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EFFECTS OF LONG-TERM TILLAGE SYSTEMS ON SOIL WATER CONTENT AND WHEAT YIELD UNDER MEDITERRANEAN CONDITIONS

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Abstract – Agricultural practices conserving soil water are needed to sustain agricultural production under changing climate. Long-term (2006-2014) effects of six different tillage systems on soil water content (SWC) and wheat yield were investigated in a clayey soil of the Çukurova region, Turkey. The tillage treatments were; conventional tillage with stubble (moldboard plowing) (CT1), conventional tillage with stubbles burned (CT2), heavy disc harrow reduced tillage (RT1), rototiller reduced tillage (RT2), heavy disc harrow zero soil tillage (RNT) and no till or zero tillage (NT). Soil moisture content was measured at different times of the rainfed wheat production season in 2014-2015. Tillage practices had statistically important effects on SWC on 6 February, 9 March, 17 April and 8 May 2015. Although moisture values measured on February, 6 and March, 9 were optimal for plant growth, SWC under conservation tillage practices were higher compared to conventional tillage practices. However, tillage practices had no significant effect on the wheat yield. These results showed that reduced and no-tillage practices can be alternative to conventional tillage practices under Mediterranean conditions.

Keywords – *Soil tillage, Soil water content, Wheat yield, Mediterranean*

1 Introduction

The shortage of water resources worldwide is one of the major limiting factors of agricultural development, which severely threats the global food security [15]. Rainfed crops such as durum wheat are highly sensitive to the dry conditions. Due to the strong influence of soil moisture on crop yield [7], management practices cause to increase soil

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water storage potential are important to be adopted for sustaining crop production in arid and semi-arid regions of the world.

Tillage treatments directly or indirectly influence soil hydraulic properties such as water infiltration, hydraulic conductivity, and water retention which determine the ability of the soil to capture and store water through precipitation or irrigation [2]. Tillage changes flow path and rate of water by rearranging aggregate size distribution [9]. Therefore, tillage systems conserving water in soil are important for plant growth under arid and semiarid conditions. Conservation tillage systems increase soil water by reducing evaporation [17, 18], increasing water infiltration [13] because of crop residues remained on soil surface. In contrast, Blanco-Canqui et al. [2] reported that disrupting compacted layers and loosening the soil by tillage may increase infiltration of water relative to no-till management.

Management practices improve soils' ability to drain when wet and hold more water under dry season are preferred to support rainfed crop growth. The extent of tillage effect on the ability of the soil to adsorb and retain water depends on the level of soil disturbance [2]. Studies from different regions of the world have shown that conservation tillage systems are important for crop production because of increasing soil water content [10, 11, 12, 19, 21]. Fernandez-Garcia et al. [11] reported that more water was stored at sowing depth under no-tillage compared to conventional tillage which improved chickpea grain yield. Copec et al. [8] reported that the highest average SWC was measured under the no-tillage compared to conventional system which reduces water infiltration by weakening soil aggregate stability and decreasing macro-porosity and increasing surface crusting [33]. In another study, SWC was improved by no-till system during whole agricultural season [19].

Understanding the changes in soil hydraulic properties under long term tillage systems is important to manage soil water under different soil types, management options, and climates [2]. However, lack of data on water retention of soils obtained in long-term experiments limits the understanding of the efficiency of tillage systems on soil water management. Therefore, this information is particularly necessary in the regions where water is limited for crop production or crop production is performed under rainfed conditions. The long-term effects of conservation tillage systems on SWC have scarcely been studied in Turkey. The objective of this study was to determine the long-term (8-year) effects of conventional, reduced and no-tillage practices on SWC and wheat yield in a heavy clay soil under Mediterranean climate.

2 Materials and Methods

2.1 Experimental Site

A long-term field experiment established in 2006 at the Experimental Farm (37° 00′ 54″ N, 35° 21′ 27″ E; 32 m above sea level) of the Çukurova University in Adana, Turkey under wheat, corn and soybean rotation (Figure 1). The soils of study were clayey Arık soils and classified as fine, smectitic, active, mesic Typic Haploxererts [29] with a pH of 7.82, $CaCO_3$ of 244 g kg^{-1}, electrical conductivity of 0.15 dS m^{-1} and particle size distribution of 50% clay, 32% silt and 18% sand at the surface horizon (0-30 cm) [5]. Arık soils are deep formed over old terraces of Seyhan River and well drained with almost zero slope.

