Impact of different tillage management on soil and grain quality in the Anatolian paddy rice production

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ABSTRACT

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The objective of this study was to examine the impact of conventional tillage (CT) and two different reduced tillage methods (RT1 and RT2) on some soil properties, grain yield and post-harvest grain quality during paddy rice production in the semi-arid Mediterranean conditions for two years. According to the results, soil bulk density was higher in CT with 1.46 and 1.47 g/cm^3, respectively for both years. N$_{tot}$ in RT1 was determined to be higher at a significant level with an average of 0.135%. The lowest soil organic carbon was found in the CT yearly as 2.91% and 2.50%. Penetration resistance did not exceed the limit value of 2–3 MPa in any method that may have impact on plant root growth. RT1 yielded higher results with regard to rice grain yield and provided the highest milling yield for both cultivars and years. There was no statistical difference among dry matter, thousand kernel mass and protein content values of rice grains in terms of cultivars, years and tillage factors. It can be observed in the light of short-term results that the RT1 is a good alternative for CT due to its positive impact on soil characteristics, grain yield and quality.

Keywords: rice quality; short-term tillage; paddy fields; puddling; *Oryza sativa* L.

Paddy rice is a source product that is used for feeding more than half of the world's population. Turkey meets 7.3% of the world's paddy rice production with a production area of 116 thousand ha (FAO 2017). As in all other production patterns, tillage in paddy rice production is carried out for manipulating the physical and chemical structure of the soil (Sharma et al. 2011), decreasing inter-plant competition and for creating a homogeneous seedbed. It is known that uniform tillage applications for products that are cultivated as mono-culture result in soil degradation (Gałązka et al. 2017). Especially, puddling applications in rice production may cause reverse degradations at this depth and below (Dengiz et al. 2017). The soil that mixes in with the water following the puddling application slumps down over time thereby covering the seeds. Reduced tillage or no-till applications should be tried for each production region thus putting forth the proper soil management models in order to overcome these negativities. Previous studies put forth that different alternative soil tillage strategies may have a positive or negative impact on various chemical properties of the soil such as soil organic content (C$_{org}$), nitrogen (N) content, pH and electrical conductivity (EC) values (Fabrizzi et al. 2009) in addition to bulk density, penetration resistance and soil aggregation (Ozpinar and Cay 2006). Moreover, post-harvest grain quality for rice is the most important factor for the supply of the product to the market and its pricing.

The objective of this pilot study for this region, carried out with support from private sector and producers, was to examine the impact of alternatively planned two different tillage methods on some soil properties, yield and quality for paddy rice production under the semi-arid Mediterranean conditions of north-western Anatolia in 2016–2017 rice production periods.

MATERIAL AND METHODS

Location, soil and climate. The study was carried out on a paddy field located in the Gönen Plains (Turkey) at coordinates of 40°15'N and 27°68'E in the north-western Anatolia. The slope is negligible for the field with an average elevation from sea level of 33 m a.s.l. and a size of 8 ha. Monoculture paddy rice production had been ongoing at the site for about 30 years. The study area and its environment has clay-loam characteristics (28.1% sand, 32.2% silt and 39.7% clay) with an alluvial structure and typical vertisol features (Efe 1999). Whereas the 0 to 30 cm soil structure characteristics put forth for the study area at the beginning of the trials were determined as organic carbon (C_{org}) (0.98%), pH (7.18), electrical conductivity (0.59 dS/m 1:2.5), total N (0.127%), available P (4.9 ppm), available K (258 ppm).

The climate is generally mild with warm summers, rainy and mild winters with typical Mediterranean climate conditions. Annual average temperature is around 14°C. Annual rainfall is around 650 mm with the highest amount of rainfall generally during October to April with almost no rainfall during the summer months. Total rainfall and average temperature data for a long-term period in the region along with data for the period when the study was taking place were shown in Figure 1.

