Effects of Surface Mid-season Drainage on Soil Water Tension and Soil Bearing Capacity on Paddy Fields at Harvest Time

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Summary

High efficiency of machine harvesting can be obtained by reducing soil moisture and achieving a suitable bearing capacity at harvest time. This study was conducted in paddy fields, to investigate the effect of surface mid-season drainage duration on soil moisture and soil bearing capacity at harvest time. The field experiment was carried out as a randomized complete block design with 6 treatments of mid-season drainage durations (MDD) i.e. 0 (control), 5, 7, 9, 11 and 13 days in three replications. Based on the averages, the rate of the increase of soil water tension (SWT) was obtained as 52.6 cm d^{-1}. For soil depths ranging from 0 to 25 cm, the difference between maximum and minimum soil bearing capacity (SBC) was on average 228.8 kPa. Generally, the increase of SBC at harvest time was observed with the prolongation of the mid-season drainage duration. Thus, considering mechanization development, energy saving and preparing land for second cultivation in paddy fields, application of mid-season drainage with 13-day duration in paddy fields is recommended for the studied area.

Key words

soil compaction, second cultivation, rice

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Introduction

Annual production and consumption of rice in Asia is about 650 million tons (FAO, 2014). In the future, the demand for rice will increase due to the growing world's population (Fonteh et al., 2013). In Iran, as in many other countries, rice has the most important role in people's nutrition following wheat. The area of cultivated rice Iran was about 565000 ha in 2013, with Mazandaran and Guilan provinces constituting 38.8% and 31.1%, respectively.

Paddy fields drainage can be used to drain ponding and logged water, as well as to increase soil temperature, improve soil salinity and aerification of the root zone. It also allows mechanized harvesting, the use of agricultural machines, and the preparation of the field for second cultivation (Darzi-Naftchali et al., 2013) while simultaneously increasing the yield and productivity (Darzi-Naftchali et al., 2014).

More than 120000 ha of paddy fields have been developed and renovated in farmland consolidation program in Northern provinces of Iran. Rice is irrigated in continuous flooding irrigation, with surface drainage channels being one of the structures of those projects. In most areas of Mazandaran province, transplanting starts from early May, and the time of mid-season drainage according to panicle initiation (for local qualitative cultivars) is about 35 days later, while the harvesting starts in late July.

Mid-season drainage of paddy fields can lead to beneficial results (Liu et al., 2013), including soil aerification and oxygen supply (Stoop et al., 2002; Rahman et al., 2013), creation of temporary oxidation in soil (Shiratori et al., 2007), prevention of toxin accumulation caused by deoxidation conditions around the roots (Furukawa et al., 2008; Osaki et al., 2001), increased yield (Palangi et al., 2015; Chakani et al., 2015), and reduction of methane emission in the soil and atmosphere (Bouman et al., 2007; Shiratori et al., 2007).

Waterlogging of paddy fields at harvest time can increase the cost of production and reduce the quantity and quality of rice yield (Vandersypen et al., 2007). About two weeks prior to harvest time, the surface layer of soil should be dried (Inoue and Tokunaga, 1995) to enhance the soil bearing capacity, and to prepare the field for the mechanized harvesting (Ogino and Ota, 2007).

To achieve sustainable agriculture, maintaining appropriate ratios between the solid, liquid, and gas phases of soil is necessary in agronomy practices. One of the indicators representing the degradation of soil physical structure is soil compaction, defined through bulk density or porosity reduction. In agricultural lands, especially in paddy fields, soil compaction causes loss of required space for root growth. These conditions reduce the soil aeration and water infiltration, thereby affecting the crop production system. The most important factor influencing the agricultural soil compaction during the tillage is soil moisture. In Mazandaran, paddy fields are often prepared for transplanting using tractors and Rotary cultivator, the depth of tillagebeing less than 15 cm, reducing the energy consumption, production costs and water consumption.

Compaction of soil varies due to weather conditions, water and soil management, as well as plant growth over time (Naderi-Boldaji et al., 2008). Mid-season drainage in paddy fields is carried out between the maximum tillering and the beginning of reproductive growth, allowing the soil surface to dry whereby creating hairline cracks. In this process, soil moisture drops below the level of saturation, while the plant growth should be sustained without drought stress (Dehghani et al., 2015). Thus, proper management of time and duration of mid-season drainage is important and can result in increasing yield (Thompson, 2006). The results of the effects of mid-season drainage on the soil compaction can also be used in identifying the important factors reducing energy consumption in mechanized harvesting (Tabatabaeikoolor and Alimardani, 2008).

