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RESEARCH ARTICLE

# EVALUATING SELECTED SOIL PHYSICAL PROPERTIES UNDER DIFFERENT SOIL TILLAGE SYSTEMS IN ARID SOUTHEAST RAWALPINDI, PAKISTAN

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**ABSTRACT**

Tillage is a critical soil management option that affect many soil physical, chemical and biological properties, which in turn may alter the soil environment and consequently impact on root growth and distribution, and crop yield. This study was carried out to evaluate the long-term effects of different soil tillage systems on some soil physical properties under both irrigated and rainfed wheat productions for nine consecutive wheat seasons (2011-12 and 2019-20) at Koont research farm, PMAS-Arid Agriculture University, Rawalpindi. Four soil tillage systems were performed i.e. conventional tillage system ($S_1$), reduced tillage system-1 ($S_2$), reduced tillage system-2 ($S_3$) and no tillage system ($S_4$). The results showed that soil moisture content measured at both soil depths (0-15 and 15-30 cm) was the maximum in direct sowing ($S_4$) and lowest in conventional soil tillage system ($S_1$). Bulk density and porosity were changes with tillage depth. Among studied tillage systems, bulk density and penetration resistance values were the maximum and porosity was lowest in direct wheat sowing system. Soil particle size distribution was affected by operations and agricultural machinery used in soil tillage systems. The aggregate size smaller than 1 mm showed higher fragmentation (42.25%) in $S_3$. This study showed that soil physical properties were influenced by tillage systems in wheat production under irrigation and rainfed environment. Although the climate of the study area is semi-arid and direct sowing system provide maximum moisture but reduced tillage method can be used for better soil physical properties and highest crop yield.

**KEYWORDS**

wheat, arid climate, soil tillage systems, soil physical properties.

## 1. INTRODUCTION

Tillage is one of fundamental agro-technical operations in an agricultural process applied to regulate and maintain the physical, chemical and biological balances of soil properties. The aim of tillage in crop production is to produce favorable physical conditions for seed germination and plant growth (Jabro et al., 2011). It is also an important soil management option for weed control, seed bed preparation, root growth stimulation, soil moisture control, soil temperature control, soil compaction alleviation and incorporation of crop residues and manure. However, an intensive soil tillage can lead to degradation of soil structure, due to the gradual loss of stable aggregates, leading to soil erosion and compaction, which will result in low moisture availability for plants (Castellini and Ventrella, 2012). In turn, this may affect plant nutrient availability, growth and root proliferation. Results on the effect of tillage in soil physical properties, to date, have been rather ambiguous, and sometimes contradictory. In some cases, in Latin America and Spain, no tillage results in high bulk density values in the surface, low infiltration rates, and less crop yield, compared with conventional tillage (Salem et al., 2015; Alegre et al., 1991). In another study, bulk density, in a loamy soil in a semiarid region with a cool climate in Turkey, increased significantly after 12 years of no tillage (Gozubuyuk et al., 2014). On the other hand, a site managed with no tillage for nine years in a silty loam soil in China resulted in a decrease of the bulk density and a significant increase of infiltration capacity. In this case, the improvement in soil physical conditions was due to an increase in the formation of macro aggregates, which was attributed to decreased soil disturbance and the addition of crop residues (Huang et al., 2015).

It is known that excessive tillage reduces the organic matter content of the soil, increases the probability of wind and water erosion due to insufficient surface residues, and causes soil compaction due to field traffic. Optimizing the soil for cultivated plants and making it sustainable is possible by cultivating the soil. With regard to ecological and economical aspects, the discussion about conventional tillage system, conservation tillage systems and no-tillage system seems to be increasingly important. These nonconventional soil tillage systems are aimed to develop favorable soil conditions and save energy. In enterprises applying modern agricultural techniques, determining the appropriate tillage-sowing system in order to reach maximum productivity and completing the production works on time is one of the most critical decisions for the

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enterprises. Since tillage strongly influences the physical properties of soil, it is important to apply that type of technology that will make it possible to sustain physical properties at a level suitable for normal growth of agricultural crops.