Experimental details. The study was started at the end of October in 2015 and was conducted during the 2015–2016 and 2016–2017 rice production period. The experiment consisted of 3 different tillage methods. The first was conventional tillage (CT) which had been in use in the region for a long period and which is based on intensive field traffic. Two different reduced (RT1 and RT2) tillage strategies were determined as an alternative to this method. Tillage sequence in the CT method starts by deep ploughing (up to 40 cm) stubble from the previous year using mould-board plough. Paddy fields are formed in the CT method after rotary tilling following chisel plough + heavy cultivator (twice diagonally) + goble disc harrowing after a second ploughing operation (approx. 30 cm) in April. Rolling and laser-supported levelling are carried out for regulating the flow and discharge of irrigation water. Special ditcher ploughs are used to form ridges for keeping the water inside while forming the paddy fields. Soil tillage was not continued in the fall season in RT1 application planned as an alternative to CT and paddy fields were formed in the beginning of April following chisel ploughing, heavy disc harrowing and rotary tilling. Water was released on the second day following the pre-weed spraying applied after laser supported levelling and plantation was completed using a centrifugal broadcast sowing machine.
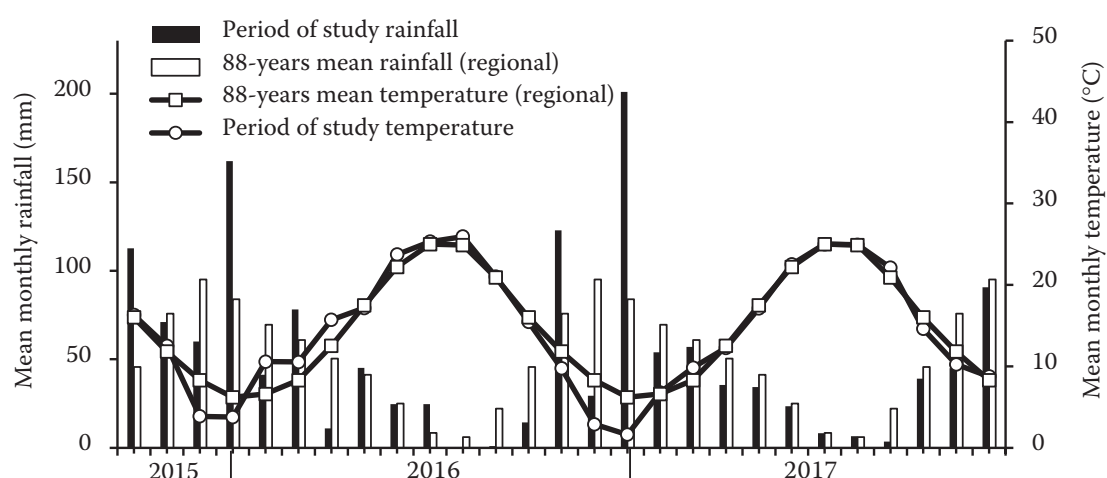

Figure 1. Mean temperature and monthly rainfall values of the experimental area for the trial and the long-term periods

While in the RT2 application, the paddy fields from the previous year were not removed and heavy disc harrow + heavy cultivator + levelling + pre-spraying, water release and sowing operations took place directly in the spring.

Sowing operations were carried out by casting the seeds using a fertilizer spreader, which is frequently used in the region in order to attain uniform seed and plant distribution. Oxadizon (300 g/ha), trifloxystrobin (200 g/ha) and penoxsulam (20.2 g/ha) were applied equally in all the field against fungi and weeds. A total of N (21 kg/ha), P (6 kg/ha) and K (8 kg/ha) were also applied equally in all methods as plant nutritional material during the production period and twice after sowing. Each tillage method was considered as a main factor on 240 × 100 m parcels during the experiment setup according to a split plot experiment design with two different rice (*Oryza sativa* L.) cvs. Baldo and Osmancık taken into consideration as split factors. Sowing procedures were carried out during the first week of May in both years and cv. Baldo was harvested during the first week of September, while cv. Osmancık was harvested during the second week.