To facilitate mechanized harvesting and prevent soil compaction, the soil bearing capacity at harvesting time should be enhanced. Meanwhile, draining soil water in paddy fields can lead to enhanced soil bearing capacity. This study aimed to investigate the variations of soil water tension and soil bearing capacity at harvesting time, as affected by different durations of the mid-season surface drainage in rice cultivation in north of Iran.

Materials and Methods

The study was conducted on paddy fields of Haraz Extension and Technology Development Center located in Mazandaran Province, Iran, with 52° 19' 11" E longitude and 36° 34' 25" N latitude and 5.5 m MSL elevation (Fig.1). The mean annual temperature and precipitation based on a 1994 to 2012 period are 16°C and 883 mm, respectively. The soil of the studied area is loamy silt, with 14.5%, 74.6%, and 10.9% of sand, silt and clay, respectively, and the following properties: electrical conductivity (EC) 1.25 dS m^{-1}, organic matter (OM) 3.2%, total-N content 0.181%, available phosphorus 27.07 ppm, and exchangeable potassium 174.9 ppm. The fields were flooded and covered with a 5-10 cm deep layer of water, and puddled before transplanting. A local cultivar of rice named *Tarom-Hashemi* was transplanted on 6^{th} May 2013. The mean, maximum and minimum temperatures of growing period (May to July 2013) were 22.8°C, 32°C and 13.5°C, respectively, while the precipitation was 104 mm.

The field experiment was carried out in a randomized complete block design with six treatments including 0 (control), 5, 7, 9, 11, and 13 days of mid-season drainage durations (MDD) in three replications (R1, R2 and R3) arranged in 4×5 m plots. The drainage duration refers to the time elapsed from discharging surface water to the next irrigation. Recommended mid-season drainage duration is about 7 or more days towards the end of tillering (Rahman et al., 2013); however, lower yield may occur if mid-season drainage duration is too long (Thompson, 2006). In the study area, duration of mid-season drainage is usually less than 10 days. Therefore, 13 days of MDD was considered as a roof of MDD treatments.

The rice was transplanted at 20 × 20 cm distance with 3 plants per hill. Land leveling, application of fertilizers, irrigation water quality, pest control management, cultivating dates, harvesting date, and the start date of mid-season drainage were similar for all plots. Fertilizers were applied as 100 and 50 kg ha^{-1} of nitrogen and phosphorus, in the form of urea and triple super phosphate, respectively, according to recommendations of Rice Research Institute of Iran (Shahdi-Kumleh et al., 2012). Triple super phosphate was applied once before transplanting, while urea was

Figure 1. Position of study area

applied three times in equal amounts: at transplanting, 21 day and35 days after transplanting. To prevent lateral penetration, edges of plots were covered with plastic. Surface drainages 40 cm wide were created on both sides of plots, located 4 further and 10 cm below the surface of plots.

To adjust water level in the plots, a reference mark was placed 5 cm above the soil surface, and the plots were irrigated until the water reached the reference level in irrigation events. Every other day, continuous irrigation of plots was conducted to maintain flooding irrigation, except during the drainage period. Irrigation water was directed into the plots through concrete channels, located above the fields and controlled with valves. The MDD treatments were applied on 18th June, at the end of tillering when the first panicle in the rice stem was observed. Surface water was drained from the plots through surface drains, while the next irrigation was applied at the end of specific MDD treatment periods. After the treatment, the irrigation operation was continued similar to pre-MDD period, and stopped two weeks prior to harvesting. No rainfall occurred during the application of treatments. The crop was harvested on 8th August.

To survey the effect of MDD treatments on creation of soil cracks, the length, width, and depth of the cracks were measured on 12 points in each experimental plot, using 1×1 meter meshes at the center of each plot (to avoid marginal effects).

During drainage periods, at mid-season and harvesting time, soil moisture for 0-25 cm depths was measured in each plot through a gravimetric procedure. To determine the soil moisture retention curve, the soil water content (θ) was measured at the soil moisture tensions (h) of 0.3, 1, 3, 5, 8, 12 and 15 kPa by a pressure cell. The best equation (van Genuchten 1980) fitting the measured data (θ and h) was specified using RETC software as Eq. (1).

$$\frac{\Theta - 0.1038}{0.5699 - 0.1038} = \frac{1}{[1+(0.0018h)^{1.4924}]^{0.3299}} \quad (1)$$

At harvesting time, SBC was measured at the same 12 points of measuring the size of cracks, in 5, 10, 15, 20, and 25 cm depth. The measurement was carried out by a cone penetrometer based on the required force for vertical penetration of metal cone from surface into the soil matrix (Mizutani et al., 1999).