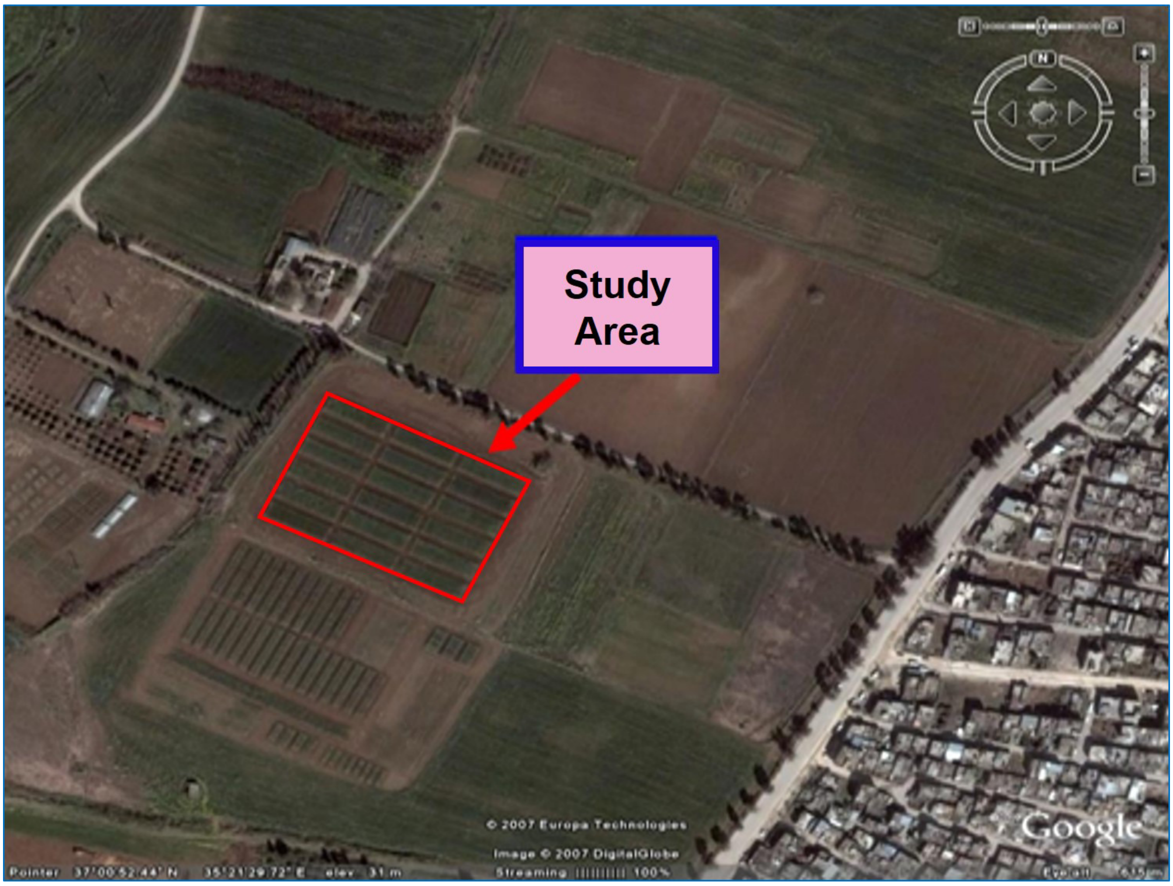

Figure 1. Study area

Table 1. Long-term (1985-2014) mean climate data of Adana province

	Months												
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Annual
Maximum Temperature (°C)	15.2	16.3	19.7	24.1	28.2	31.6	33.8	34.7	33.1	29.0	22.2	16.7	25.4
Minimum Temperature (°C)	5.5	6.0	8.5	12.4	16.3	20.5	24.0	24.4	21.0	16.4	10.7	7.1	14.4
Annual Temperature (°C)	9.6	10.4	13.5	17.8	22.0	25.9	28.5	29.0	26.4	21.7	15.2	11.0	19.2
Evaporation (mm)	48.4	55.4	87.2	118.7	165.2	214.3	239.7	226.9	175.5	120.9	66.5	48.1	130.6 (Total:1567)
Annual Precipitation (mm)	96.1	81.7	62.0	46.7	46.5	17.9	9.0	6.8	17.6	48.1	81.6	125.1	53.3 (Total: 639)

The prevailing climate of the study area is Mediterranean with a long-term (30 years) mean annual precipitation from 1985 to 2014 was 639 mm, about 75% of which falls during the winter and spring (from November to May) and the long-term mean annual potential evapotranspiration is 1567 mm. The summers are hot and dry, and winters are wet and mild.