Measurement procedures. Undisturbed soil sampling cylinders with a volume of 100 cm^3 were used for determining soil bulk density (BD). Sampling was carried out for BD and soil total porosity (TPO) during the periods when the root growth and activity of paddy rice was completed after harvesting. TPO was calculated from the BD values by using Eq. 1:

$$\text{TPO} = [1 - \delta_b/\text{BD}] \times 100 \qquad (1)$$

Where: δ_b – soil particle density; BD – soil bulk density. Samplings and calculations were carried out according to Blake and Hartge (1986).

Penetration resistance (PR) measurements were carried out after each harvest using a digital penetrologger (Eijkelkamp Equipment, Model 06.15 Eijkelkamp, Giesbeck, the Netherlands). Samples (0–15 cm) were collected in both years of the study from the seedbed immediately after the completion of tillage and prior to sowing in order to determine the soil aggregate size distribution. Soil samples randomly collected with three replications were then left to air-dry until the change in moisture at room temperature stopped, thus removing all foreign substances. Afterwards, steel sieves with average diameters of 0.25, 0.5, 1, 2 and 4 mm were used and sieving was carried out about 30 s at 50 Hz frequency (Altikat and Celik 2011). Mean weight diameter (MWD) of soil aggregates were calculated from the soil sample weights retained on each sieve opening using Eq. 2. C_{org} and N_{tot} analyses were carried out using soil samples and the carbon-nitrogen device that operates according to the Dumas dry combustion method:

$$\text{MWD} = \sum_{i=1}^{n} X_i W_i \qquad (2)$$

Where: X_i – mean diameter of size class midpoint; *n* – number of size fraction (5); W_i – proportion of total sample retained on the sieves.

Harvesting operations were carried out as three repetitions for each parcel on areas of 10 m^2 randomly selected manually. Harvested grains were dried in air-assisted driers until their moisture level reached about 14% for ensuring that they can withstand post-harvest operations such as cleaning and classification. Rice samples were then cleansed of both the husk and broken parts using a milling device (Zaccaria PAZ-1 DTA, Limeira, São Paulo, Brasil) with rubber rolls thus reaching the net whole kernels amount. The milling yield (MY) values were calculated by proportioning with the initial paddy rice amount. A total of 250 pieces of rice were counted and weighed for thousand kernel mass (TKM). In addition, the samples ground for PC, DM, FY content were scanned in the NIR device (Spectrastar 2400D, UnityScientific, Milford, USA). Infostar^{TM} software (UnityScientific, Milford, USA) and library were used for procedures related with sample spectra. Minitab V17 statistical software (StatSoft, Inc. Tulsa, USA) was used for analysing the data. ANOVA (one-way) analysis of variance and the Tukey's multiple comparison tests were applied at a level of *P* < 0.05.

RESULTS AND DISCUSSIONS

The BD and TPO values which are very important for rice root development in both years were determined to be higher in the CT method (1.47 and 1.46 g/cm^3) in comparison with the RT1 and RT2 (Table 1). The higher BD and lower TPO values acquired in the RT2 method were determined comparing with those acquired in the RT1 and CT methods in both years. This is an indication that

Table 1. Influence of tillage practices (CT, RT1 and RT2) on bulk density (BD), soil total porosity (TPO), total nitrogen (N_{tot}), organic carbon (C_{org}), pH and electical conductivity (EC) of soil (tested soil depth 0–30 cm)

	Treatment	BD (g/cm^3)	TPO	N_{tot}	C_{org}	pH	EC (dS/m)
			(%)				
2016	CT	1.47 ± 0.09[a]	0.44 ± 0.07[b]	0.09 ± 0.01[b]	2.91 ± 0.03[ns*]	7.26 ± 0.05[b]	0.34 ± 0.04[b]
	RT1	1.37 ± 0.02[b]	0.48 ± 0.02[a]	0.13 ± 0.01[a]	3.22 ± 0.17	7.49 ± 0.12[ab]	0.41 ± 0.05[b]
	RT2	1.41 ± 0.04[a]	0.47 ± 0.02[a]	0.10 ± 0.01[b]	3.36 ± 0.21	7.53 ± 0.11[a]	0.58 ± 0.06[a]
2017	CT	1.46 ± 0.05[a]	0.45 ± 0.02[b]	0.10 ± 0.01[b]	2.50 ± 0.20[ns]	7.48 ± 0.12[ns]	0.51 ± 0.08[a]
	RT1	1.34 ± 0.03[b]	0.49 ± 0.03[a]	0.14 ± 0.02[a]	3.18 ± 0.14	7.43 ± 0.10	0.46 ± 0.11[ab]
	RT2	1.35 ± 0.07[b]	0.49 ± 0.03[a]	0.11 ± 0.01[ab]	3.25 ± 0.24	7.37 ± 0.11	0.35 ± 0.06[b]

