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Soil Tillage Effects on Root Development Pepper Plant Part 1: Grown Inside the Greenhouse

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Abstract: Soil compaction can restrict root growth and water infiltration, resulting in yield reduction. Tillage often promotes root growth. In nature however, roots grow without tillage. Problems with root growth in agricultural soils often occur when a soil lacks of permanent pore system and has poor tilt. In this study, the effects of soil tillage method on penetration resistance and root development of pepper grown inside a greenhouse were investigated. Four tillage systems were ploughing, ploughing and rotary tillage, rotary tillage and no tillage. There was significant ($p<0.01$) effect of soil tillage method on penetration resistance at 0-10 cm depth. Primary tillage using a moldboard plough and following a secondary tillage using a rotary tillage supplied lower penetration resistance. Better root growth was obtained under this tillage method.

Key words: Roots, pepper root, soil tillage, root length, root diameter, penetration resistance

INTRODUCTION

Mechanization of agricultural production in a greenhouse, particularly machinery application has been advanced for decades. Consequently, soil under cultivation for agricultural production exposed to soil compaction which is defined as increasing in bulk density due to increasing equipment pass. Increased soil bulk density reduces the air filled porosity, the air diffusivity and the air permeability as well as the hydraulic conductivity of soil and sometimes the root development. The ideal bulk density for salty clay loam, loam, silt, clay loam and sandy loam soils is less than 1.40 g cm^{-3}. Bulk density higher than 1.60 g cm^{-3} may affect root growth and bulk density higher than 1.75 g cm^{-3} may restrict root growth (USDA NACS soil quality test kid guide). Threshold level at which soil strength hinders root elongation varies with plant species, but usually ranges between 2000 and 3000 kPa and the peak value is 1800 kPa. More plant residues were left on or near the soil surface after ploughless tillage, which led to lower evapotranspiration and higher soil water content in the upper (0-10 cm) soil layer (Chen *et al*., 2004).

Root elongation is strongly related to soil physical conditions. Alleviation of soil compaction is a reason to till soil. Tillage is often promoted to stimulate root growth, but in nature roots grow without tillage. Problems with root growth in agricultural soils often occur when a soil lacks of permanent pore space and has poor tilt. Soil tillage destroys the natural pores created by decomposing roots, earthworms and other soil dwelling creatures. In addition, organic matter that improves soil tilt is mixed with soil and buried below the seed zone. This cycle makes the soil addicted to tillage and is probably as major reason why a temporary yield depression is sometimes observed in the first years after switching from a conventional tillage system to a no till system.

Tillage treatments are expected to affect soil response and crop yield (Comia *et al*., 1994; Larney and Bullock, 1994; Shafiq *et al*., 1994; Stewart and Vyn, 1994; Tessier *et al*., 1997). Erbach *et al*. (1992) evaluated the effect of the following tillage treatments: no-tillage, chisel plow, moldboard plow and para plow systems on three soils (poorly drained, medium and fine textured) in Iowa. Results showed that all tillage tools reduced bulk density and cone penetration resistance to the depth of tillage. However, after planting, only the soil tilled with the para plow remained less dense than before tillage. Voorhees (1993) measured soil physical properties in the topsoil following normal farming operations using a tractor weighing 7.3 t. He found that fall moldboard plowing decreased bulk density on the tilled layer to essentially the same level as in nontrafficked soil.

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Chen and Tessier (1997) found that the effect of wheel traffic associated with the plowing operation on soil density could be extended to the depth of 30 cm.

Lipiec and Stepniewski (1995) expressed that evidence is presented to indicate interactive relationships between the amount of soil compaction, root growth, soil water and soil aeration status and nutrient supply and uptake by plants. Root growth of barley under three different tillage systems on two soils in semiarid conditions was studied. It was found that root length density was greater in no till than in subsoiler or minimum tillage systems (Lampurlanes *et al*., 2001). Hilfiker and Lovery (1988) observed that wheel track reduced root growth and maximum root densities occurred at 10 to 40 cm depth in all the tillage systems for corn root growth. Moldboard plowing decreased root densities comparing to chisel, ridge tillage and no tillage systems. Ehlers *et al*. (1981) observed that water uptake rate functionally related to rooting density and soil water potential for oats. Tillage favors initial shoot growth, but shoot growth is accelerated later in untilled soil. Shoot growth associated with higher evapotranspiration and linearly related to transpiration rate.

