Legume Research, 39 (1) 2016: 52-60
Print ISSN:0250-5371 / Online ISSN:0976-0571

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
www.arccjournals.com/www.legumeresearch.in

Effects of irrigation, soil compaction and fertilization treatments on physiological – vegetative characteristics and root development of soybean

Halil Kirnak[1], Zeki Gokalp*[1], Ergün Dogan[2] and Osman Çopur

Harran University, Agricultural Faculty,
Field Crops Department, Sanliurfa, Turkey.
Received: 28-08-2015 Accepted: 30-12-2015 DOI: 10.18805/lr.v39i1.8864

ABSTRACT

The present study was conducted to investigate the effects of different soil compaction levels (non-compacted control, low compaction, high compaction), irrigation management practices (conventional furrow and alternate furrow) and nitrogenous fertilizer levels (60, 90, 120 kg ha^{-1}) on vegetative characteristics (dry biomass production, plant height, number of branch and number of pod per plant, height of the first pod, leaf area index, stem diameter), physiological characteristics (leaf relative water content, leaf chlorophyll content and leaf temperature) and root development through 0 - 80 cm soil profile of soybean grown in Harran Plain of Turkey. Experiments were conducted in Sanliurfa Province of Turkey in split-split plots experimental design with 3 replications during the years of 2006 and 2007. Irrigation program was created by using KanSched simulation model. The amount of applied irrigation water in conventional and alternate furrow systems in 2006 and 2007 were measured as 435.61 and 291.59 mm, and 429.51 and 271.72 mm, respectively. While the highest yield (947.8 kg ha^{-1}) was observed in control treatment of the year 2006, conventional furrow system had the highest yield (2099.3 kg ha^{-1}) in the year 2007. Soil compaction, irrigation and nitrogenous fertilization in general had significant effects on entire vegetative characteristics investigated in the present study. Increasing compaction levels yielded decreasing plant height, stem diameter and leaf area indexes. Biomass production increased with increasing nitrogen doses. Results indicated that negative impacts of soil compaction in agricultural fields due to traffic and various other reasons could be eliminated with proper irrigation and fertilization implementations.

Key words: Alternate furrow irrigation, Nitrogen level, Soil compaction, Soybean, Vegetative characteristics.

INTRODUCTION

Water resources are the critical component of sustainable agricultural development polices. Significance of limited resources is ever-increasing together with current climate change and global warming concerns especially in dry climates. Agricultural sector is in a great competition with domestic and industrial sectors in water demands. Such a competition for limited water resources enforces fresh-water users to use water efficiently. Agriculture is the largest water consuming sector (around 70%) in Turkey as it was in all around the world. Therefore, water-saving methods and technologies should be implemented in irrigations. However, the largest water consuming surface irrigation is still widely used in irrigations across the world (FAO, 2012).

Among the surface irrigation methods, furrow irrigation is used for row crops. Furrow irrigation can be operated in two fashions, either as conventional furrow or as alternate furrows just based on available water resources. In conventional system, every furrow is irrigated at the same time whereas in alternate system a furrow is irrigated while the adjacent furrow is left non-irrigated. In other words, every-other furrow is irrigated in alternate furrow system (Graterol *et al*., 1993).

Compaction is mostly resulted from intense machinery activity over agricultural fields. Soil particles move closer to each other, obstruct the void spaces and consequently limit air and water flow through the void spaces. Soil compaction reduces water holding capacity of soils (Motavalli *et al*., 2003). It has also various adverse impacts on drainage, infiltration rates and root development of plants (Van Ouwerkerk and Soane, 1994; Soane and Van Ouwerkerk, 1995). Compaction may significantly reduce plant growth and result in significant yield loses (Williamson and Neilsen, 2003; Czyz, 2004). Irrigated farming opportunities in GAP (Southeastern Anatolia Project) have brought together an intense machinery use and consequently severe soil compaction cases over irrigated fields.

Soybean is widely used in animal feeding, human nutrition and various industries. It is highly rich in protein (about 36%) and also contains 18% oil, 20% carbohydrate, 5% mineral and 1% lecithin. Since soybean is a leguminous crop, it is able to fixate the atmospheric nitrogen into soil

*Corresponding author's e-mail: zekigokalp@yahoo.com. [1]Erciyes University, Agricultural Faculty, Biosystems Eng. Dept., Kayseri, Turkey.
[2]Inönü University, Agricultural Faculty, Horticulture Department, Malatya, Turkey.

and mostly included in plant rotations to improve soil nutrient contents. Furrow irrigation is used in soybean irrigation and it is usually planted as second crop in GAP region.

In present study, vegetative characteristics (dry biomass production, plant height, number of branch and number of pod per plant, height of the first pod, leaf area index, stem diameter), physiological characteristics (leaf relative water content, leaf chlorophyll content and leaf temperature) and root development through 0 - 80 cm soil profile for soybean grown in Harran Plain were investigated.