Values are means ± standard errors of three soil samples. Different letters indicate statistical significance ($P < 0.05$) for in-column comparisons for each year; ns – no significant difference; CT – conventional tillage; RT – reduced tillage methods

the chisel ploughing, heavy-disc harrowing and rototiller applications in the RT1 may have positive impacts on reducing compaction at sampling depths. This increase related with the intensity of autumn and spring tillage applications in the CT method also reduced the TPO values. In addition to these findings, the N_{tot} values were found to be higher for the RT1 method with lower BD and higher TPO at statistically significant levels in both years respectively as 0.13% and 0.14%. Even though it is reported in similar studies that traditional tillage applications may generally have adverse impacts on TPO (Tangyuan et al. 2009), it is put forth that N_{tot} changes may result in different reactions in the Mediterranean climate belt according to climate and crop requirements in addition to soil struc-

ture (Ozpinar 2006). Contrary to high compaction indicators (BD and TPO) determined in the CT, the C_{org} values in this method were found to be numerically lower in comparison with other methods. However, no statistically significant difference with regard to C_{org} values was detected between the tillage methods. Similarly, it was reported in a study carried out close to the study area that the C_{org} ratio is not affected from tillage methods (Çakir et al. 2010). It was stated in another study that puddling may trigger compaction especially on CT parcel areas subject to mouldboard-plough application and that high BD values along with cracks may occur after the harvest (Bhagat 2003). Furthermore, it can be concluded that the release of C_{org} to the atmosphere may be reduced in rice
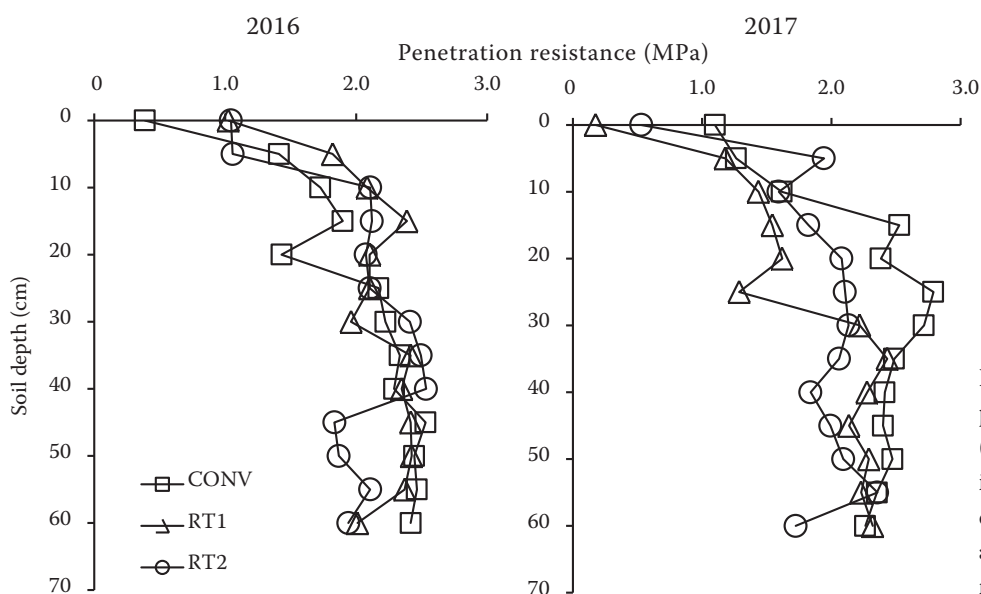