At early development, most of the pepper roots spread rather horizontally, some obliquely and a few penetrated quite vertically downward. On the larger roots near the base of the plant, laterals are occurred at the rate of four to six per inch. Farther out, they were fewer and shorter. Pepper seeds germinate and produce a taproot system in a remarkably short time. Then secondary laterals produce approximately 5-10 on taproot. The formation and speedily development of secondary roots remain on primary root. The thinner roots are produced on secondary roots (Weaver and Bruner, 1927).

Studies on the influence of seed bed condition on the emergence and development of pepper seedlings revealed that seed bed compaction delayed and reduced seedling emergence. High soil moisture content and high nutrient content reduce the severity of soil compaction on seedling root and shoot development. Soil compaction also causes abnormal hypocotyls morphology in seedlings that germinate but fail to emerge (Fawusi, 1978). Leskovar *et al*. (1990) observed that an increase in the root growth over 56 days was linear for transplants while in direct seeded pepper plant root growth had a lag phase of approximately 14 days, with a sharp increase thereafter. The coordination of growth between root and shoot changed after fruit set only in transplants, which indicates that transplants exhibited a greater fruit sink demand and fruit production than seeded plants. The objective of this study was to investigate the effect of soil tillage systems on penetration resistance and root development of pepper grown inside a greenhouse.

MATERIALS AND METHODS

Greenhouse: Experiments were conducted in an unheated greenhouse (glass) located at GOP University, Horticulture Department, Tokat, Turkey from May 16 through November 31, 2004. Total size of the 12 experimental plots used for this study was 58.8 m^2. The size of the greenhouse was approximately 12 m wide and 35 m long with natural ventilation. The only plants growing in the greenhouse were 240 potted pepper seedlings used in the experiment.

Dry-bulb temperature and humidity of the greenhouse were measured at pre-determined period of time using a load heated cell and stored within a computer. The readings of temperature and humidity for each period were averaged. The average temperature was 24.91°C ranging from 14.49 to 39.22°C and the average humidity was 33.64% ranging from 22.4 to 78.5% inside the greenhouse in May. Average temperature was 24.55°C and maximum temperature was 46.4°C during the early growth period.

In the experimental field, the analyses of soil physical and chemical properties were carried out before the experiment (before soil tillage application) for each plot in order to characterize soil uniformity between the plots. Particle size analysis was done based on the hydrometer method (Gee and Bouder, 1986). Moisture content, bulk densities, penetration resistance for each plot were measured before the experiment. A 100 cm^3 cylindrical sampler was used to collect undisturbed soil samples. Soil samples were taken randomly for each plot from 0-10, 10-20 and 20-30 cm depths. Soil samples were used for both moisture content and bulk density determinations. Standard gravimetric method was used for moisture content determination.

Table 1: Mean dimensons of pepper seedling

Measurement	Mean	Minimum	Maximum	SD[a]	CV[b]
Primary root length	33.89	25.18	41.82	3.06	9.02
Secondary root length	69.89	53.00	79.18	5.78	8.27
Total root length	103.78	92.00	119.00	4.38	4.22
Primary root diameter	2.06	1.06	3.00	0.23	10.95
Stem length	33.89	25.15	41.82	3.15	9.31
Total plant length	137.67	117.70	169.87	8.88	6.45

[a]Standard deviation, [b]Coefficient of variation

Table 2: Working depths of the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: No-till

Treatment	Tillage equipment	Working depth (mm)
Y1	Moldboard plough	125
Y2	Moldboard plough+rotary tillage	125
Y3	Rotary cultivator	65
Control	No-till	-

Penetration resistance measurements were taken with a hand pushing penetrometer (Eijkelkamp, 1990) having maximum measurement range of 5,000 kPa. Points exceeded 5,000 kPa of PR were considered as missing data values in later depths. The penetrometer consists of a handle, a compression bar with a compression helical spring, a recording pen, a card controller, helix bar with its support and a conic penetration type. The handle is used to apply the proper penetration force for insertion. During penetration resistance measurement, the compression bar compresses the helical spring. The spring deflection under this force is also calibrated to obtain the cone indexes. At the same time, the helix bar rotates the card control roller with a constant rotation. The card control roller pulls the recording card that is tightened in the card support with a recording pen. Therefore, during the measurement process, recording pen records data on a scaled paper. The data for each 5 cm depth were compiled and individual values were averaged for each 10 cm depth increment to a depth of 30 cm. Data was converted in to the cone indexes using the calibration curve of the penetrometer. Values of penetration resistance of 0-10, 10-20 and 20-30 cm depths were averaged.