Soil tillage is generally the process of changing the physical condition of the soil in order to provide the necessary conditions for plant cultivation and it is the process in which the most energy is consumed in agricultural production activities. It is aimed to produce at least without interfering with the soil in the protective tillage and sowing application without disturbing the physical, chemical and biological structure of the soil. This method is the method of planting where enough plant remains are left on the surface to protect the soil from erosion throughout the year. Soil physical properties represent a group of properties having a substantial impact on the different physical-chemical and biological processes in soil and hence they should be kept optimal (Lal 1991). For this reason, it is essential to know the soil physical properties not only during the growing season, but also after the harvest of agricultural crops. They may condition the potential of growing crops in crop rotation as well as the choice of the soil tillage method.

Many authors examined influence of different tillage systems on the soil physical proper- ties. Based on a recent study the effect of no tillage, vertical tillage and conventional tillage on physical soil properties and on oat yields, in a semiarid area of Mexico and found that tillage systems did not have a significant effect on the physical properties of the soil, nor on the yield of oats due to short range results (Altuntaş and Dede, 2007). Shittu et al., conducted a field experiment to examine the effects of different moisture contents at tillage on selected soil physical properties in maize crop production in south western Nigeria (Shittu et al., 2017). It was concluded that the choice of appropriate moisture content before tillage is critical for maintenance of optimum soil physical properties necessary for sustainable agriculture. Then a study evaluated the effects of tillage practices on soil physical properties in Mwala district, Eastern Kenya, received insignificant results due to short-term study, and recommended long long-term investigation for significant results (Karuma et al., 2014). A recent research carried a field experiment to evaluate different less intensive tillage systems on soil physical properties and crop yield in a subtropical dry land of Pakistan and concluded that that minimum tillage and disc plough can be used as an alternative to conventional intensive tillage systems for better soil physical health and wheat crop (Hussain et al., 2013). Others study examined traditional soil cultivation method (eared plow + cultivator + toothed rake), reduced soil cultivation method (chisel + toothed rake) and soil and back sowing methods of physical soil properties (soil moisture content, bulk density and penetration resistance) (Altuntaş and Dede, 2007). Moisture content, bulk density and penetration resistance values of 0-10 and 10-20 cm depths were (24.39-25.42 %, 1.24-1.33 g cm$^3$, 0.58-1.18 MPa) and (25.70-26.0 %, 1.25-1.34 g cm$^3$, 0.95-1.60 MPa), respectively. Taa et al. examined the effects of traditional tillage and stubble direct sowing methods on yield and yield components and soil properties in wheat and found that the amount of water accumulated in the stubble direct sowing method was 40% more than traditional tillage method and obtained more yields (Taa et al., 2004). A research stated that traditional soil tillage decreases the aggregate stability of the soil, the total and macro porosity of the soil at the depth of cultivation increases, minimum soil tillage below the better results for the soil stability gives better soil stability, the traditional soil tillage reduces the soil, density and dispersion resistance (Hermawan and Cameron, 1993). Based on previous studied the effects of three conventional soil tillage systems on soil physical properties. The moisture content, bulk density and penetration resistance of soil increased with the increase in field traffic and soil profile depth (Oni and Adeoti, 1986).

Irrigated and rainfed wheat production in arid and semi-arid regions of Pakistan is generally practiced under conventional tillage systems while soil physical degradation in agricultural production systems of such kind of environment has always been a major concern. However, there are no recorded data or experiences on the influence of different tillage systems on the soil physical properties in agroclimatic conditions of the arid region of southeast Rawalpindi. The general objectives of this study were to determine the influence of different soil tillage system on the soil physical properties and their influence on crop yield under both irrigated and rainfed wheat productions. This study is unique in term of its application because the field experiment was conducted for irrigated wheat and rainfed wheat using long-term data, which is done first time in our area.