Figure 2. Change of soil penetration resistance (PR) with depth measured in different tillage methods. CT – conventional tillage; RT – reduced tillage methods

Table 2. Effect of tillage systems on dry aggregate size classes and mean weight diameter (MWD)

Tillage system	Dry aggregate size groups				MWD
	> 4 mm	4–2 mm	2–0.5 mm	< 0.5 mm	
	(%)				
2016					
CT	69.4[ns]	3.73[b]	14.69[a]	12.16[ns]	3.21[ns]
RT1	71.03	3.93[b]	11.51[b]	13.52	2.86
RT2	67.97	5.10[a]	11.36[b]	15.55	3.26
2017					
CT	68.69[ns]	4.72[a]	9.46	17.12[a]	2.97[ns]
RT1	72.32	3.42[b]	10.53	13.71[b]	2.64
RT2	70.30	3.86[b]	10.35[ns]	15.48[ab]	2.82

Values are means, different letters indicate statistical significance ($P < 0.05$) for in-column comparisons for each year. ns – no significant difference. CT – conventional tillage; RT – reduced tillage methods

cultivation by way of conservational tillage applications (Shao et al. 2007).

While the highest pH was determined as 7.53 with the RT2 during the first year of the study, these values were measured as 7.26 for CT and 7.49 for RT1. No statistically significant difference was found between the methods during the second year and the values were measured as 7.48, 7.43 and 7.37 for CT, RT1 and RT2, respectively. All measurements for pH values in the study indicated that the pH class is at the sub-alkaline level. In this sense, it was determined that the pH values remain in normal limits in all methods as stated by Dunjó et al. (2003) for plant production.

EC values ranged between 0.34 and 0.58 ds/m for all tillage methods. While the highest EC in 2016 was measured as 0.58 ds/m for the RT2 method, it was found that RT2 had the lowest value in 2017 with 0.35 ds/m. In this case, it is possible to state that RT applications may cause a decrease in EC values over time. Different RT or CT management methods may be used for regulating soil EC in areas with salinity issues, however, EC may generally be affected not solely from tillage but also other interactions such as N fertilization etc. (Tabaglio et al. 2009). In addition to these results, even though PR values did not show any statistical difference between the tillage factors, it was observed that RT1 and RT2 methods provided lower PR values than the CT at the root growth depth of 10–30 cm (Figure 2). It was seen that the acquired PR values did not exceed the limit value of 2–3 MPa in any method, which may affect plant root growth and health (Håkansson and Lipiec 2000). In addition, the change in the values of both years was quite limited and stable for RT2 method in which PR paddy fields were used in the second year without any degradation. It was put forth in a study carried out that high soil moisture content of paddy fields with water inside them may have triggered the increase of PR values in the traditional method together with excessive tillage (Bhagat et al. 1994).

The highest fine aggregate (< 0.5 mm) ratio obtained with CT in 2017 was 17.2% (Table 2). In other words, the fine aggregate ratio determined for the CT method in 2017 was 19% higher than that of RT1 and 16% higher than that of RT2. In the light of this result, it is possible to put forth that the first year responses of reduced tillage methods applied against CT may be low, but that
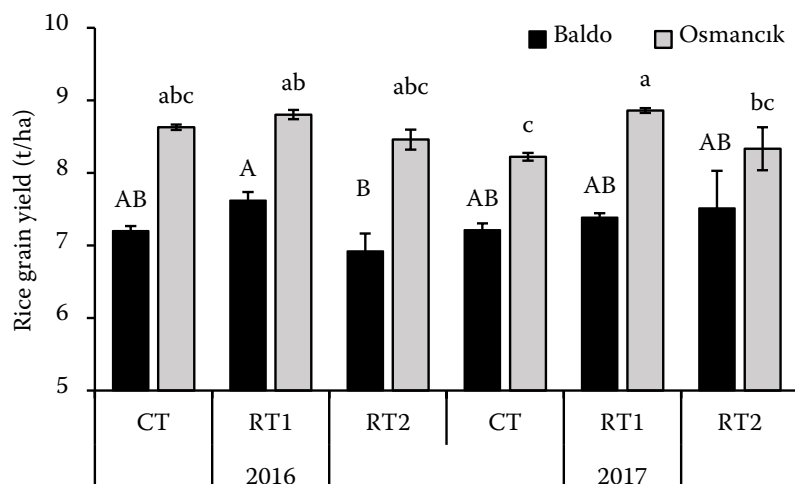