Pepper seedling dimensions were measured before the experiment. The measurements of 60 pepper seedlings were taken and average of 60 measurements of primary root length, secondary root length, total root length and primary root diameter were obtained (Table 1).

Moisture contents, bulk densities, penetration resistances, primary and secondary root lengths, total root lengths, primary root diameters and root weights of pepper plants for each plot were measured at five times during the growth period. The first measurements were done when first flower opened, which was 47 day after planting. The second measurements were done at first fruit harvesting, which was 76 day after planting. The other three measurements were taken at 109th day (the third measurements), 144th day (the fourth measurements) and 173rd day (the last measurements) after planting.

The pepper seedling was grown in a potted torf medium, then transferred inside a greenhouse when pepper plants had 6-7 leaves in May 6. 8 kg day^{-1} DAP and 22 kg day^{-1} ammonium sulfate were applied based on the soil analysis results before the seedling drilling. Drip irrigation pipe was installed through each row with a 70 cm row space. The space of pepper in row was 35 cm. Two pepper roots from each plot were taken from soil by loosening the soil using a shovel for each measurement. For precise measurement of primary and total root length and, root diameter, a digital compass was used. The pepper roots were weighted by an electronic balance. The roots were put on a scaled paper sheet and a 300 mm ruler was arranged on the paper sheet as a scale reference. The measurements were performed horizontally (lateral root spread) and vertically (root penetration depth).

Soil tillage treatments: In the study, Y1 ploughing, Y2 ploughing+rotary tillage, Y3 rotary tillage and no tillage (control) were applied as soil tillage treatments (Table 2). Soil tillage methods were applied as complete randomized blocks design with three replications. Therefore, total 12 plots with dimension 1.4×3.5 m were included in the experiment. A two wheel 7.5 KW tractor which has a single axle was used as a power source of soil tillage.

Data analysis: Statistical analysis (ANOVA) was applied to penetration resistance and moisture content data in order to determine significance of difference between the plots. Same procedure was applied in order to figure out the effect of tillage method on penetration resistance and pepper growth. A randomized complete block design was applied with three replications. The statistical inferences were made at a 0.01 and 0.05 level of significance.

RESULTS AND DISCUSSION

Preliminary field tests were conducted to characterize soil physical and chemical properties of the experimental field. Soil analysis suggested that field was silty clay loam (Table 3).

Table 3: Soil physical and chemical properties of the field

Parameter	Level (%)
Loam	38.25
Clay	28.42
Silt	33.33
Organic matter	1.3
Lime	12.9
Total saline	0.044
Total phosphorous	6.18
PH	7.94

Table 4: Mean moisture content and penetration resistance of the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

Treatment	Soil profile (cm)	Moisture content (%)	Penetration resistance (Mpa)
Y1	0-10	4.02	1.256
	10-20	9.56	2.678
	20-30	11.86	3.022
Y2	0-10	3.34	1.589
	10-20	8.61	2.233
	20-30	11.96	2.711
Y3	0-10	3.27	1.722
	10-20	10.16	2.189
	20-30	11.79	2.633
Control	0-10	7.21	0.756
	10-20	9.73	2.667
	20-30	14.25	2.356

Table 5: Penetration resistance Duncan ($p<0.01$) of the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till.

	Soil profile (cm)		
Treatment	10	20	30
Y1	1.33 bc	2.26	2.48
Y2	1.09 ab	2.1	2.32
Y3	0.88 a	2.25	2.31
Control	1.43 c	1.8	2.11

Initial tests were also conducted to determine moisture content and penetration resistance of each treatment (Table 4). There was no significant difference in moisture content between the treatments at all depths. Statistical analysis showed that while there was no significant difference ($p>0.05$) in penetration resistance at 10-20 and 20-30 cm depths, there was a significant difference between the treatments at 0-10 cm depth. The lowest mean penetration resistance was obtained as 0.756 MPa in control treatment while the highest penetration resistance was obtained in Y3 treatment at 0-10 cm depth.