All collected data were statistically analyzed, using analysis of variance to evaluate the main effects of treatments. The mean values of treatments were compared using Duncan test at $P \leq 0.05$. Statistical analyses were conducted using SPSS software.

Results and Discussion

Soil water tension

The variations of soil water tension (SWT) over time across different treatments of drainage duration are shown in Fig. 2. The trends of SWT changes were similar for different treatments, increasing with the prolongation of the duration of the mid-season drainage. Based on the averages, the rate of the increase of SWT was obtained as 52.6 cm d^{-1}.

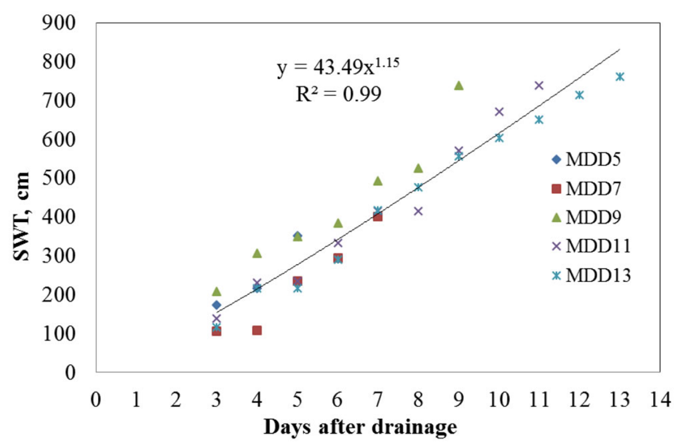

Figure 2. The variations of soil water tension (SWT) during different mid-season drainage duration (MDD) treatments

The SWT for different mid-season drainage treatments at harvesting time are shown in Fig. 3. The minimum (325 cm) and maximum (756 cm) SWT at harvesting time were observed in the control and MDD13 treatments, respectively. Accordingly, the SWT at harvesting time increased as much as 132.5% upon applying 13-day mid-season drainage duration compared to the control treatment. Other obtained values were 16.2%, 78.2%, 130.5%, and 125.5% for MDD5, MDD7, MDD9, and MDD11 treatments, respectively. No significant difference was found between the SWT values in the control and MDD5 treatments, while significant differences were found from the SWT values in other treatments. Also, no significant differences were found between SWT values in MDD7, MDD9, MDD11, and MDD13 treatments. Note that mid-season drainage of paddy fields develops cracks inside the soil (Dehghani et al. 2015). Thus, at harvesting time, the soil water content diminishes more quickly through cracks where the field soil dries faster. This leads to facilitation of traffic for harvesting machines and reduces the energy consumption. The impact of soil moisture on the energy consumption of agricultural machines has been mentioned by Mosadeghi et al. (2000).

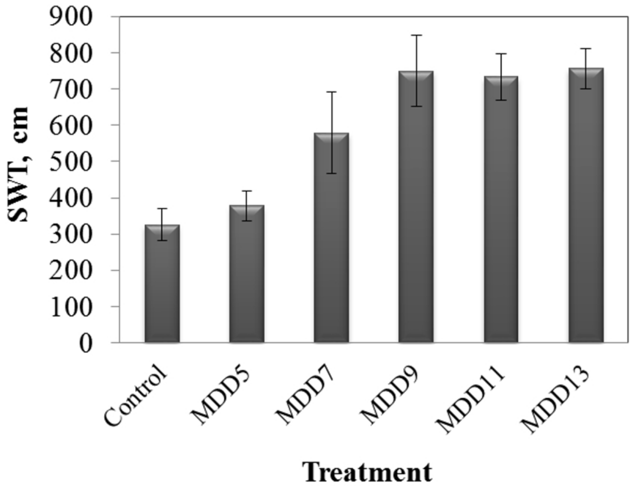

Figure 3. Soil water tensions (SWT) (depth of 0-25 cm) for different mid-season drainage duration (MDD) treatments at harvesting time

Also, knowing the relationship between soil compaction and soil water content helps plan the application of machines at appropriate moisture (Ohu et al., 1989).

