Silage maize (*Zea mays* L.) seedlings emergence as influenced by soil compaction treatments and contact pressures

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ABSTRACT

Soil compaction caused by mechanical force affects the vegetative and generative plant growth. Field experiments were conducted to study the effects of soil compaction treatments and soil contact pressures on bulk density, penetration resistance and silage maize emergence in a clay-loam soil. Soil compaction treatments were applied while planting as follows: Compaction on furrow surface (F-surface), compaction on furrow bottom (F-bottom), compaction on inter row (I-row), and non-extra compaction as a control (C). The soil contact pressures of 0.025, 0.051 and 0.076 MPa were applied while the control was 0.0085 MPa. Significant differences between soil compaction treatments and contact pressures were recorded in bulk density, penetration resistance and silage maize emergence. Percentage of emerged seedlings increased as the soil contact pressure was increased slightly. The lowest mean percentage of emerged seedlings (52.63%) was obtained with 0.076 MPa contact pressure in F-surface treatment and the highest mean value (81.58%) was obtained with 0.025 MPa contact pressure in F-bottom compaction treatment. The control treatment gave the 69% mean value under the non-irrigated condition.

Keywords: soil compaction treatments; soil contact pressures; soil physical properties; maize emergence

Silage maize (*Zea mays* L.) and soybean growth area has been extended with the increase of animal farming in central Anatolia. Many projects have been conducted to expand the areas of silage maize growth as a second crop, following the harvest of wheat and barley in July. The cropland of Central Anatolia includes approximately 7 million ha, of which 51% is used for wheat and 25% for barley production (Anonymous 2001a). Most of Central Anatolia soils are clay-loams, low in organic matter. One of the difficulties of extending the silage maize sown area as a second crop is a deficiency of water for irrigation in summer. The soil is compacted by an intensive use of machinery during the wheat, barley and second crop maize production. Compaction increases bulk density and penetrometer resistance while it reduces penetrability of roots to soil (Unger and Kaspar 1994) and crop yield (Husnjak et al. 2002, Birkás et al. 2002). Penetration resistance over 1000 kPa usually decreases yield (Khalilian et al. 1991). Soil compaction may significantly impair productivity of soil by decreasing the aeration, soil water storage and crop water use efficiency (Radford et al. 2001). For an adequate productivity, the pore space of a soil should be around 50% of its volume.

Effects of soil compaction treatments on plant growth with different soil contact pressures have not been sufficiently studied for divers crop production.

A limited degree of soil compaction under the seeding depth tends to increase the soil moisture content in the vicinity of planted seeds, encouraging capillary ascent of water from subsoil. Bicki and Siemens (1991) reported that a limited surface compaction is beneficial around the planted seeds because it provides a better seed-soil contact and rapid germination and reduces the rate of soil drying. However, an excessive compaction can hamper root growth, limit nutrient uptake and decrease soil aeration.

Crop yield is influenced by soil compaction, weather conditions and soil nutrient status. Swan et al. (1987) concluded from their study that the effect of soil compaction on plant vegetative and generative growth could vary depending on the soil and climatic conditions. Limited compaction may be beneficial under dry conditions; excessive compaction is detrimental to crop growth under wet conditions. Voorhees et al. (1986) and Swan et al. (1987) reported that limited soil compaction helped to increase the soybean yield, when May through August rainfall was less than 360 mm in Minnesota (USA). A similar study was performed by Gameda et al. (1983) who found that when May through September rainfall was less than 360 mm in Quebec (Canada), corn yield increased as tire-soil contact pressure was increased slightly. Above the 530 mm rainfall, corn yield decreased as tire-soil contact pressure was increased.

Some researchers explained that soil compaction by traffic might have an effect on yield. Ngunjiri and Siemens (1995) concluded that the corn yield was affected by wheel traffic compaction. The yield was found significantly lower on entire plot compaction treatment than the yield from no wheel compaction on rows and between rows compaction treatments. Similar results were presented by Bayhan et al. (2002). Honsson and Reeder (1994) reported that repeated wheel traffic on agricultural soils in seven different countries of Europe and North America caused 14% crop yield loss. As penetrometer resistance increased, mean emergence date was delayed and percentage of emerged seedling decreased. Bilbro and Wanjura (1982), Unger and Kaspar (1994) came to similar conclusions. They suggested that field traffic treatments resulted in soil compaction and decreased yield.