Similarly, the literature studies suggested the long-term investigation in order to determine the effects of tillage methods, in particular environmental conditions. In this study, instead of traditional soil tillage methods the alternative soil tillage system has been investigated with field experiment to evaluate the selected soil physical properties under irrigated and rainfed agricultural conditions (Ordoñez-Morales et al., 2019; Karuma et al., 2014).

## 2. Material and Methods

The field experiments were carried out for nine cultivation years (2011-12 and 2019-20) for wheat production in the research field of Koont research station Chakwal, PMAS-Arid Agriculture University, Rawalpindi. Research area (semi-arid to sub humid, sub-tropical continental) is located between 33° 1' N to 33° 6' N and longitude 73° 30' to 73° 45' E southeast of Rawalpindi as shown in Figure 1. The soil texture at experimental site was sandy clay loam (56% sand, 22.8% silt, 21.2% clay) with a pH of 7.7. The bimodal rainfall occurs in late summer and winter season. Generally, about 60-70% rainfall received in monsoon season (15-June to 15-September). However, winter rainfall occurs as gentle showers of longer duration, and thus, are more productive for agriculture (Shafiq et al., 2005). Mean monthly rainfall and temperature data were also recorded.

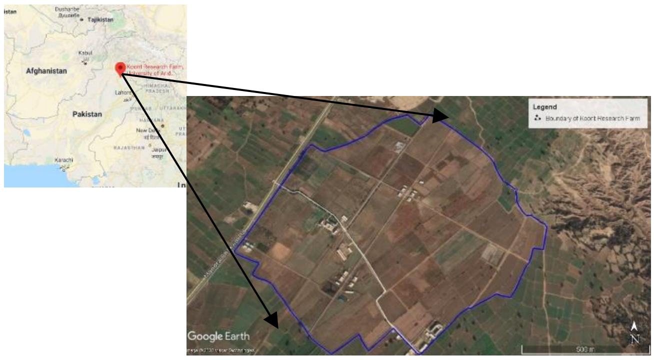


**Figure1:** Study area

### 2.1 Cultivation Methods

Tillage modifies the soil physical properties. Conventional tillage involves the mechanical soil manipulation of an entire field, by ploughing (inverting the soil) followed by one or more harrowings. The most common conventional tillage practiced in study area involves the use of MB plow and disc harrow in wet condition or cultivator in dry condition followed by planker and sowing machine. To promote the capture and conservation of water in agricultural systems in arid and semiarid regions, conservation tillage practices are important, in that they can contribute to avoiding soil degradation by compaction. Zero or no tillage with direct planters, do not invert the soil and leave crop residues on the surface. The conventional tillage system not only needs a high energy input but also results in soil physical degradation while reduced tillage systems are effective in improving soil physical properties. Reduced tillage minimizes soil disturbance and allows crop residues to remain on the ground instead of being thrown away or incorporated into the soil.

Soil cultivation methods applied in this experiment carried out on parcels of 2,023 m$^2$ (0.5 acre) were;

- ✓ $S_1$, Conventional tillage (mouldboard plow + disc harrow (in wet conditions) –cultivator (dry conditions) + planker + sowing machine)
- ✓ $S_2$, Reduced tillage-1 (cultivator + planker + sowing machine)
- ✓ $S_3$, Reduced tillage (rotavator + sowing machine)
- ✓ $S_4$, Direct sowing (direct sowing machine)

### 2.2 Soil Physical Properties

Effect of tillage on soil compaction and plant growth was evaluated (soil penetration resistance) using three repetitive measurements after different soil tillage (0–10, 10–20, 20–30 cm) by following the recommendation of Bradford et al., (1986). Soil samples were taken from 0-5 and 10-15 cm soil depth after the tillage with three replications and then taken to lab for bulk density, porosity and moisture content determination. A 5 cm diameter and 100 cm$^3$ volume soil sampler was used to collect soil samples. Soil samples taken from each plot after about

3 kg of effective working depth have hole diameters of 1, 2, 4, 8, 16, 32, 63 mm with 200 mm pulley diameter. Eghball and Maranville, (1993) prescribed method was used and soil samples were divided into 8 separate fractions and calculations were made according to the optimum particle spacing fractions in the diameter range of 1–8 mm (Bradford et al., 1986; Eghball and Maranville, 1993.