Soil cracks properties

Considering the irrigation management, investigating the properties of soil surface cracks regarding the effect of mid-season drainage is very important. With increasing drainage duration, the frequency and size of soil surface cracks will increase. The results of analysis of variance on the average length and width of cracks affected by MDD treatments are presented in Table 1. The effects of MDD treatments on the average width and length of cracks were statistically significant.

Table 1. Least square resulting from variance analysis of soil cracks length and width in different surface drainage duration treatments

Source of variations	Degree of freedom	Cracks length (cm)	Cracks width (mm)
Drainage duration	5	34.13 *	2.49 *
Standard error	12	1.75	0.12
Coefficient of variation (%)	-	61.65	66.12

*: Significant differences ($P<0.05$)

The average length, width, and maximum depth of cracks in MDD treatments are shown in Figs 4 to 6, respectively. The maximum values of crack length (10 cm) and width (7 mm) were observed in the MDD13 treatment. The length, width, and maximum depth of cracks increased with the prolongation of the mid-season drainage duration, whereupon SWT at the end of drainage period increased. In this regard, Jafari et al. (2007) found a considerable increase in the length and width of soil cracks with a slight variation in the soil moisture when the soil moisture was below the field capacity. Noteworthy, the development of cracks on soil surface of paddy fields, affected by reduction of soil moisture, could lead to a serious damage to the crop.

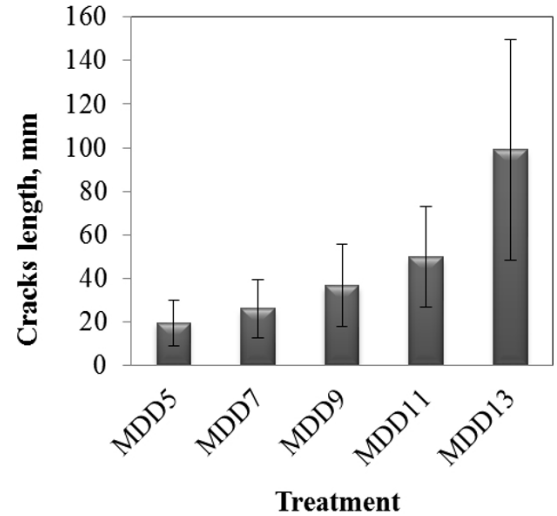

Figure 4. Length of cracks created on soil surface in different mid-season drainage duration (MDD) treatments

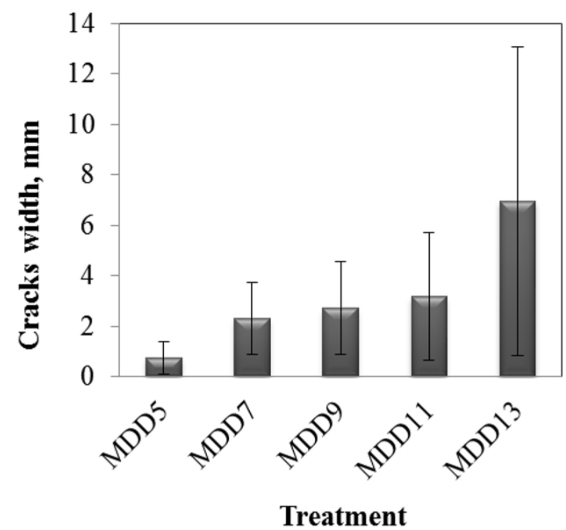

Figure 5. Width of cracks created on soil surface in different mid-season drainage duration (MDD) treatments

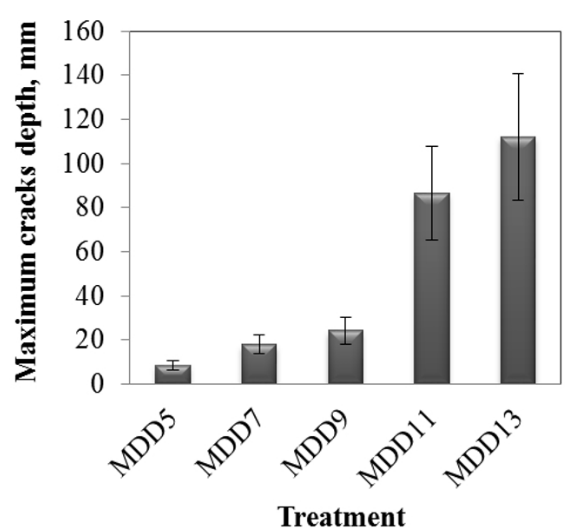

Figure 6. Maximum depth of cracks created on soil surface in different mid-season drainage duration (MDD) treatments

Thus, the management of mid-season drainage duration and control of soil moisture variation are necessary. Deeper soil cracks, in turn, reduce the damage of excessive soil moisture to plant roots and also increase the water loss at the end of the drainage periods. Liu et al. (2003) found that the development of soil cracks could significantly increase the water loss as deep percolation in paddy fields. In this study, the maximum depth of cracks was less than the measured depth (25 to 30 cm) of the hardpan layer, hereupon, cracks could not result in the establishing of preferential flow and the increase of water loss.