MATERIALS AND METHODS

Experiments were conducted in the years 2006 and 2007 in Sanliurfa, Turkey. Experimental site has an altitude of 400 m and located between 36º42' north latitudes and 38º56' east longitudes (Fig. 1). High-yield soybean cultivar of Nova was selected as the plant material of the study. Experimental site has clay soils with average lime contents of between 30 - 49%. Soil analyses were performed before the experiments and relevant physical and chemical characteristics are presented in Table 1. The research site has semi-arid climate and climate parameters for both experimental years and long term averages are presented in Table 2. Irrigation water quality analyses were performed and quality parameters are provided in Table 3.

Soybean seeds were sown on 17th of July of the year 2006 and on 20th of June of the year 2007. Seeding rate was 90 kg ha-1. Experiments were conducted in split-split plot experimental design with 3 replications over 54 plots. Compaction levels were placed in main plots, irrigation management systems placed in subplots and nitrogen doses were placed in sub sub-plots. Three different nitrogen doses (N1=60, N2=90, N3=120 kg ha^{-1}) were used in this research.

Three different compaction levels were used to see the effects of compaction levels on vegetative, physiological characteristics and root development. The compaction levels were 1) Non-compacted case (Control, C); 2) Low-compaction case (LC); 3) High-Compaction case (HC). Soil compaction was created by a tractor (Styer-768) with four passes for LC and 12 passes for HC. Soil bulk densities measured to ascertain compaction levels for two different depth segments (0-30 and 30-60 cm) in both experimental years are provided in Table 4.

Two different irrigation management practices were applied for surface irrigation as of alternate furrow (AF) and conventional furrow (CF). In alternate furrow irrigation, a furrow was irrigated and adjacent furrow was left non-irrigated. In conventional furrow irrigation, every furrow was irrigated. Furrow ends were closed and runoffs were prevented in both furrow management systems. Irrigation

TABLE 1: Physical and chemical soil characteristics

Soil Layer (cm)	Density (g cm^{-3})	Texture	Organic Matter (%)	$CaCO_3$ (%)	pH	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Pw FC (%)	Pw PWP (%)
0-30	1.37	Clay	1.63	15.8	7.3	25	27	1280	31.55	22.15
30-60	1.40	Clay	1.40	26.2	7.2	12	20	900	31.80	22.60
60-90	1.43	Clay	1.25	33.0	7.2	6	17	810	32.80	21.53
90-120	1.42	Clay	1.15	38.2	7.2	-	-	-	32.84	23.11

TABLE 2: Irrigation water characteristics

Source	EC (dS m^{-1})	Cations			Anions				pH	SAR	Class
		Na^+	K^+	$Ca^{++}+Mg^{++}$	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$			
Canal	0.31	0.25	0.02	1.98	-	0.9	0.6	0.75	7.2	0.25	C_2S_1