Soil samples taken from the effective working depth of each system were screened in order to reveal the effects of soil tillage methods after tillage. Six different fractions were obtained by dry sieving in rotary sieves based on five different diameter groups of 0.42, 0.84, 2.00, 6.40, 12.70 mm diameter.

### 2.3 Statistical Analysis

In this study, soil tillage methods, soil weight, porosity, moisture, penetration resistance, mechanical stability and particle distribution values were compared by using ANOVA separately under irrigated and dry farming conditions. In the analysis of variance, the effects of the methods on the parameters examined were investigated according to the significance level of 1% and 5%, separately and the groups from which the difference originates were made based on the 5% significance level by means of multiple comparison tests.

## 3. Results

### 3.1 Soil Physical Properties

### 3.1.1 Bulk Density, Porosity and Moisture Content

The effect of different tillage – sowing methods on soil physical properties were examined and variance analysis values are given in Table 1 and average comparison values are given in Figure 2–3–4 and 5. The effect of soil tillage subjects on the volume, porosity and moisture values of the soil were significant differences in different cultivation processes (years) and different agricultural conditions (wet-dry) at P <0.01 and P <0.05 levels.

**Table 1:** Variance analysis values of soil physical properties

| Parameter | Source of variance | df | Analysis of Variance, P Values | | | |
|---|---|---|---|---|---|---|
| | | | Wet | | Dry | |
| | | | 0–5 | 10–15 | 0–5 | 10–15 |
| Density (g cm$^{-3}$) | Year | 2 | 0.042* | 0.096 | 0.005** | 0.276 |
| | TİC | 3 | 0.003** | 0.003** | 0.342 | 0.603 |
| | Block | 2 | 0.080 | 0.911 | 0.576 | 0.261 |
| Porosity (%) | Year | 2 | 0.042* | 0.096 | 0.005** | 0.276 |
| | TİC | 3 | 0.003** | 0.003** | 0.342 | 0.603 |
| | Block | 2 | 0.080 | 0.911 | 0.576 | 0.261 |
| Humidity (%) | Year | 2 | 0.001** | 0.098 | 0.010** | 0.018* |
| | TİC | 3 | 0.440 | 0.338 | 0.059 | 0.000** |
| | Block | 2 | 0.238 | 0.035* | 0.081 | 0.133 |
| MSD OPD (%) | | | MSD (>0.84) | OPD (1-8) | MSD (>0.84) | OPD (1-8) |
| | Year | 1 2 | 0.702 | 0.000** | 0.100 | 0.000** |
| | TİC | 3 3 | 0.102 | 0.000** | 0.069 | 0.000** |
| | Block | 2 2 | 0.320 | 0.249 | 0.252 | 0.249 |

| Parameter | Source of variance | df | 0-10 | 10–20 | 20–30 | 0-10 | 10–20 | 20–30 |
|---|---|---|---|---|---|---|---|---|
| Penetration Resistance (MPa) | Year | 2 | 0.042* | 0.269 | 0.016* | 0.021* | 0.459 | 0.983 |
| | TİC | 3 | 0.000** | 0.000** | 0.000** | 0.000** | 0.000** | 0.000** |
| | Block | 2 | 0.158 | 0.893 | 0.130 | 0.638 | 0.961 | 0.891 |

** P <0.01 significant; * Important TIC at P <0.05: Tillage treatments; MSD: Mechanical Stability Values; OPD: Optimum Particle Distribution

The effect of soil tillage-sowing methods on bulk density, porosity and penetration resistance values in irrigated agricultural conditions and all soil layers were found significant at P <0.01 level. The effect of soil tillage – sowing methods at all depths measured in moisture and penetration resistance values of 10–15 cm soil layer under rainfed conditions was found significant at P <0.01 level. The effects of soil tillage methods on wind erosion (mechanical stability) were found insignificant in both agricultural conditions. The effect of soil tillage – sowing methods was significant at P <0.01 level in both agricultural conditions in soil particle size distributions of 1–8 mm which are important for optimum seed bed.