Soil bearing capacity

The results of statistical analysis and mean squares of variance analysis on SBC at harvesting time affected by MDD treatments are reported in Table 2. In addition, the measured values of SBC at harvesting time at different depths and MDD treatments are provided in Table 3. A relationship was also observed between length, width, as well as maximum depth of soil cracks and SBC at harvesting time in Fig. 7. As shown, SBC rose upon the increase in the soil depth as it approaches the plow pan and the hardpan. The rates of increasing SBC were 21.2 and 55.1 kPa cm^{-1} for depths of 0-15 cm and 15-25 cm, on average, respectively. This difference can be mainly attributed to greater activity and development of roots and tillage practices in the depth of 0-15 cm as compared to 15-25 cm.

The lowest (111.2 kPa) and the highest (1175.9 kPa) SBCs at harvesting time were obtained with the control treatment, depth of 5 cm, and MDD13 treatment, depth of 25 cm, respectively. Increasing duration of mid-season drainage resulted in higher SBC at the harvesting time.

Regarding the changes of SBC in relation to depth, statistically significant differences were found between the values of SBC at different depths for the control treatment. For MDD5, no significant difference was found between SBC at the depths of 5 and 10 cm, while they were significantly different from the SBC obtained at the depths of 15, 20, and 25 cm. Also, significant differences were found between the SBC at the three mentioned depths. In MDD7, MDD9, MDD11, and MDD13 treatments, the values of SBC between 5 and 10 cm as well as between 10 and 15 cm were not significantly different; however, significant differences were observed in other cases. In the control treatment, no cracks occurred inside the soil due to continuous flooding irritation. Therefore, the changes in SBC were only affected by the increase in the soil bulk density at the measured depths. For MDD5, it seems that the development of the cracks and the variation of bulk density were similar at the depths 0-10 cm, while at other depths, SBC was less affected by the cracks and the resulting compaction and more by the natural changes in soil bulk density at different depths. The prolongation of the duration of mid-season drainage resulted with the effect of the development of cracks and soil compaction on a greater soil depth.

Considering the changes in SBC towards drainage duration, no statistically significant difference was found between control treatment and MDD5 at the depth of 5 cm, while significant differences were observed from the values for MDD7, MDD9, MDD11, and MDD13. No significant differences were found between the SBC for these four treatments. In other words, the increase in the drainage duration from 5 to 7 days caused a statistically significant difference between the values of SBC at the depth of 5 cm. Similar results was observed at the depths of 10 and 15 cm.

Table 2. Least square resulting from variance analysis of soil bearing capacity in various depth at harvesting time

Source of variations	Degree of freedom	Depth (cm)				
		5	10	15	20	25
Drainage duration	5	19951.8 *	34212.6 *	28272.1 *	14066.5 ^{ns}	31975 ^{ns}
Standard error	12	3122.8	4869.6	3544.9	5173.1	22910.1
Coefficient of variation (%)	-	41	36	23	12	16

*: Significant differences (P<0.05), ^{ns}: Nonsignificant differences

Table 3. Average of soil bearing capacity (SBC) values at harvesting time (kPa) for different drainage duration treatments and soil depth

Depth (cm)	Drainage duration treatments					
	Control	MDD5	MDD7	MDD9	MDD11	MDD13
5	112.2 Aa*	127.0 Aa	252.3 Ab	237.5 Ab	274.6 Ab	311.8 Ab
10	196.1 Ba	191.6 Aa	355.6 ABb	339.6 ABb	410.2 ABb	444.2 ABb
15	314.6 Ca	354.5 Ba	484.5 Bb	469.3 Bb	516.1 Bb	567.2 Bb
20	661.0 Da	657.3 Ca	730.6 Cab	774.6 Cab	773.9 Cab	836.5 Cb
25	909.0 Ea	891.3 Da	978.6 Da	1038.1 Da	1019 Da	1175.9 Da