Based on LSD tests, all treatments fall in different group. These preliminary trials provided basis for the investigations.

The effect of soil tillage method on penetration resistance: To investigate the effects of different soil tillage method: Y1 ploughing, Y2 ploughing+rotary tillage, Y3 rotary tillage and no tillage (control) were applied with three replications as soil tillage treatments. The effects of soil tillage methods on penetration resistance were significant ($p<0.01$) at 0-10 cm depth while there were no significant effects of tillage methods at 10-20 and 20-30 cm depths. Each treatment fell in different group based on Duncan test (Table 5).

Control treatment had the lowest mean penetration resistance for all treatments. After soil tillage, Y1 treatment had the lowest mean penetration resistance while the highest penetration resistance was obtained with Y3 treatment at 0-10 cm depth (Fig. 1). After 47 days from planting, penetration resistance increased due to irrigation management, mechanical weed control and root growth for all treatment (Fig. 2). But the lowest penetration resistance was obtained with Y3 treatment (rotary tiller) and the highest penetration resistance was obtained with control treatment at 0-10 cm depth in the last measurement (Fig. 3).

The effect of soil tillage method on root length development: Primary and secondary root lengths were measured at five times during the growth period. The first measurement was done when first flower opened, which was 47 day after planting. The second measurement was done at first fruit harvesting, which was 76 day after planting. Mean values of primary and total root length measurements were shown in Fig. 4 and 5.

The effect of tillage method on primary root length was significant ($p<0.05$) at the first, the fourth and the fifth measurements. However, there was no significant effect of tillage method at the second and the third measurements. There was a rapid growth in primary root

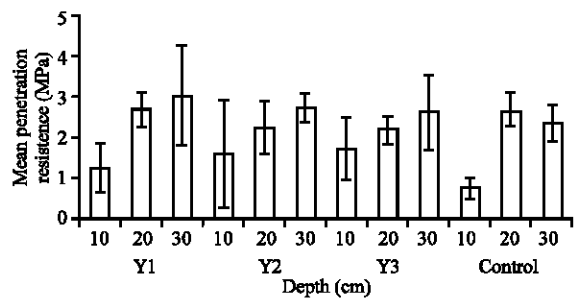

Fig. 1: Penetration resistance after soil tillage application for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: Rotary tillage and control: no-till

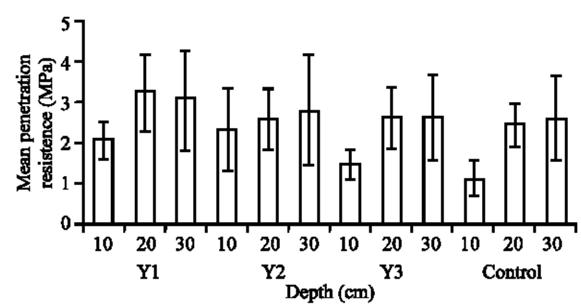

Fig. 2: Penetration resistance after 47 days from planting for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

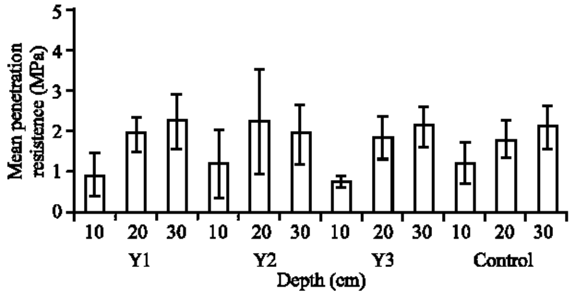

Fig. 3: Penetration resistance after 173 days from planting for of the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