Many others examined the effect of soil compaction on crop growth and yield. In some of these studies, compactions were applied on inter-rows, furrow surface, and then yields were evaluated and compared. Effects of furrow bottom compaction on second crop silage maize germination as well as the other compaction treatments with different soil contact pressures have not been studied sufficiently so far.

In this study, effects of different soil compaction treatments and contact pressures on second crop silage maize emergence were investigated under clay-loam soil conditions. Seeds were planted into the soil in July with adequate moisture content and were not irrigated during the period of emergence.

MATERIAL AND METHODS

Description of the study area

Field experiments were conducted on the research area of Agricultural Faculty of Gaziosmanpasa University, Turkey, in July 2001. Soil in experimental plots was clay-loam (23.69% sand, 37.21% silt and 39.10% clay). The soils had 0.024% of total salt, 1.68% of organic matter, 3.84% Ca, 20 mg/kg P and 95 mg/kg K. The experimental soils were slightly alkaline (pH 7.7). The altitude is 580 m. According to the records of last 35 years, average annual precipitation is 444 mm, air temperature is 12°C and relative humidity is 61% (Anonymous 2001b). During the experimentation, average minimum and maximum air temperatures were 20.58°C and 32.76°C, daily relative humidity was 59.2%. Precipitation was not recorded.

Field procedures and soil measurements

Experiments were planned in a randomised complete block design with three replications. Plots inside the blocks were 3 m wide and 20 m long. Trials were conducted after growing season of wheat. Soil was tilled by tillage tools plough, field cultivator and disc harrow seedbed combination implements that are commonly used in the region. Soil bulk density and penetration resistance were measured before the seedbed preparation and after the soil compaction treatments. Soil moisture content was measured after the seedbed preparation. To determine the soil bulk density and the moisture content, undisturbed soil samples were taken from 0–10 and 10–20 cm depths using the 100 cm^3 cylinders with 10 cm in length. Soil penetration resistance was measured with a hand-pushing penetrometer having maximum measurement range 5000 kPa, and 80 cm depth. The standard set of cone penetrometer has a cone with 30° tip angle, a standard cone base area (1 cm^2) and shaft diameter (8 mm).

Silage maize was planted in July and harvested in October 2001. TTM-813 maize variety was used as seed material. The pneumatic precision planter weighed to 0.64 mg with vacuum pressure, holed disk and 4 rows (2800 mm working width) was used in the experiment. The planter consists of four shoe coulters, furrow coverer and compaction tires. Planting depth, row space, rate of seed and working speed of planter were arranged as 8 cm, 65 cm, 76 920 seeds/ha and 6 km/h, respectively. Plots were compacted with different compaction treatments and soil contact pressures during the planting applications. Soil compaction treatments were:

1. F-surface: compaction on furrow surface
2. F-bottom: compaction on bottom of furrow
3. I-row: compaction on inter-rows
4. C: non-extra compaction as control

On F-surface treatment, surface of row was compacted by compaction tire. On F-bottom and I-row treatments, some constructional changes were made on drilling machines. On F-bottom treatment; furrow was firstly opened by shoe coulter, then compacted, afterwards seeds were drilled on compacted bottom of furrow and finally seeds were covered with soil. On the I-row treatment, inter rows were compacted with compaction tires while the standard planting applications were performed. Standard planting applications were also performed for control treatments by using the same planter with compaction tires without extra weights.

Three different soil compaction pressures were applied to each treatment plots, 0.025 MPa (P_1), 0.051 MPa (P_2) and 0.076 MPa (P_3). To obtain different soil compaction pressures, the compaction tires were loaded with extra weights. Control plots were compacted with 0.0085 MPa by standard planter tire soil contact pressure. After the soil compaction trials, soil penetration resistance was measured and soil bulk density was determined in plots from the undisturbed soil samples. Soil bulk density was determined by cylinder method (Blake and Hartge 1986). Bulk density and gravimetric water content were measured on duplicate undisturbed samples in cylinders, after drying at 105°C for 24 h. Soil penetration resistance values were determined at depths 0–10 and 10–20 cm. Soil penetrometer measurements were made by pushing the penetrometer vertically into the soil at an aproximate speed of 2 cm/s (Eijkelkamp 1990).