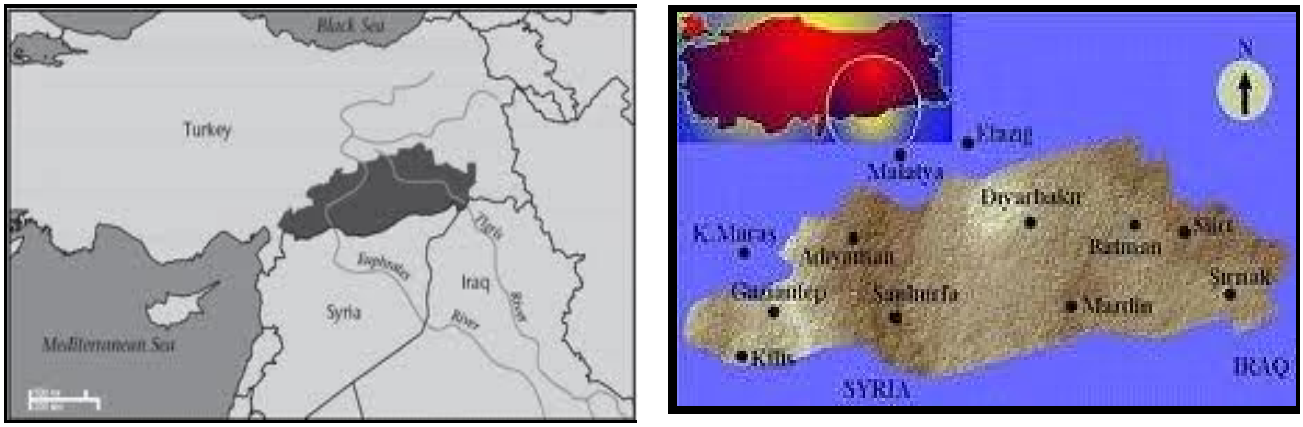


FIG 1: Research site

TABLE 3: Climate characteristics

Parameter	June	July	August	September	October
			Long-Term		
Minimum temperature (ºC)	9.4	11.0	10.2	8.4	0.7
Maximum temperature (ºC)	45.4	46.8	46.7	44.0	37.4
Average temperature (ºC)	28.0	31.4	30.4	26.6	18.3
Precipitation (mm)	2.5	0.1	-	0.1	23.7
Relative humidity (%)	35	33	36	34	43
Wind speed (m s^{-1})	2.5	2.6	2.1	1.5	1.0
Evaporation, CAP (mm)	322.7	385.0	368.4	275.7	160.1
			Growth Season (2006)		
Minimum temperature (ºC)	12.9	15	15	10.7	0.2
Maximum temperature (ºC)	39.3	42.5	41.8	37.8	34.1
Average temperature (ºC)	27.9	30	28.2	24.3	19.4
Precipitation (mm)	0	0	0	0	18.1
Relative humidity (%)	39.9	43	45.2	40.7	51.2
Wind speed (m s^{-1})	2.0	2.2	1.4	1.2	1.1
Evaporation, CAP (mm)	293	273	225	171	110
			Growth Season (2007)		
Minimum temperature (ºC)	13.4	18.0	18.5	11.0	0.3
Maximum temperature (ºC)	44.3	43.0	44.5	38.8	34.1
Average temperature (ºC)	23.8	30.8	32.5	24.8	18.1
Precipitation (mm)	0	0	0	0	12.5
Relative humidity (%)	40.8	45.5	44.6	40.5	54
Wind speed (m s^{-1})	1.9	2.0	1.5	1.1	1.0
Evaporation, CAP (mm)	295	281	215	180	100

TABLE 4: Soil bulk densities at different compaction levels

Treatment	2006		2007	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm
C	1.198	1.232	1.180	1.227
LC	1.247	1.301	1.227	1.284
HC	1.302	1.377	1.282	1.372

programs were started to be implemented at the end of flowering period. Equal flow (0.8 L s-1) was provided to each furrow. Irrigation program was created by using the software called "KanSched simulation model" (Clark *et al*., 2002). This model was developed at Kansas State University and it is mostly used for irrigation scheduling and to determine the amount of irrigation water to be applied.

Leaf relative water contents (LRWC) were measured over 3 fully-developed leaves just before the irrigations. Leaf samples were taken from the middle of each plot early in the morning at 8 o'clock. To avoid sampling of leaves with different physiological age and appearance, the youngest fully developed leaves of the 3rd node from the top were selected. First of all, fresh leaf weights (FW) were determined. The leaves were inundated in distilled water for 6 hours and their turgor weights (TW) were determined. Leaf samples were then dried at 65°C until a constant weight (for about 24-48 hours) and their dry weights (DW) were determined. Resultant weight values were used to calculate LRWC by using the following equation;

$$LRWC = \frac{FW - DW}{TW - DW} \times 100$$

Chlorophyll contents were measured in three replications with Field Scout CM 1000 Chlorophyll Meter (spectrum chlorophyll meter) over previously selected and marked five leaves. The measurements were expressed as index values.

Canopy temperatures were measured with an infrared thermometer (IRT- Raytek-Ranger ST30 ProTM Enhanced Model with a filter passing 8-14 μ wave lengths and an emissivity coefficient of 0.98) between the hours 11:00 – 15:00 of the day with a clear uncloudy sky. Field of view of the device (FOV) is 3°. Measurements were taken just before the irrigations along the diagonals of each plot in tree replications. A total of 6 measurements were performed for each plot and average of 6 measurements was taken as the canopy temperature of the relevant plot. To keep the soil surface out of the sight of IRT, the device was directed to plants at 30 - 40° from the horizontal.

Vegetative growth parameters were measured at four different periods as of flowering period, end of pod-set period, kernel formation period and just before harvest. Plant heights were measured over 10 plants selected randomly from the center of each plot. The height from the inter-node from which cotyledon leaves come out to tip of the plant was taken as the plant height. Stem diameter was measured with a digital caliper from the section right above the soil surface.

Leaf area was measured over 5 plants from each treatment with a portable leaf area meter. The total leaf area of each plant was divided by plant canopy to calculate the

leaf area index (LAI). These plants were cut into small pieces, placed into paper bags and dried at 65°C until they reach to a constant weight and this weight was taken as dry biomass.

Plant root development was observed with a soil profile pit of 90 cm. Steel sampling cylinders (200 cm3) were driven horizontally into the profile at 0 - 20, 30 - 50 and 60 - 80 cm layers and samples were taken into cylinders. Soil samples were inundated in 0.1 N NaOH solution for 24 hours for easy dispersion and wash out of the roots. Dispersed samples were sieved through number-4 mesh (1.00 mm) sieve and dried at 65°C for 24 hours. Plant root analysis was performed only for the year 2007.

Variance analysis was performed on data of two experimental years by using MSTATC statistical software and Duncan's multiple range test was used to compare the means.