Table 2. Daily rainfall in wheat production season (November 2014-June 2015)

Days	November 2014	December 2014	January 2015	February 2015	March 2015	April 2015	May 2015	June 2015
	(mm)							
1	2.1	-	3.1	3.5	-	0.4	-	-
2	-	-	18.0	-	8.9	-	-	-
3	-	-	6.7	-	1.5	1.7	-	-
4	-	-	-	1.2	-	1.7	-	4.0
5	-	-	1.5	-	-	4.4	-	0.1
6	-	-	58.5	-	-	-	-	-
7	-	-	3.2	-	-	-	-	-
8	-	-	0.9	-	-	-	-	-
9	-	6.7	-	1.8	-	0.3	-	-
10	-	34.6	-	3.3	-	-	0.5	-
11	-	-	-	26.5	0.5	8.5	-	-
12	-	-	-	47.0	32.2	-	32.4	-
13	-	36.0	-	10.8	28.8	-	0.7	-
14	-	-	-	4.9	0.4	-	4.3	-
15	-	-	-	0.7	-	-	0.4	-
16	-	-	-	4.2	18.2	-	-	-
17	0.1	-	-	0.6	-	-	-	-
18	-	-	-	1.5	-	-	-	-
19	-	2.9	-	1.2	1.2	-	-	-
20	-	0.3	-	10.0	8.2	-	-	-
21	6.2	-	-	-	18.9	-	-	-
22	15.4	0.2	-	-	3.8	1.0	-	-
23	-	-	-	-	-	3.5	-	-
24	-	-	-	-	3.7	-	-	-
25	-	-	-	4.8	-	-	-	-
26	39.5	-	-	-	-	-	-	-
27	3.2	-	-	-	-	-	-	0.7
28	-	4.9	-	-	-	-	-	-
29	-	5.5	2.3	-	5.3	-	-	-
30	-	0.2	4.9	-	3.5	-	10.4	-
31	-	15.1	8.4	-	-	-	17.0	-
Total	66.5	106.4	107.5	122.0	135.1	21.5	65.7	4.8
General total (November 2014-June 2015): 630 mm								

Long term total mean precipitation between November and June, wheat production season for Çukurova region was recorded as 558 mm. Total mean rainfall from November 2014 through June 2015 wheat production season was 630 mm which corresponds to %13 more rainfall compared to the last 30 years' average. During the wheat production season, the rainfalls recorded for the months of January, February, March and May were above the average of the last 30 years. In these months, %12, %49, %118 and %41 more rain was obtained, respectively.

2.2 Experimental Design and Tillage Systems

The experiment was designed in a randomized complete block where similar experimental units were grouped into the blocks or replicates. The treatments were conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow followed by no-tillage (RNT) for the second crop, and no tillage (NT). The tillage plots were 12 m wide and 40 m long (480 m^2). A buffer-zone of 4 m was reserved around each plot for tractor and, tillage equipment operations. The detailed information on treatments within each practice and sowing methods were given in detail by Celik et al. [6].

The rotation of winter wheat (*Triticum aestivum* L.)-corn (*Zea Mays* L.), winter wheat (*Triticum aestivum* L.)-soybean (*Glycine max.* L.) were applied in all tillage treatments from 2006 to 2014. In each growing season, the first crop was winter wheat and the second crop was either corn or soybean. Two weeks prior to sowing, the total herbicide (500 g ha^{-1} Glyphosate) was used to control weeds in the NT and RNT treatments. Compound NP-fertilizers were applied in the seedbed at the rates of 172 kg N ha^{-1} and 55 kg P ha^{-1} for wheat, 250 kg N ha^{-1} and 60 kg P ha^{-1} for corn, and 120 kg N ha^{-1} and 40 kg P ha^{-1} for soybean. Winter wheat was sown in the first week of November from 2006 to 2013 at a seeding rate of 240 kg ha^{-1}, and harvested in the first week of June 2007 to 2014. The second crop (corn or soybean) were sown in the third week of June, and harvested in the second week of October. Corn and soybean seeding rates were 8.4 and 23.6 plants per m^2, respectively. Soybean and corn were irrigated nine times by sprinklers in 13-day intervals. The amount of water applied for each irrigation was identical for all treatments and no irrigation water was applied to the wheat.