The highest bulk density (1.29–1.40 in irrigation conditions, 1.30–1.32 g cm$^{-3}$ in dry conditions) and consequently the lowest porosity values were obtained from direct cultivation (S4) method and other methods had similar effect. The effect of soil tillage – sowing methods on moisture values was significant at 10–15 cm layer in P <0.05 level under rainfed conditions, but no effect on other layers (Figure 2). The highest moisture values were obtained from the direct sowing method (15.1–17.2% in irrigated conditions, 7.2–9.3% in dry conditions) and the lowest values were obtained from traditional soil cultivation – sowing method (Figure 3).

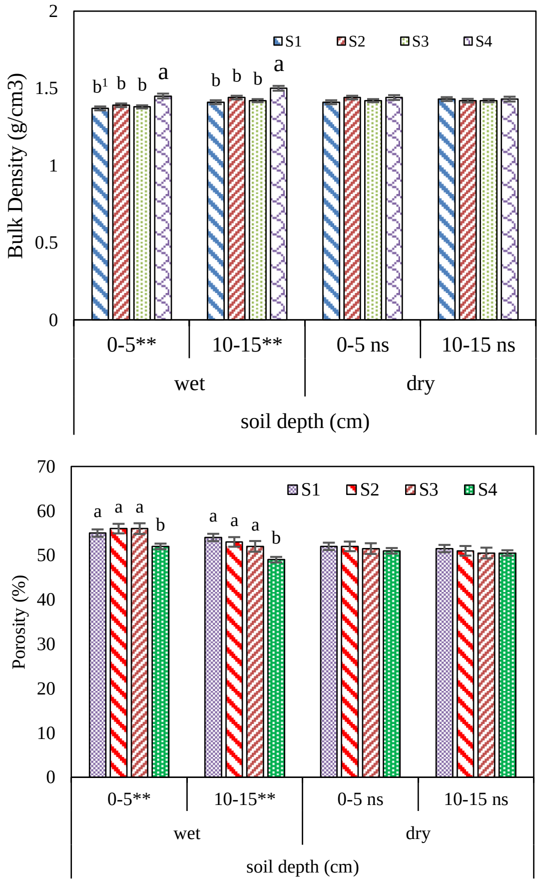


**Figure 2:** Average comparison results of bulk density and porosity

** P <0.01 significant; ns: non-significance; [1]The difference between the means with the same letter is statistically insignificant. S1: Conventional tillage, S2: Reduced tillage-1, S3: Reduced tillage-2, S4: Direct sowing

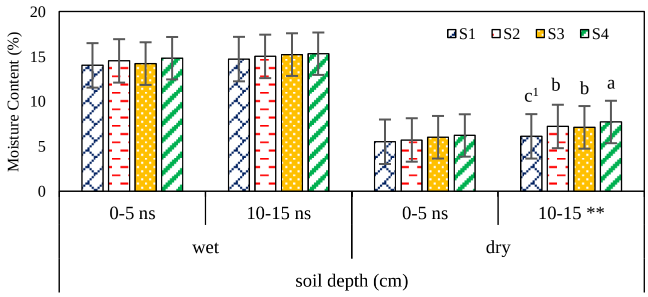


**Figure 3:** Average comparison results of moisture values

[1]The difference between the means with the same letter is statistically insignificant; S1: Conventional tillage, S2: Reduced tillage-1, S3: Reduced tillage-2, S4: Direct sowing

### 3.1.2 Soil Penetration Resistance Values

The penetration resistance values which are important for plant root development were obtained from the traditional application with the lowest soil cultivation depth (20-25 cm) in both cultivation conditions and the highest resistance values were obtained from direct sowing method (Figure 4).