RESULTS AND DISCUSSION

Applied irrigation water and seed yield: Applied irrigation water and average seed yields of experimental treatments are provided in Table 5 just to provide a brief overview about the these parameters since they were not the target parameters of the present study (Kirnak *et al*., 2013). About 35% less water was applied to alternate furrows than conventional ones. A general increase in seed yields were observed with nitrogen treatments and irrigations. The yield values of the first year were remarkably lower than the second year since the sowing was performed about one month later in the first year. Kokten *et al* (2014) reported the similar yield levels (1204.7 – 1652.7 kg ha-1) for soybean grown in Turkey under similar conditions.

Effects of treatments on physiological characteristics: Effects of soil compaction, irrigation and nitrogen doses on plant physiological characteristics (leaf relative water content, chlorophyll content, leaf temperature) are presented in Table 6 for the years 2006 and 2007.

Effects of nitrogen dose, irrigation and soil compaction on leaf relative water content (LRWC) were found to be significant in both experimental years at $P < 0.05$ level. Decreasing LRWC values were observed with increasing soil compaction. While the LRWC in non-compacted control treatments were found to be 68.67 and 69.80% respectively for the years 2006 and 2007, the values in high compaction treatments were respectively decreased to 59.64 and 58.74%. LRWC of plants irrigated with conventional furrow system were higher than the plants of alternate furrow system. While the LRWC in conventional furrow system was observed as 65.91 and 65.71% respectively in the years 2006 and 2007, the values in alternate furrow system were respectively decreased to 64.31 and 64.10%. Higher nitrogen doses did not increase LRWC and the average of years in N3 treatment was observed as 64.48%. Average values in N1 and N2 treatments were respectively observed as 65.02 and 65.53%. With regard to interactions, only the irrigation x compaction interaction had significant effects on LRWC in both years and effects of other interactions were not found to be significant.

Effects of soil compaction, nitrogen dose and irrigation management systems on leaf total chlorophyll content were found to be significant in both years at $P < 0.01$ level. Increasing chlorophyll contents were observed

TABLE 5: Applied irrigation water and average seed yield

Years	2006		2007	
	I (mm)	Average seed yield (kg ha^{-1})	I(mm)	Average seed yield (kg ha^{-1})
C x CF x N1	436	759.2 ± 5.05 defg	430	1736.7 ± 5.00 ns
C x CF x N2	436	1309.3± 6.60 a	430	2353.3 ± 6.15
C x CF x N3	436	955.3 ± 6.15 b	430	2673.3 ± 6.80
C x AF x N1	292	817.2 ± 5.45 cdef	271	1373.2 ± 3.95
C x AF x N2	292	946.3 ± 6.10 b	271	1486.6 ± 4.20
C x AF x N3	292	899.2 ± 5.65 bc	271	1716.7 ± 4.85
LC x CF x N1	436	1202.7 ± 6.50 a*	430	1870.0 ± 5.50
LC x CF x N2	436	707.1 ± 4.90 efgh	430	2256.7 ± 5.85
LC x CF x N3	436	827.7 ± 5.50 bcde	430	2506.7 ± 6.45
LC x AF x N1	292	697.1± 4.45 fgh	271	1510.0 ± 4.25
LC x AF x N2	292	801.3 ± 5.05 bcd	271	1390.0 ± 3.95
LC x AF x N3	292	807.5 ± 5.30 bc	271	1773.3 ± 5.15
HC x CF x N1	436	516.3 ± 4.00 ijk	430	1406.7 ± 4.00
HC x CF x N2	436	598.5 ± 4.05 hij	430	1907.3 ± 5.70
HC x CF x N3	436	637.3 ± 4.15 ghi	430	2183.3 ± 5.75
HC x AF x N1	292	482.7 ± 3.21 jk	271	1076.7 ± 3.75
HC x AF x N2	292	446.8 ± 3.15 k	271	1450.0 ± 4.15
HC x AF x N3	292	650.5 ± 4.25 gh	271	1613.3 ± 4.75

HC: High compaction; LC: Low compaction; C: Non-compacted (control); CF: Conventional furrow; AF: Alternated furrow; N1:Low nitrogen (60 kg ha^{-1}); N2: Normal nitrogen (90 kg ha^{-1}); N3:High nitrogen (120 kg ha^{-1}); *: same letters are not different; ns: not significant.

TABLE 6: Effects of treatments on physiological characteristics of the years 2006-2007

	2006			2007		
Treatment	LRWC (%)	Chlorophyll	Leaf Temp. (°C)	LRWC (%)	Chlorophyll	Leaf Temp. (°C)
Compaction						
LC	59.64b	280.89b	28.405a	58.74c	312.78c	35.12a
HC	67.02a	316.19a	26.99b	68.18b	369.06b	33.28b
C	68.67a	329.83a	26.85b	69.80a	401.44a	31.82c
Mean	65.11	308.97	27.41	64.91	361.10	33.407
LSD (0.05)	2.87	19.05	0.17	0.444	8.23	0.335
CV (%)	3.95	4.07	0.68	0.81	2.05	0.98
Irrigation						
CF	65.91a	320.98a	27.31b	65.71a	372.56a	33.02b
AF	64.31b	296.96b	27.52a	64.10b	349.63b	33.80a
Mean	65.11	308.97	27.41	64.91	361.10	33.407
LSD(0.05)	1.46	8.67	0.11	0.322	5.32	0.143
CV (%)	3.95	4.07	0.68	0.81	2.05	0.98
Nitrogen						
N1	65.75a	261.01c	27.19b	64.28c	316.28c	33.01c
N2	66.06a	305.44b	27.51a	65.00b	363.56b	33.29b
N3	63.52b	360.46a	27.53a	65.44a	403.44a	33.92a
Mean	65.11	308.97	27.41	64.91	361.10	33.407
LSD(0.05)	1.77	8.66	0.13	0.36	5.08	0.225
CV (%)	3.95	4.07	0.68	0.81	2.05	0.98

