korucu et al., 2009). Crop residues are usually burnt to enable tillage and seeding machinery to work effectively and complete the planting of next crops included in the rotation. However, no studies have been conducted yet to assess the long-term impacts of these practices on soil physical properties in the country.

Plenty of work has been done to study the effects of ST on soil physical properties of no-tilled soils around the world. However, there is no comprehensive study investigating the effects of ST on physical properties of no-tilled soil in a long-term experiment in Turkey. Therefore, we conducted this study to investigate the effects of different tillage systems on physical properties of a Vertisol.

We hypothesized that strategic tillage could eliminate deterioration of soil physical properties resulting from intensive crop production under long-term RT or NT in Vertisols. The objective of this ten-year old tillage experiment was to investigate how aggregate stability, mean weight diameter, bulk density, penetration resistance, water filled pore space, porosity and soil water content responded to long-term tillage practices, in a Vertisol. The ultimate objective was to evaluate the overall effects of ST on sustainability of long-term NT management by analyzing the alteration of functional soils physical properties.

2. Material and methods

2.1. Study area, experimental design and tillage practices

The long-term tillage and crop rotation experiment was performed on agricultural fields of Agricultural Experimental Station, Çukurova University, Adana situated in southern Turkey (37°00′54″ N, 35°21′27″ E; 32m altitude), with slope of less than 1%. The soils had a clay texture (50% clay, 32% silt and 18% sand), formed over old terraces of Seyhan River, and classified as Haplic Vertisol in World Reference Base (IUSS Working Group, 2015) and fine, smectitic, active, mesic Typic Haploxererts in Soil Taxonomy (Soil Survey Staff, 1999). The mean pH, electrical conductivity and calcium carbonate of the experimental soil are 7.82, 0.15 dS m^{-1}, and 244 g kg^{-1}, respectively at 0–30 cm depth (Celik et al., 2011) (Table 1). The climate of the study area is Mediterranean with a mean annual temperature 19.3 °C and 642 mm precipitation, 72% of which is received during winter and spring (from November to May) and annual potential evapotranspiration is 1577 mm.

The experiment was laid out according to randomized complete block design and had 3 replications for each treatment/tillage system. The tillage practices include; two conventional (CT-1 and CT-2), three reduced (RT-1, RT-2 and RT-3) and two no-till (NT and ST) tillage systems (Table 2). The tillage plots were of 12 × 40 m (480 m^2) with a 4 m buffer zone between each plot. The experiment was initiated in summer, 2006 with six tillage treatments, excluding ST. The soils in the experimental site had been under continuous CT system, and cultivated by moldboard plow for wheat, corn and soybean production until the

Table 1
Some characteristics of Arik soil at the beginning (in 2006) of experiment.

Soil property	Soil depth (cm)		
	0–10	10–20	20–30
Sand (50–2000 μm), (g kg^{-1})	175	177	172
Silt (2–50 μm), (g kg^{-1})	333	324	324
Clay (< 2 μm), (g kg^{-1})	492	499	504
Texture	Clay	Clay	Clay
pH (H_2O, 1:2.5)	7.86	7.82	7.80
Electrical conductivity (1:5) (dS m^{-1})	0.13	0.16	0.16
$CaCO_3$ (g kg^{-1})	242	247	244
Total salt (g kg^{-1})	0.08	0.10	0.10
Total organic carbon (g kg^{-1})	8.95	8.80	8.52
Bulk density (Mg m^{-3})	1.23	1.33	1.38