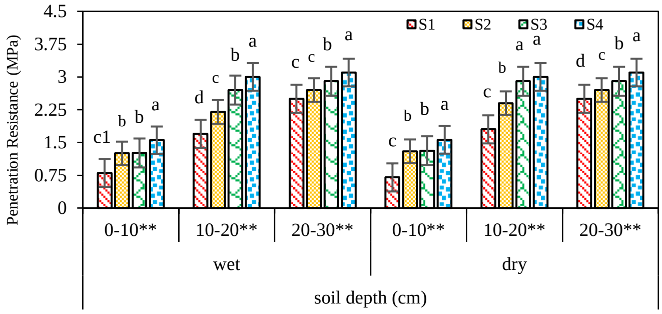


**Figure 4:** Average comparison results of penetration resistance values

[1]The difference between the means with the same letter is statistically insignificant; $S_1$: conventional soil tillage, $S_2$: Reduced soil tillage-1, $S_3$: Reduced soil tillage-2, $S_4$: Direct sowing

### 3.1.3 Soil Mechanical Stability and Particle Distributions

In order to determine the effect of different soil tillage applications on mechanical stability of soil, mechanical stability values of soil aggregates after the first sieve were determined (Table 2). In this study, it was determined that the ratio of non-erodible fractions (> 0.84) to erodible (<0.849) fractions was around two thirds by weight and this was accepted as an indication that the soil was more resistant to wind erosion (Chepil and woodruff, 1957). In aggregate stability analysis made from non-wearable particles (> 0.84), it was found that tillage-sowing methods were resistant to wind erosion (96.9% and 98.6%) and no effect of tillage practices in both agricultural conditions (Figure 5).

**Table 2:** Dry aggregate percentage values in different tillage applications

| Fraction diameter (mm) | Tillage-Sowing Methods | | | |
|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
| < 0.42 | 23.98 | 25.34 | 25.19 | 22.18 |
| 0.42 – 0.84 | 7.82 | 7.57 | 8.40 | 9.04 |
| 0.84 – 2.00 | 14.29 | 14.27 | 16.24 | 16.13 |
| 2.00 – 6.40 | 19.09 | 18.55 | 19.91 | 21.04 |
| 6.40 – 12.70 | 23.97 | 23.58 | 22.42 | 25.89 |
| 12.70 > | 10.84 | 10.68 | 7.84 | 5.72 |
| Non-wearable granules (> 0.84) | 68.19 | 67.09 | 66.41 | 68.78 |
| Wearable particles (<0.84) | 31.81 | 32.91 | 33.59 | 31.22 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |
| Stability index | 2.14 | 2.04 | 1.98 | 2.20 |

It was determined that the effect of the subjects in the range of 1–8 mm, which is considered as the optimum particle size, constitutes the ideal environment for the seed of different tillage – sowing applications is significant at 1% level. Reduced tillage – 2 (S3) gave the best particle size distribution with size distribution of about 36.5% in both irrigated and dry farming conditions, followed by direct sowing (S4), reduced tillage – 1 (S2) and conventional (S1) methods.

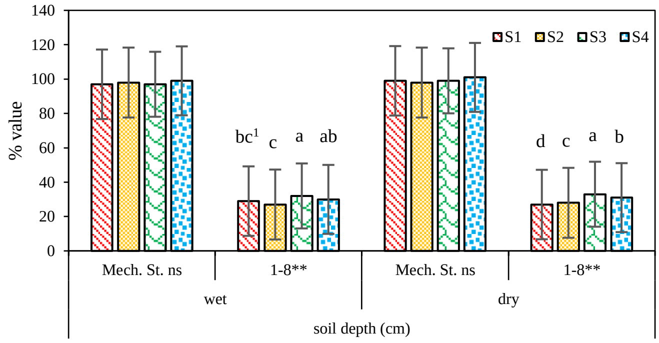


**Figure 5:** Average comparison results of mechanical stability values

[1] The difference between the means with the same letter is statistically insignificant; Tİ: Soil cultivation, S1: Conventional tillage, S2: Reduced tillage-1, S3: Reduced tillage-2, S4: Direct sowing