HC: High compaction; LC: Low compaction; C: Non-compacted (control); CF: Continuous furrow; AF: Alternated furrow; N1:Low nitrogen (60 kg ha^{-1}); N2: Normal nitrogen (90 kg ha^{-1}); N3:High nitrogen (120 kg ha^{-1}); *: sane letters are not different; ns: not significant.

with increasing nitrogen doses and decreasing soil compaction levels. Leaf chlorophyll content in alternate furrow system was 7.5% and 6.15% lower than conventional furrow system respectively of the years 2006 and 2007. With regard to effects of interactions in the year 2006, compaction x irrigation and irrigation x nitrogen dose interactions were found to be significant at $P < 0.01$ level and the others were not found to be significant. In the year 2007, effects of entire interactions, except for compaction x irrigation x nitrogen dose, on leaf chlorophyll content were found to be significant at $P < 0.01$ level.

Effects of treatments on leaf temperature were found to be significant in both experimental years at $P < 0.01$ level. Increase in leaf temperature may be explained by stress exerted on plants. Increasing leaf temperatures were observed with increasing soil compaction levels, decreasing irrigation water and increasing nitrogen doses. Nitrogen doses above the normal levels (N3) affected negatively the plant physiology and therefore increased leaf temperature. The highest average leaf temperature was observed in high-compaction treatment with 28.41°C in the year 2006 and with 35.12°C in the year 2007.

Despite the negative impacts of stress on LRWC, various impacts of different treatments on chlorophyll content and leaf temperature were put forward by several researchers (Harris *et al*., 1984; McKinney *et al*., 1989; Saitoh *et al*., 2004; Djanaguiraman *et al*., 2011; Ries *et al*., 2012; Keep, 2013). The values observed in the present study revealed higher impacts of stress on plant physiological characteristics. Climate, plant, irrigation program and applied compaction levels might have caused to have such higher effects.

Effects of treatments on vegetative characteristics: Effects of soil compaction, irrigation management practice and nitrogen fertilization on vegetative characteristics of second-crop soybean (dry biomass, plant height, number of branch per plant, height of the first pod, number of pod per plant, leaf area index and plant stem diameter) are provided in Table 7 and Table 8 respectively for the years 2006 and 2007.

Effects of soil compaction, irrigation management practices and nitrogen fertilization on dry biomass production were found to be significant at $P < 0.05$ level. Significant increases were observed in dry biomass production with decreasing compaction levels and increasing nitrogen doses. While the highest biomass production of the year 2006 was observed in N3 treatment with 507.52 gr m-2, the highest value of the year 2007 was seen in control treatment (C).

In the year 2006, compaction x irrigation x nitrogen interaction was found to be insignificant and the other interactions were found to be significant. Effects of entire interactions of the year 2007 on dry biomass production were found to be significant.

Only the soil compaction had significant effects on plant heights of the year 2006 ($p < 0.01$). Effects of irrigation management practices and nitrogen doses on plant heights were not found to be significant ($P < 0.01$). In the year 2007, effects of entire main factors (soil compaction, irrigation management practices, nitrogen doses) on plant height were

TABLE 7: Effects of treatments on vegetative characteristics 2006

Treatment	Biomass (gr m^{-2})	Plant height (cm)	Number of branches	Height of the first pod (cm)	Number of pod per plant	LAI	Stem diameter (mm)
Compaction							
C	544.00 a	59.46 a	1.58 ns	4.37 ns	34.47 ns	0.712a	7.64a
LC	440.58 ab	57.61 ab	1.03	3.96	35.18	0.517b	7.28a
HC	310.55 b*	53.95 b	0.94	4.32	34.11	0.330b	6.3b
Mean	431.71	57.01	1.18	4.22	34.59	0.519	7.07
LSD(0.05)	141.7	3.96	-	-	-	0.029	0.86
CV (%)	9.53	5.49	23.71	24.95	20.06	5.59	8.39
Irrigation							
CF	467.02 a	57.45 ns	1.19 ns	4.21 ns	33.64 ns	0.570a	7.50a
AF	396.40 b	56.56	1.17	4.22	35.53	0.469b	6.64b
Mean	431.71	57.01	1.18	4.22	34.64	0.519	7.07
LSD(0.05)	49.56	-	-	-	-	0.029	0.48
CV (%)	9.53	5.49	23.71	24.95	20.06	5.59	8.39
Nitrogen							
N1	348.46 c	56.78 ns	1.06 ns	4.29 ns	37.00 ns	0.477c	6.73b
N2	439.14 b	58.04	1.18	3.96	34.22	0.522b	6.90b
N3	507.52 a	56.19	1.30	4.40	32.53	0.560a	7.58a
Mean	431.71	57.00	1.18	4.22	34.58	0.519	7.07
LSD(0.05)	28.30	-	-	-	-	0.022	0.41
CV (%)	9.53	5.49	23.71	24.95	20.06	5.59	8.39