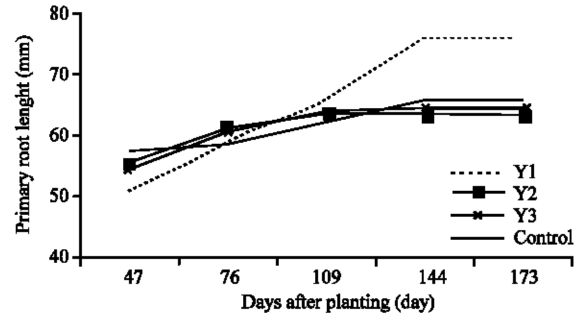

Fig. 4: Mean primary root lengths for the tillage systems; Y1: Ploughing, Y2: Ploughing+Rotary tillage, Y3: Rotary tillage and Control: No-till.

length in Y1 treatment at the third measurement while the lowest value was obtained in Y1 treatment at the first measurement. Y1 treatment had the lowest penetration resistance at the third measurement (Fig. 6). Lower penetration resistance favored primary and secondary root development. The highest primary root length was measured in control treatment at the first measurement. Y2, Y3 and control treatments showed similar growth trend in primary root length.

The effect of tillage method on total root length was significant ($p<0.05$) at the first and the third measurement. There was a rapid growth in total root length between the first and the second measurements in Y3 and control treatments. Lower penetration resistance favored rapid total root growth due to growth in secondary root. However, total root growth stopped after the second measurement. This was due to the lowest soil tillage depth in Y3 treatment. There was a lower penetration resistance at 0-10 cm depth in Y3 treatment at this measurement. The highest penetration resistance at 0-10 cm soil depth was obtained in Y3 treatment at the first measurement. Total root length increased due to increase in secondary root length. There was similar trend in the control treatment with same causation (Fig. 2). Total root length of Y1 and Y2 treatments were increased until the last measurement. But the highest total root length was observed at the all measurements in Y3 treatment. The growth of many fine lateral roots leads to higher root length density in the more favorable soil zone in the all treatments.

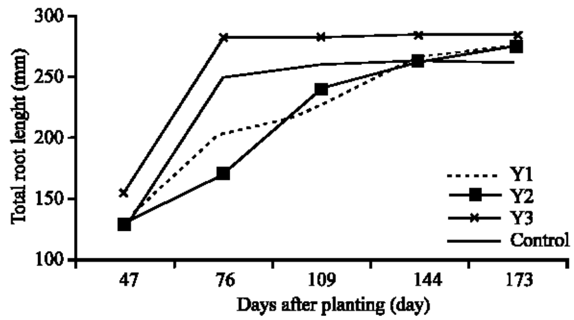

Fig. 5: Mean total root lengths for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

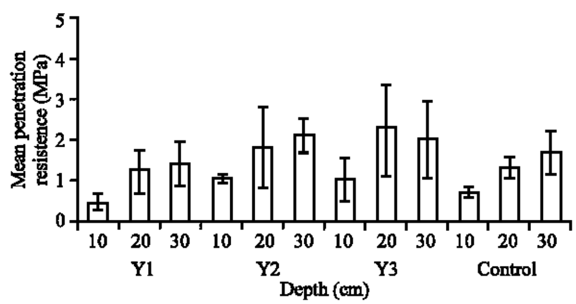

Fig. 6: Penetration resistance after 109 days from planting for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

The effect of soil tillage method on root distrubution: The effect of tillage method was significant ($p<0.05$) on the root penetration depth and lateral root spread. The root penetration depths were 266.66, 330, 221.66 and 243.33 mm for Y1, Y2, Y3 and control treatments, respectively at the last measurement (Fig. 7). Lateral root spread were 288.33, 390, 343.33 and 288.33 mm for Y1, Y2, Y3 and control treatments, respectively. This could be explained by the greater tillage depth (125 mm) at Y2 treatment which allowed for easier root penetration to a greater depth. Penetration resistance at 20-30 cm depth in Y2 treatment was the highest at the third measurement

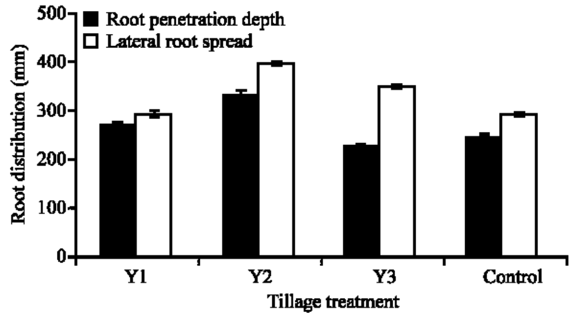

Fig. 7: Root distributions of the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