## 4. Discussion

In this study, the effects of different soil tillage applications in semi-arid and high-altitude cold zone conditions on the physical properties of the soils affected by freezing and thawing process were investigated. The high sand content in the soil of the trial area minimizes the freeze-thaw process. The change in the physical properties of the soil can be explained by the effects of different tillage machines on the soil. Statistically insignificant difference was determined between the bulk density, reduced soil tillage values and conventional application, and it was determined that the values obtained between 1.15–1.40 g $cm^{-3}$ did not affect plant root growth. The vertical rotovator in the S3 application, which produced the most disintegration effect in the soil, produced the lowest bulk density value in the 0-5 cm layer and the bulk density value of 1.29 g $cm^{-3}$ in the 10-15 cm layer increased the penetration resistance value in the 0-10 cm layer. Lipiec and Hatano, (2003) determined that soil physical properties (penetration resistance, clay content, saturated hydraulic conductivity, field capacity and moisture at the permanent wilt point) are directly related to the degree of spatial dependence and the resulting variation in soil physical properties due to tillage for successful agricultural activity. they noted that it would be useful to consider.

Although soil moisture values, which affect germination and yield positively in rainfed conditions, are higher in direct sowing application compared to other applications, penetration resistance values are not reflected positively. Although there was a linear negative correlation between soil moisture content and penetration resistance, a linear positive relationship was determined with soil tillage and accordingly bulk density. During the study, it was determined that the penetration values decreased with increasing soil depth.

In this study, significant differences in penetration resistance were determined between the applications and the layers. In general, the values that occurred in the range of 0.81 MPa to 3.86 MPa were found to be around 1.45 to 3.86 MPa in direct planting plots. Although it is generally higher than 3 MPa (Busscher and Sojka, 1987; Gülser and Candemir, 2012), which is generally accepted as the limit of root growth, winter and spring rainfall is more rapid and more effective in the direct sowing of unprocessed soils and rainwater. It can be said that it reduces high soil resistance by penetrating deep and eliminating this negative effect.

Soil cultivation methods did not affect the aggregate stability values, which are defined as the resistance of aggregates against the relaxing and disintegrating effects of mechanical factors such as water and processing structure. The very low slope of the trial area did not pose an erosion threat according to the mechanical stability values determined among the tillage subjects. Therefore, soil aggregate stability; soil aeration is important for moisture retention and productivity. In areas exposed to wind and water erosion, reduced and direct planting treatments can be recommended for soil conservation as the soil does not upside down and leaves more residues and stubble.

In the seedbed preparation, for the optimum particle size group of 1–8 mm, the S3 treatment with the vertical rotovator, which took its movement from the tail shaft, gave the best results in terms of particle distribution. It has been determined that tillage has significant effect on particle distribution of agricultural soils. The productivity level of agricultural production in our country is still below the potential in certain products and regions. In many crops, unnecessary excessive tillage and agricultural soils are exposed to erosion and adverse environmental effects. Plant cultivation techniques need to be revised in order to achieve sustainable agriculture, to make the best use of future generations and to minimize the negative effects on the environment.

## 5. Conclusion

The experimental study showed that the values of bulk density statistically insignificant among tillage systems at any depth in the soil profile. Direct sowing ($S_4$) system showed maximum soil moisture content measured at both soil depths (0-15 and 15-30 cm) while, lowest in conventional soil tillage system ($S_1$). Bulk density and porosity were dependent with tillage depth. Bulk density and penetration resistance values were the maximum and porosity was lowest in direct wheat sowing system (S4). Soil particle size distribution was affected by operations and agricultural machinery used in soil tillage systems. The aggregate size smaller than 1 mm showed higher fragmentation (42.25%) in $S_3$. The significant differences in penetration resistance were determined between the tillage systems and the layers. This study showed that soil physical properties were influenced by tillage systems in wheat production under irrigation and rainfed environment. Although the climate of the study area is semi-arid and direct sowing system provide maximum moisture but reduced tillage method can be used for better soil physical properties and highest crop yield.

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