HC: High compaction; LC: Low compaction; C: Non-compacted (control); CF: Continuous furrow; AF: Alternated furrow; N1: Low nitrogen (60 kg ha^{-1}); N2: Normal nitrogen (90 kg ha^{-1}); N3: High nitrogen (120 kg ha^{-1}); *: sane letters are not different; ns: not significant.

TABLE 8: Effects of treatments on vegetative characteristics 2007

Treatment	Biomass (gr m^{-2})	Plant height (cm)	Number of branches	Height of the first pod (cm)	Number of pod per plant	LAI	Stem diameter (mm)
Compaction							
C	973.33 a	84.00 a	1.23 a	6.29 a	61.11 a	2.947	9.48a
LC	746.67 b	68.83 b	0.82 b	5.87 b	49.28 b	2.408b	8.42b
HC	487.78 c*	60.11 c	0.72 c	4.79 c	38.78 c	1.452c	6.41c
Mean	735.93	70.98	0.92	5.65	49.72	2.269	8.106
LSD(0.05)	16.04	1.054	0.029	0.093	1.195	0.029	0.109
CV (%)	2.07	1.52	2.60	2.43	1.69	2.20	0.94
Irrigation							
CF	807.04 a	73.22 a	1.03 a	5.71 a	50.71 a	2.304a	8.45a
AF	664.82 b	68.74 b	0.82 b	5.58 b	48.74 b	2.234b	7.76b
Mean	735.93	70.98	0.92	5.65	49.72	2.269	8.106
LSD(0.05)	11.69	1.29	0.021	0.115	0.395	0.021	0.047
CV (%)	2.07	1.52	2.60	2.43	1.69	2.20	0.94
Nitrogen							
N1	615.00 c	66.39 c	0.79 c	5.64 ns	47.39 c	1.925c	7.31c
N2	733.61 b	71.56 b	0.96 b	5.63	48.72 b	2.258b	8.22b
N3	859.17 a	75.00 a	1.03 a	5.67	53.06 a	2.624a	8.79a
Mean	735.93	70.98	0.92	5.65	49.72	2.269	8.106
LSD(0.05)	10.50	0.743	0.022	-	0.577	0.031	0.053
CV (%)	2.07	1.52	2.60	2.43	1.69	2.20	0.94

HC: High compaction; LC: Low compaction; C: Non-compacted (control); CF: Continuous furrow; AF: Alternated furrow; N1:Low nitrogen (60 kg ha^{-1}); N2: Normal nitrogen (90 kg ha^{-1}); N3:High nitrogen (120 kg ha^{-1}); *: sane letters are not different; ns: not significant.

found to be significant at $P < 0.01$ level. The highest plant heights were observed in control treatments of both years respectively as 59.46 and 84.00 cm. Decreasing plant heights were observed with increasing soil compaction levels. While the effects of compaction x nitrogen and irrigation x irrigation x nitrogen interactions on plant heights were found to be significant, effects of other interactions were not significant. Effects of soil compaction, irrigation management practices and nitrogen doses on number of branch per plant were found to be insignificant. The highest number of branch per plant

was observed in control (C) treatments of both years respectively as 1.58 and 1.23. While the effects of compaction x irrigation and compaction x irrigation x nitrogen interactions of the year 2006 on number of branch per plant were found to be significant, effects of other interactions were not found to be significant. However, entire interactions of the year 2007 were found to be significant with regard to number of branch per plant. Compared to control treatment, 41.46% decrease was observed in number of branch per plant in high-compaction (HC) treatment of the year 2007.

As it was in number of branch per plant, effects of compaction, irrigation and nitrogen on the first pod heights of the first year were not found to be significant. The highest value was obtained from N3 treatment with 4.40 cm. Only the compaction x irrigation interaction of the year 2006 was found to be significant with regard to height of the first pod ($P < 0.05$). In the year 2007, while the effects of nitrogen dose on height of the first pod were found to be insignificant, effects of soil compaction and irrigation management practices were found to be significant ($P < 0.05$). The highest value was obtained from the control treatment with 6.29 cm. Effects of entire interactions of the year 2007 on height of the first pod were found to be insignificant.