Seedlings were counted several times during the emergence period in rows of plots. Mean emergence dates (MED) and percentage of emerged seedlings (PE) were calculated as follows (Bilbro and Wanjura 1982, Bayhan et al. 2002):

$$MED = (N_1D_1 + N_2D_2 + \dots + N_nD_n)/(N_1 + N_2 + N_3 + \dots + N_n) \quad (1)$$

where: N – the number of seed emerged since previous count

D – the number of days since planting

$$PE= [(\text{total emerged seedlings/m})/(\text{number of seeds planted/m})] \times 100 \quad (2)$$

RESULTS AND DISCUSSION

Soil bulk density and penetration resistance

After the soil compaction treatments, moisture content, bulk density and penetration resistance were determined. Average soil moisture content was found as 13.12% and 15.03% at 0–10 cm and 10–20 cm depths, respectively.

The results of analysis of variance (ANOVA) with effect of soil compaction treatments and soil contact pressures on soil bulk density and penetration resistance is shown in Table 1.

With the exception of effects of contact pressures on soil bulk density at 0–10 cm soil depth, soil bulk density and penetration resistance were affected significantly ($P < 0.01$) by soil compaction treatments and contact pressures (Table 1). The low, medium and high soil bulk density and penetration resistance mean values were obtained from F-bottom (1.23 mg/m^3, 0.97 MPa), I-row (1.28 mg/m^3, 1.12 MPa), and F-surface (1.37 mg/m^3, 1.44 MPa) treatments, respectively, for each contact pressure at 0–10 cm soil depth (Figure 1). I-row and F-bottom treatments gave statistically similar bulk density results. Soil bulk density and penetration resistance values increased with the soil contact pressures. The lowest mean values were obtained with P_1 contact pressure and the maximum with P_3 contact pressure. F-bottom treatment with P_1 contact pressure resulted in lower mean soil bulk density and penetration resistance values (1.22 mg/m^3, 0.77 MPa, respectively), and F-surface treatment with P_3 contact pressure gave highest values (1.43 mg/m^3 and 1.80 MPa, respectively, Figure 1).

Soil bulk density and penetration resistance values increased with the soil depth. At the 10–20 cm soil depth, the low, medium and high soil bulk

Table 1. The ANOVA of the effects of compaction treatments and contact pressures on soil bulk density and penetration resistance

		Bulk density (mg/m^3)				Penetration resistance (MPa)			
		0–10 cm		10–20 cm		0–10 cm		10–20 cm	
Source	*DF*	*MS*	F_{cal}	*MS*	F_{cal}	*MS*	F_{cal}	*MS*	F_{cal}
CT	2	0.045	17.22**	0.050	19.62**	0.534	75.45**	2.201	299.02**
SCP	2	0.007	2.54ns	0.018	6.94**	0.588	82.98**	1.688	229.28**
CT × SCP	4	0.001	0.52ns	0.002	0.64ns	0.021	2.90ns	0.106	14.34**
Error	16	0.003		0.003		0.007		0.007	

MS – mean square, *DF* – degrees of freedom, F_{cal} – calculated *F*-ratio
CT – compaction treatment, SCP – soil contact pressure (MPa)
* indicates significance at $P < 0.05$, ** indicates significance at $P < 0.01$, ns indicates not significant