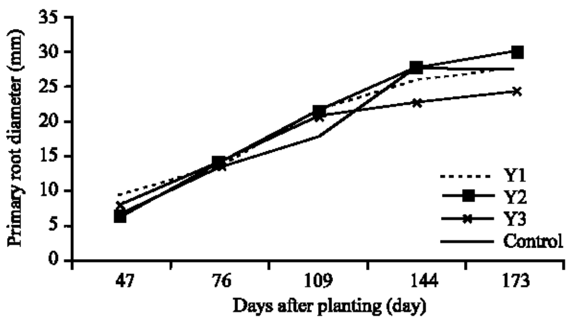

Fig. 8: Primary root diameters for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

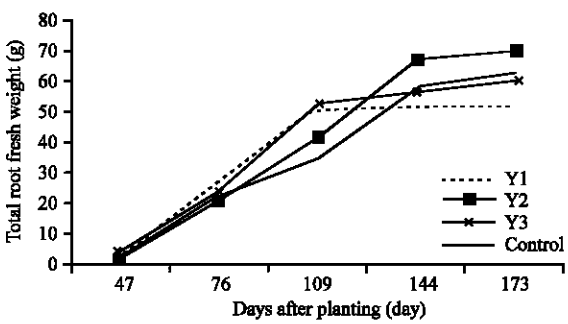

Fig. 9: Root fresh weights for the tillage systems; Y1: ploughing, Y2: ploughing+rotary tillage, Y3: rotary tillage and control: no-till

(Fig. 6). Penetration resistance for all treatments decreased as measurement time increased due to effect of root elongation.

Plants tried to compensate for the restricted rooting depth by increasing lateral root production as explained by Schumacher and Smacker (1981). Present results showed similar trend with their findings.

The effect of soil tillage method on development of primary root diameter: Effect of tillage method was significant ($p<0.05$) on primary root diameter at the first measurement. Y2 treatment had the highest primary root diameter while Y3 treatment supplied the lowest primary root diameter at the fourth and the fifth measurements (Fig. 8). There was similar growth trend in Y1, Y2 and Y3 treatment at the second and the third measurements. Control treatment supplied the lowest primary root diameter at the third measurement. Primary root diameter in Y1 and Y2 treatments having equal tilling depth showed similar growth trend. Lund and Elkins (1978), Whitely and Dexter (1984) observed that plants with numerous fine roots had better growth in compacted layers, but according to Materechera *et al*. (1992) thicker roots would have a higher ability to grow in high resistance soil layers since they exert a higher growth pressure. In this study, it was observed that soil layer with lower penetration resistance supplied better growth of pepper plant in root length. However, primary root diameter was thinner in compacted soil layer.

The number of roots growing through the compacted layer could be more important then the sensitivity of the root system to the compaction. According to Chassot *et al*. (2001), average root diameter of maize was lower under conventional tillage than under no till. Increases in soil cone index decrease root elongation and growth (Chen *et al*., 2004).

The effect of soil tillage method on root fresh weight: Effect of tillage method was significant ($p<0.05$) on root fresh weight for all measurement. Figure 9 shows root fresh weight measurements for all treatments.

After the second measurement, root fresh weight increased in Y3 treatment. The root growth was due to growth in secondary root length. The fresh root weight in Y1 and Y3 treatment showed similar trend between the first and the third measurements. Control treatment supplied smaller root weight at the third measurements; however the fresh root weight increased until the last measurements. The highest root weight was obtained in Y2 treatment at the fourth and the fifth measurements. There was a similar trend in plant growth for the all treatments at fourth and fourth measurement.

The effects of four different soil tillage methods on plant growth were investigated inside the greenhouse. Statistical results showed that the effect of the tillage systems on the growth of primary root length and diameter, total root length and weight were significant ($p<0.05$). Primary tillage using a moldboard plough and fallowing a secondary tillage using a rotary tillage supplied lower penetration resistance. Therefore, better root growth in terms of root distribution, primary root diameter and fresh root weight was obtained under this tillage method. However, longer primary root length was observed in the tillage method using only a moldboard plough and the highest total root length was observed in the tillage method using only a rotary cultivator.

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