While the effects of main factors on number of pod per plant were not found to be significant in the year 2006, the effects were significant in the year 2007. Average number of pod per plant was found to be as 34 in 2006 and as 49.72 in 2007. Only the effects of compaction x irrigation interaction of the year were significant with regard to number of pod per plant ($P < 0.05$). In the year 2007 on the other hand, only the nitrogen x irrigation interaction was not found to be significant and the other interactions were found to be significant ($P < 0.05$). The highest value of the year 2007 was observed in control treatment with 61.11 and the lowest in high-compaction treatment with 38.78. Number of pod per plant increased with increasing nitrogen doses of the year 2007.

With regard to leaf area index (LAI), effects of soil compaction, irrigation management practices and nitrogen doses were found to be significant ($P < 0.01$) in both years. Increasing LAI values were observed with increasing nitrogen doses. The highest LAI was observed in non-compacted control treatments of both years as 0.712 in 2006 and 2.95 in 2007. LAI values decreased with increasing soil compaction levels. When the non-compacted and compacted treatments are compared, 46.3% decrease was observed in LAI values in 2006 and 50.73% in 2007. While the nitrogen x irrigation interaction was not found to be significant with regard to LAI, all the other interactions were found to be significant. In the year 2007, entire interactions were found to be significant. A decrease in LAI toward the harvest season was also reported by various researchers (Meckel *et al*., 1984; Reeves *et al*., 1993; Yazar *et al*., 1999; Irmak *et al*., 2002).

Effects of soil compaction, irrigation management practices and nitrogen doses on stem diameter were found to be significant in both years at $P < 0.01$ level. While the irrigation x nitrogen and compaction x irrigation x nitrogen interactions were not found to significant with regard to stem diameter, other interactions of the year were found to be significant. In the year 2007, entire interactions were significant. The highest stem diameters were observed in non-compacted control treatment of both years as 7.64 cm in 2006 and 9.48 cm in 2007. The values in high-compaction treatments of the years 2006 and 2007 respectively decreased to 6.30 and 6.41 cm. Effect of nitrogen dose on stem diameter was especially distinctive in N3 treatment. Previous studies also reported elevated vegetative growth with irrigation practices (Hodges and Heatherly, 1983; Heatherly *et al*., 1994; Yazar *et al*., 1999).

Effects of treatments on root development: Plant root development was only investigated in the year 2007. Statistical analyses revealed significant effects of compaction, irrigation and nitrogen doses on root development ($P < 0.01$). Roots were mainly concentrated (85.61%) within 0 - 50 cm soil profile of entire treatments (Table 9). Root density at 0 - 20 cm soil profile was 5.9% lower than the density at 30-50 cm profile. While root density at 30-50 cm was 0.560 mg cm-3, the value was observed as 0.177 mg cm-3 at 60 - 80 cm. The highest root density was observed at 30-50 cm of non-compacted control

TABLE 9: Effects of treatments on root development of the year 2007

Treatment	0 - 20 cm	30 - 50 cm	60 - 80 cm
Compaction			
LC	0.550b	0.506b	0.223b
HC	0.358c	0.355c	0.048c
C	0.571a	0.820a	0.261a
Mean	0.493	0.560	0.177
LSD(0.05)	0.009	0.009	0.009
CV (%)	3.18	3.22	5.44
Irrigation			
CF	0.523a	0.565öd	0.201a
AF	0.463b	0.556	0.153b
Mean	0.493	0.560	0.177
LSD(0.05)	0.007	-	0.007
CV (%)	3.18	3.22	5.44
Nitrogen			
N1	0.484b	0.467c	0.151c
N2	0.475c	0.567b	0.181b
N3	0.521a	0.648a	0.199a
Mean	0.493	0.560	0.177
LSD(0.05)	0.007	0.007	0.007
CV (%)	3.18	3.22	5.44

HC: High compaction; LC: Low compaction; C: Non-compacted (control); CF: Continuous furrow; AF: Alternated furrow; N1: Low nitrogen (60 kg ha^{-1}); N2: Normal nitrogen (90 kg ha^{-1}); N3: High nitrogen (120 kg ha^{-1}); *: same letters are not different; ns: not significant.

treatment with 0.82 mg cm-3 and the lowest value was seen at 60 - 80 cm of high-compaction treatment with 0.048 mg cm-3.

Kanber *et al*. (1996) investigated root development and density in young orange trees and reported significant impacts of irrigation on root development and intensity and indicated that about 80% of roots concentered within 60 cm soil profile. Laboski *et al*. (1988) reported that soil compaction limited the root development within 0 -60 cm layer of corn. In the present study, roots were mostly (85%) located within 50 cm soil layer.

Various measures should be taken to prevent soil compaction and consequent negative impacts on root development. Excessive tillage with heavy machinery may be prevented and deep-rooted plants may be incorporated into cropping patters. Proper irrigation and fertilization may also reduce the impacts of soil compaction on root development.

ACKNOWLEDGMENT

This research was funded by "The Scientific and Technological Research Council of Turkey – TUBÝTAK" with a Project Number of TOVAG-104 O 389.