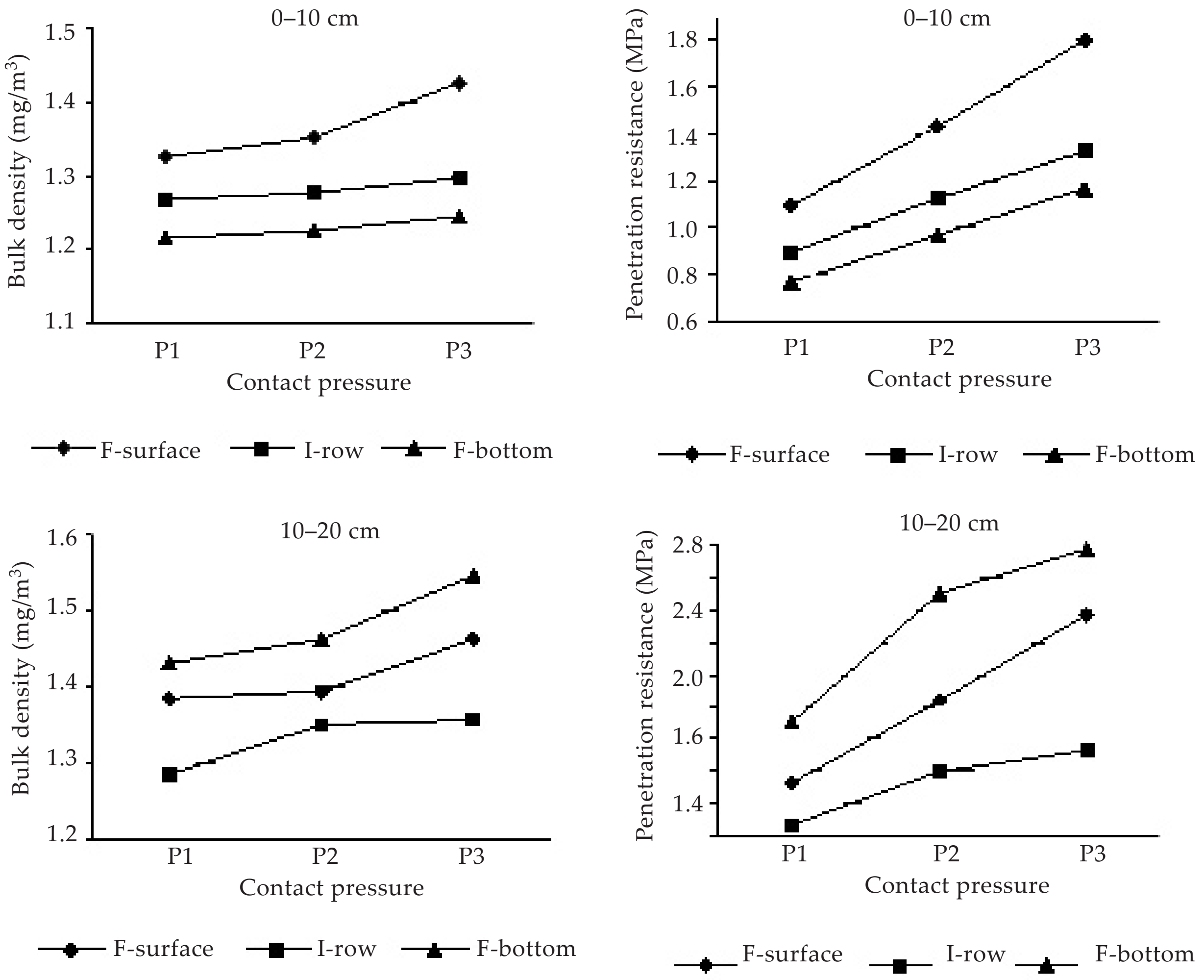

Figure 1. Soil bulk density and penetration resistance as affected by compaction treatment and contact pressure

density and penetration resistance mean values were obtained from I-row (1.33 mg/m^3, 1.33 MPa), F-surface (1.41 mg/m^3, 1.84 MPa), and F-bottom (1.48 mg/m^3, 2.32 MPa) treatments, respectively, for each contact pressure (Figure 1). F-surface and F-bottom treatments resulted in statistically similar bulk density values. I-row treatment with P_1 contact pressure gave lower soil bulk density and penetration resistance mean values (1.28 mg/m^3, 1.07 MPa, respectively), and F-bottom treatment with P_3 contact pressure gave higher mean values (1.55 mg/m^3 and 2.77 MPa respectively, Figure 1).

Soil bulk density and soil penetration resistance values in control (C) were 1.21 mg/m^3 and 0.800 MPa, respectively, at the 0–10 cm soil depth, and 1.29 mg/m^3, 1.03 MPa, respectively, at the 10–20 cm soil depth.