2.3 Soil Moisture Measurements

After the wheat planting, with the aim of monitoring and determining the effects of tillage practices on SWC, three time-domain reflectometry (TDR) probes were placed in each research plot and moisture measurements were performed from spring rains till wheat harvest (Figure 2). The moisture measurements were conducted on February 6, March 9, April 17, April 28, May 8, May 29 and June 8, 2015. Since the deepest tillage equipment had an impact on 30-32 cm depth, the TDR probes were placed in 0-30 cm depth.

Figure 2. Measuring with time domain reflectometer (TDR) in experimental plots

For the calibration of the moisture measurements made with TDR device, the gravimetric moisture content of the soil was measured on each measurement period. In order to convert gravimetric moisture measurement to volumetric moisture, bulk density was determined in the undisturbed soil samples taken from parcels and converted to the volumetric moisture (%) as shown on equation 1 [34].

$$\theta = \rho_b . P_w \tag{1}$$

θ: Volumetric moisture content (%),
ρ_b: Bulk density (g cm^{-3}),
P_w: Gravimetric moisture content (%).

In order to calibrate the volumetric moisture values measured with the TDR device, a calibration curve was created. The equation for the created curve was given on Equation 2. With the help of this equation, each moisture value measured in 0-30 cm soil depth with TDR device was calibrated.

$$y = 0{,}68x + 13{,}47$$
$$R^2 = 0{,}7914 \tag{2}$$

y: Calibrated volumetric moisture values (%).
x: Volumetric moisture value measured with TDR device.

2.4 Statistical Analyses

The effects of tillage practices on SWC was assessed by one-way analyses of variance test (ANOVA) using JMP statistical program. The least-significant difference (LSD) method was used for mean comparisons among different treatments. Differences among means of tillage treatments were reported at the 0.05 probability level.

3 Results and Discussion

3.1 Soil Water Content

Water contents of soils measured at different periods of wheat growing season were presented in Table 3. Tillage practices had significant effect on soil water retention measured in February 6, March 9, April 17 and May 8. The SWC decreased by time as precipitation decreased. The highest soil water contents in February 6 and March 9 were obtained under RT2 whereas the lowest soil water contents at the same measurements were obtained in CT2 treatment (Table 3). The differences in SWC for February 6 and March 9 measurements were distinct between CT that moldboard plow used and the rest of tillage systems. Higher moisture content retention of conservation tillage practices is a result of crop residues left on the soil surface which increased the water infiltration [13, 17, 23, 25, 30, 31, 32] and water storage capacity of soils [3, 4, 16, 25, 27]. The highest SWC in April 17 and May 8 were measured under RNT and CT2 systems, respectively. However, the lowest values were obtained in CT1 and RT2 practices in April 17 and May 8. Inconsistent results have been published on comparing soil hydraulic properties among different tillage systems. Lyon et al. [24] reported a significant increase in soil water retention under no-till practice, whereas McVay et al. [26] and Blanco-Canqui et al. [2] could not observe a meaningful change in soil water retention under no-till compared to reduced and conventional practices.

Table 3. Effects of different tillage treatments on soil water content

Tillage treatments	Measure times							
	6 February	9 March	17 April	28 April	8 May	20 May	29 May	8 June
	Soil water content (Volumetric, %)							
CT1	37.6±0.6^{d}	34.7±1.3^{c}	30.9±2.7^{c}	31.7±1.8^{a}	31.1±0.9^{abc}	32.3±0.6^{a}	31.6±0.6^{a}	32.5±0.8^{a}
CT2	37.8±0.6^{d}	35.7±0.7^{b}	33.4±1.8^{ab}	33.1±0.9^{a}	32.1±0.9^{a}	33.3±0.7^{a}	32.2±0.5^{a}	34.2±0.8^{a}
RT1	38.7±0.4^{ab}	37.9±0.4^{a}	32.2±1.5^{abc}	31.9±1.4^{a}	30.3±0.3^{c}	32.2±2.1^{a}	30.7±0.8^{a}	33.2±0.9^{a}
RT2	39.1±0.3^{a}	38.1±0.7^{a}	31.9±0.5^{bc}	31.0±1.3^{a}	29.9±1.8^{c}	32.0±1.4^{a}	31.9±1.7^{a}	33.4±1.3^{a}
RNT	38.4±0.6^{bc}	37.7±0.3^{a}	34.0±0.7^{a}	32.5±0.6^{a}	31.5±0.4^{ab}	32.3±0.7^{a}	31.5±0.2^{a}	33.0±1.0^{a}
NT	39.0±0.5^{ab}	37.8±0.5^{a}	31.8±0.7^{bc}	30.9±0.3^{a}	30.7±0.2^{bc}	31.7±0.6^{a}	31.3±0.9^{a}	34.2±0.8^{a}
LSD_{till}	0.16**	0.98**	2.00*	ns	1.22*	ns	ns	ns

*Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different (P < 0.05). *: Difference is significant at P ≤ 0.05 level, **: Difference is significant at P ≤ 0.01 level, ns: Difference is not significant. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow fallowed by no tillage for the second crop, NT: No tillage*

The moisture contents measured in February 6 and March 9 at all experimental plots were optimal for plant growth, and SWC under conservation tillage practices were higher compared to conventional tillage practices. The results showed that especially for the high moisture contents, conservation tillage practices retained higher moisture compared to conventional tillage practices. The absence of crop residue on soil surface under conventional practices may increase the formation of surface crust and consequently decreases the infiltration of water to soil. The SWC under conservational tillage systems decreased from April 17 to April 28, whereas SWC under CT1 and CT2 either not changed or slightly increased. The moisture contents under different tillage practices seemed was similar and non-significant in April 28 measurement.

The highest moisture content in April 17 was obtained under RNT treatment (34.0%) and this value was 10% higher than the CT1 (%30.9) that had the lowest value in April 17. As the SWC decreased with the evaporation and plant use, soil water content in May 8 under CT2 system was 6% and 7% higher than that obtained in RT1 and RT2 systems, respectively. The effects of tillage practices on soil water retention was not significant in May 20, May 29 and June 8 measurements. The precipitation (32.4 mm) occurred eight days prior to the May 20 measurement increased the soil moisture content compared to May 8 water content. Celik et al. [6] reported higher organic matter content under no-till (2.56%) compared to CT2 (1.48%) and CT1 (1.51%) systems at 0-15 cm depth. Indeed, increased organic matter content of soils is expected to increase ability of soils water retention. We have observed higher SWC under no-till system than CT system in rainy months of February and March, but the SWC was not significantly higher under no-till for the rest of the moths. Raws et al. [28] reported that soil water retention may or may not change with the change in soil organic carbon. Because soil water retention depends on clay content, initial organic matter content and site-specific interactions of clay and organic matter. High clay content of soil which has inherently high water holding capacity, may mask the effects of increased organic matter on water retention under no-till system. Blanco-Canqui et al. [2] recommended additional conservative practices such as addition of cover crops to improve hydraulic properties of soils under no-till management

3.2 Winter Wheat Yield

The tillage practices had no significant effect on wheat yield. The highest wheat yield was obtained under RT1 (6.29 t ha^{-1}), and the lowest (5.66 t ha^{-1}) yield was obtained under CT2 (Table 4).

Table 4. Effects of different tillage treatments on wheat yield

Tillage Treatments	Wheat yield (t ha^{-1})
CT1	6.10 ± 0.50^a
CT2	5.66 ± 0.79^a
RT1	5.96 ± 0.40^a
RT2	6.29 ± 0.67^a
RNT	6.11 ± 0.10^a
NT	6.24 ± 0.55^a

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different (P < 0.05). CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow fallowed by no tillage for the second crop, NT: No tillage

Total rainfall during 2014-2015 wheat growing season was %13 higher compared to the last 30 years average. High rainfall probably masked the effects of tillage practices on water retention and wheat yield. Our results are in accordance with the Anken et al. [1] and Kosutic et al. [20] who also no significant effect of tillage practices on wheat crop yield. On the contrary, some researchers reported lower wheat yield under conservation tillage practices compared to conventional tillage practices [14, 22]. The results showed that as an alternative to conventional tillage, reduced and no-tillage practices provided successful wheat crop production in a clay soil under a semi-arid Mediterranean climate.

4 Conclusions

The long-term (8-years) effects of six different tillage practices on SWC and wheat yield were evaluated. The results indicated that SWC under conservation tillage practices at rainy months was higher than that obtained under conventional tillage practices. Significant differences on SWC were obtained among tillage practices evaluated, whereas the effect of tillage practices on wheat yield was not statistically significant. The results of water content indicated that six tillage systems were similar in their ability to capture precipitation during wheat growing period. In spite of non-significant effect, wheat yield under no-till and one of the reduced till systems was higher compared to CT2 where moldboard plow is used and crop residue is burned. The results revealed that reduced and no-tillage practices can be an alternative to conventional tillage practices under Mediterranean climate. It is important to note that the data presented in this paper is belonged to a single season which had more rain than the long-term average. The differences among tillage systems can be better defined by monitoring hydraulic properties on a regular basis.

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