* Means followed by the same letters in each row and column (capital letters) are not significantly different at P<0.05

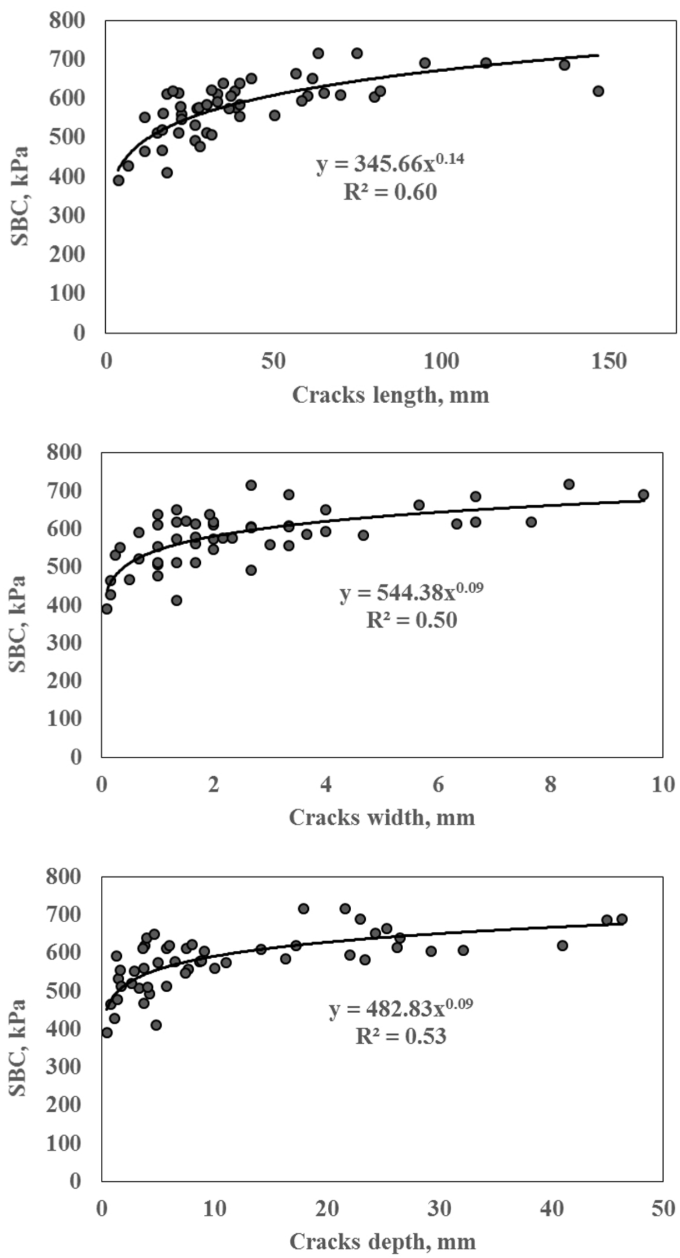

Figure 7. The relationship between length, width and maximum depth of soil cracks with soil bearing capacity (SBC) at harvesting time

At the depth of 20 cm, a significant difference between SBC values in control as well as MDD5 treatments and MDD13 treatment was found.

At the depth of 25 cm, no statistically significant differences were found between the SBC for different treatments. Generally, the increase of soil depth resulted with a decline in the impact of drainage duration treatments on SBC. Since the surface water is discharged in surface drainage and it is accompanied with evapotranspiration, its impact is usually observed at the depth of roots zone.

Conclusion

The results indicated the effect of surface mid-season drainage duration in the paddy fields (*Tarom-Hashemi* cultivar) on soil water tension (SWT) and soil bearing capacity (SBC) at the harvesting time. Accordingly, the application of MDD13 treatment increased SWT at the harvesting time from 325 cm (control treatment) to 756 cm. In all treatments, the increase rate of SBC from the soil surface to 15 cm depth was lesser than the rate from 15 to 25 cm depth. For different soil depths from 0 to 25 cm, the difference between maximum (MDD13) and minimum (control) SBC was 228.8 kpa on average. Generally, following the increase in the mid-season drainage duration, accordingly causing a reduction in soil moisture, the bearing capacity at harvesting time increased. Thus, considering mechanization development, energy saving, and preparing the land for second cultivation in paddy fields, application of mid-season drainage with 13-day duration in is recommended for the studied area.

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