These results suggested that soil compaction treatments and soil contact pressures might have a significant effect on soil bulk density and penetration resistance. Similar results were obtained by Bayhan et al. (2002) who reported that tractor wheel compaction treatments were found to increase penetration resistance. Average of soil penetration resistance in 0–20 cm depth was between 1.60 and 1.85 MPa. The penetrometer resistance and its effect on root growth and development was studied by Ishaq et al. (2001). In this study, penetration resistance over 1.0 MPa caused a beginning of a root growth reduction. Any resistance over 2.0 MPa can significantly reduce root growth and development (Oussible et al. 1992, Ishaq et al. 2001). The optimum soil bulk density for growth and yield was detected to be between 1.40 and 1.68 mg/m^3 (Czyż 2004) for spring barley, and varied from 1.55 mg/m^3 to 1.77 mg/m^3 for pea roots at different field water capacity and soil textures (Pabin et al. 1998). In the present study, 0.025 MPa (P_1) soil contact pressure caused less than 1.10 MPa penetration resistance and 1.33 mg/m^3 soil bulk density at the 0–10 cm soil depth, and less than 1.70 MPa penetration resistance and 1.43 mg/m^3 soil bulk density at the 10–20 cm soil depth, within the compaction treatments. The highest percentage of emerged seedlings was obtained with P_1 (Figure 2).

Table 2. The ANOVA of the effects of compaction treatments and soil contact pressures on mean emergence dates (MED) and percentage of emerged seedlings (PE)

		MED		PE	
Source	*DF*	*MS*	F_{cal}	*MS*	F_{cal}
CT	2	0.030	59.86**	1158.063	293.08**
SCP	2	0.001	1.79ns	33.373	8.45**
CT × SCP	4	0.002	3.74**	25.677	6.50 **
Error	16	0.001		3.59	

CT – compaction treatments, SCP – soil contact pressure
* indicates significance at $P < 0.05$, ** indicates significance at $P < 0.01$, ns indicates not significant

Mean emergence dates and percentage of emerged seedlings

The results of analysis of variance with effects of soil compaction treatments and soil contact pressures on mean emergence dates and percentage of emerged seedlings are shown in Table 2. The effects of soil compaction treatment and compaction treatment vs. soil contact pressure interactions on mean emerged days (MED) were significant. Soil contact pressures were not significant on MED (Table 2). The mean MED were 2.15 (F-surface), 12.16 (I-row), and 12.23 days (F-bottom) for each contact pressure. F-bottom treatment delayed the mean emerged days (Figure 2). F-surface and I-rows compaction treatments gave statistically similar results. The MED in control (C) was 12.14 days.

The compaction treatments, soil contact pressures and also compaction treatment vs. compaction pressure interactions significantly affected the percentage of emerged seedlings (PE) (Table 2). The mean PE values varied from 57.99 (F-surface) to 72.22 (I-row) and 80.41% (F-bottom), for each contact pressure (Figure 2). The P_3 compaction pressure resulted in the lowest PE result (52.63%) in F-surface treatment. Compaction on F-bottom treatment increased PE values. F-bottom treatment with P_1 compaction pressure resulted in the highest PE result (81.58%; Figure 2).

Compacting the soil on the seedbed with contact pressure up to 0.025 MPa, then covering the furrow by loosened soils, resulted in PE increase from 69 to 81.58% in a clay-loam soil with 13.12% moisture content. F-surface and I-row compaction treatments were not recommended for PE. These results may be used for further planning of planting applications of silage maize seeds at similar conditions, and for designing the shoe coulters and planters for improving the seedlings emergence at insufficient soil water contents.