Figure 3. Rice grain yields based on rice cultivar and tillage methods in 2016 and 2017. Different upper and lower case letters indicate statistical significance ($P < 0.05$). CT – conventional tillage; RT – reduced tillage methods

Table 3. Influence of tillage systems (CT, RT1 and RT2) on post-harvest grain quality

		MY	DM	TKM	PC	FY
		(%)				
Cv. Baldo						
	CT	54.02[b]	87.9[ns]	29.5[ns]	9.2[a]	5.8[a]
2016	RT1	56.90[a]	88.3	30.6	7.2[b]	4.1[b]
	RT2	56.85[b]	87.9	28.9	8.5[a]	4.8[b]
	CT	55.50[b]	87.3[ns]	29.6[ns]	8.9[ns]	4.0[ns]
2017	RT1	57.41[a]	87.3	30.3	7.4	4.2
	RT2	55.37[b]	86.4	29.1	8.0	4.4
Cv. Osmancık						
	CT	58.7[a]	88.5[ns]	24.7[ns]	8.6[ns]	5.0[ns]
2016	RT1	58.8[a]	88.4	25.2	9.1	4.9
	RT2	57.3[b]	88.3	24.6	8.7	4.7
	CT	58.6[ns]	87.3[ns]	24.7[ns]	9.1[ns]	4.74[ns]
2017	RT1	59.0	87.2	24.7	8.9	4.97
	RT2	57.1	88.2	25.0	8.8	5.08

MY – milling yield; DM – dry matter; TKM – thousand kernel mass; PC – protein content; FY – fiber yield. Values are means, different letters indicate statistical significance ($P < 0.05$) for in-column comparisons. ns – no significant difference. CT – conventional tillage; RT – reduced tillage methods

a significant difference develops in the following year. RT methods had a positive impact on the decrease of fertile fine aggregates removed with the water discharged in paddy rice production in which irrigation water is continuously discharged. MWD values vary between 2.64 mm and 3.21 mm for all tillage methods and no statistically significant difference was detected among the methods. It can be observed that coarse aggregates (> 4 mm) had the highest value in both years in the RT1 method. However, no statistically significant difference was determined between the coarse aggregate distributions. Although the higher MWD was emphasized in the conventional tillage method in which mouldboard plough was used (Altıkat and Çelik 2011), it was reported in another study that the higher MWD could also be provided with no-till application (Mrabet et al. 2001). In addition, while excessive tillage forces reduced soil aggregation, it may also decrease C_{org} (Fabrizzi et al. 2009).

The cumulative grain yield results were shown in Figure 3. The lowest grain yield for cv. Baldo was determined in 2016 for the RT2 method. There was no statistical difference between CT and RT1 methods in both years. CT was determined to have the lowest yield in 2017 (8.22 t/ha). The RT1 method yielded the highest yield values in both years for the cv. Osmancık with values of 8.80 and 8.86 t/ha, respectively. Hormozi et al. (2012) reported that the puddling method had positive or negative effects for increasing production. Tillage in the following year is almost obligatory since the soil is moist during the harvest of paddy rice with combine excluding puddling and zero tillage options that are limited in these areas. It was reported in a similar study on paddy rice production at vertisol soils of India that direct seeding together with traditional tillage application is the best method to increase grain yield.

The post-harvest grain quality parameters obtained in the experiments are given in Table 3. RT1 provided the highest value of MY for both cultivars and years. There was no statistical difference between DM, TKM, PC values in terms of cultivars, years and tillage factors. The RT1 seems to be a successful alternative to the CT method which is applied intensely at the region, both in terms of yield and post-harvest quality.

Acknowledgements

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