REFERENCES

Clark, G.A., Rogers, D.H. and Briggeman, S. (2002). KANSCHED: An ET-based irrigation scheduling tool for Kansas summer annual crops." Kansas State University Research and Extension Service.

Czyz, E. and Tomaszewska, J. (2004). Changes of aeration conditions and the yield of sugar beet on sandy soil of different density. *Pol J Soil Sci* **26:** 1-9.

Djanaguiraman, M., Prasad, P.V.V., Boyle, D.L. and Schapaugh, W.T. (2011). High-temperature stress and soybean leaves: Leaf anatomy and photosynthesis. *Crop Sci* **51:** 2125-2131.

FAO. 2012. Guidelines for designing and evaluating surface irrigation systems. FAO Corporate Document Repository.

Graterol Y.E, Eisenhauer, D.E. and Elmore, R.W. (1993). Alternate-furrow irrigation for soybean production. *Agr Water Manage* **24:** 133-145.

Harris D.S, Schapaugh, W.T. and Kanemasu, E.T. (1984). Genetic diversity in soybeans for leaf canopy temperature and the association of leaf canopy temperature and yield. *Crop Sci* **24:** 839-842.

Heatherly, L.G., Elmore, C.D. and Spurlock, S.R. (1994). Effect of irrigation and weed control treatment on yield and net return from soybean (Glycine max), *Weed Technology* **8:**69-76.

Hodges, H.F. and Heatherly, L.G. (1983). Principles of water management for soybean production. Bull. 919, Missisippi State University, Starkville, USA.

Irmak, A., Batchelor, W.D., Jones, J.W., Irmak, S., Paz, J.O., Beck, H.W. and Egeh, M. (2002). Relationship between plant available soil water and yield for explaining soybean yield variability. *Applied Eng. in Agric*. **18:** 471-482.

Kanber, R., Köksal, H., Önder, S. and Eylen, M. (1996). The effects of different irrigation methods on young orange tree's yield, water consumption and root growth. Ankara. *Turk J Agric For* **20:** 163-172.

Keep, N.R. (2013). Characterization of physiological parameters in soybean with genetic improvement in seed yield. MS Thesis, Kansas State University, Collage of Agriculture, USA.

Kirnak, H., Dogan, E., Cupur, O. and Gokalp, Z. (2013). Irrigation and yield parameters of soybean as effected irrigation managements, soil compaction and nitrogen fertilization. *J. of Agr. Sci*. **19:**297-309.

Kokten, K., Seydosoglu, S., Kapla, M. and Boydak, E. 2014. Forage nutritive value of soybean varieties. Legume Res. **37:**201-206.

Laboski, C.A.M., Dowdy, R.H., Allmaras, R.R. and Lamb, J.A. (1998). Soil strength and water content influences on corn root distribution in a sandy soil. *Plant Soil* **203:** 239-247.

McKinney, N.V., Schapaugh, W.T. and Kanemasu, E.T. (1989). Canopy temperature, seed yield, and vapor-pressure deficit relationships in soybean. *Crop Sci* **29:** 1038-1041.

Meckel, L., Egli, D.B., Philips, R.E., Radcliffe, D. and Leggett, J.E. (1984). Effect of moisture stress on seed growth in soybeans. *Agronomy Journal* **75:**1027-1031.

Motavalli, P.P., Anderson, S.H. and Pengthamkeerati, P. (2003). Surface compaction and turkey litter on corn growth, N availability, and physical properties of a clay-pan soil. *Field Crop Res* **84:** 303-318.

Reeves, D.W., Wood, C.V. and Touchton, J.T. (1993). Timing nitrogen applications for corn in a winter legume conservation-tillage system. *Agronomy Journal*, **85:**98-106.

Ries, L.L., Purcell, L., Carter, T.E., Edwards, J.T. and King, C.A. (2012). Physiological traits contributing to differential canopy wilting in soybean under drought. *Crop Sci* **52:** 272-281.

Saitoh, K., Nishimura, K. and Kuroda, T. (2004). Comparison of leaf photosynthesis between wild and cultivated types of soybean. *Plant Produc Sci* **7:** 277-279.

Soane, B.D. and Van Ouwerkerk, C. (1995). Implications of soil compaction in crop production for the quality of the environment. *Soil Tillage Res* **35:** 5-22.

Van Ouwerkerk, C. and Soane, B.D. (1994). Conclusions and recommendations for further research on soil compaction in crop production. In: Soane, B.D., Van Ouwerkerk, C. (Eds.), Soil Compaction in Crop Production. *Dev Agric Eng* **11:** 627-642.

Williamson, J.R. and Nielsen, W.A. (2003). The effect of soil compaction, profile disturbance and fertilizer application on the growth of eucalypt seedlings in two glasshouse studies. Soil Tillage Res **71:** 95-107.

Yazar, A., Howell, T.A., Dusek, D.A and Copeland, K.S. (1999). Evaluation of crop water stress index for LEPA irrigated corn. Irrigation Science **18:**171-180.