In this research, mean emergence dates (MED) and percentage of emerged seedlings (PE) were signifi-

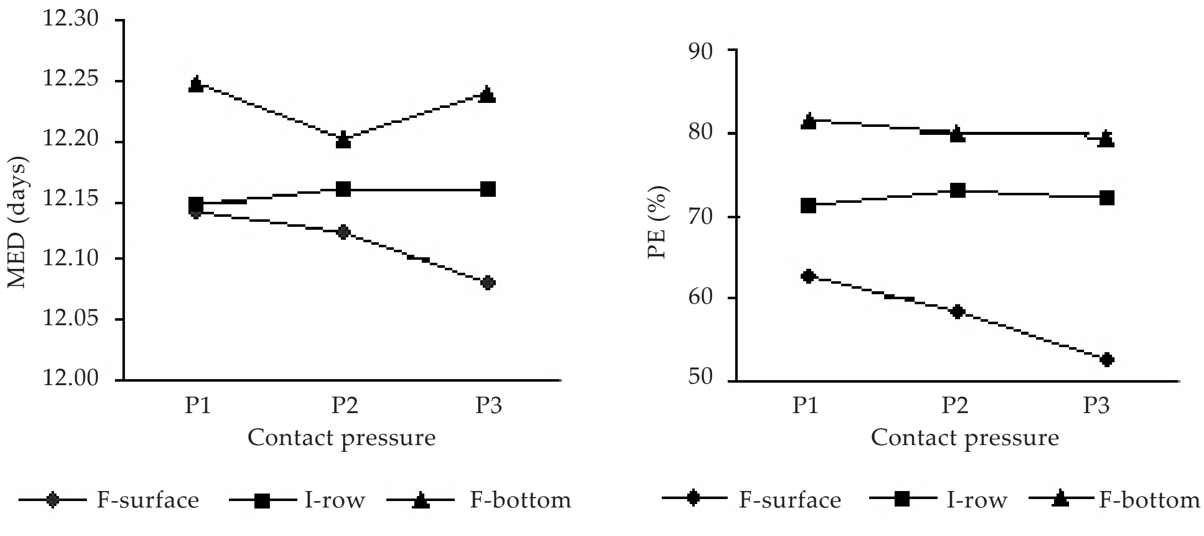

Figure 2. Values of mean emerged dates (MED) and percentage of emerged seedlings (PE) as affected by compaction treatments and compaction pressures

cantly affected ($P < 0.01$) by compaction treatments. Similar results were obtained by Bayhan et al. (2002) who reported that tractor compaction treatments affected significantly ($P < 0.01$) the MED and PE. PE values declined with an increasing penetration resistance (Bilbro and Wanjura 1982).

To conclude, soil compaction treatments and contact pressures affected soil bulk density and penetration resistance. PE was affected significantly with soil compaction treatments and soil contact pressures. Percentage of emerged seedlings increased as soil contact pressure was increased slightly. The highest PE mean value (81.58%) was obtained with 0.025 MPa contact pressure in F-bottom compaction treatment; the control treatment gave the 69% mean value of this treatment.

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ABSTRACT

Vliv různého utužení půdy a kontaktních tlaků na vzcházení silážní kukuřice (*Zea mays* L.)

Utužení půdy způsobené mechanickými silami ovlivňuje vegetativní i generativní růst rostlin. V polním pokusu byl studován vliv různých způsobů utužení půdy a různých kontaktních tlaků na objemovou hmotnost půdy, penetrační odpor půdy a vzcházení silážní kukuřice v jílovitohlinité půdě. Různé utužení půdy bylo aplikováno během setí takto: utužení na povrchu brázdy (varianta F-surface), utužení na dně brázdy (F-bottom) a utužení v meziřádku (I-row); jako kontrola (C) bylo použito ošetření bez zvýšeného utužení půdy. Použité kontaktní tlaky na půdu byly

0,025, 0,051 a 0,076 MPa; kontrola měla hodnotu 0,0085 MPa. Byly zjištěny významné rozdíly mezi jednotlivými způsoby utužení a mezi různými kontaktními tlaky v objemové hmotnosti, penetračním odporu i vzcházení silážní kukuřice. Podíl vzešlých klíčních rostlin vzrostl s mírným zvýšením kontaktních tlaků na půdu. Nejnižší průměrný podíl vzešlých rostlin (52,63 %) byl získán při tlaku 0,076 MPa ve variantě F-surface. Nejvyšší průměrná hodnota (81,58 %) byla získána při kontaktním tlaku 0,025 MPa ve variantě F-bottom; hodnota u kontrolní varianty v nezavlažovaných podmínkách činila pouze 69 %.

Klíčová slova: utužení půdy; kontaktní tlaky na půdu; půdní fyzikální vlastnosti; vzcházení kukuřice

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