PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.140386
2022, No. 52 (I–III): 166–171

Impact of tractor wheels on physical properties of different soil types and the irrigation efficiency of the furrow irrigation method

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RECEIVED 06.05.2021 REVIEWED 16.07.2021 ACCEPTED 18.09.2021

Abstract: In furrow irrigation, the maximum lateral movement of water in ridges is more desirable than the vertical downward movement. This can be achieved by compacting the furrows. Thus, the study examines the impact on furrow soil compaction by tractor wheel trafficking during mechanical operations in the different soil types. In this experiment, the three-wheel tractor compaction includes: 1) control (no soil compaction), 2) compaction through 3-wheel tractor passes, and 3) compaction through 6-wheel passes under three different soil textural classes such as: clay loam, silty clay loam and silty loam soils. The impact of various treatments on clay loam, silty clay loam, and silty loam under 3- and 6-wheel passes showed increased bulk density (7–12%), field capacity (9–19%), ridge storage efficiency (35–38%), water use efficiency (16–20.5%) and decreased soil porosity (7–16%), infiltration (8–20%), and furrow storage efficiency (28–41%) over the control. This study shows comparable results of 6-passes with other studies in which more than 6-passes were used to compact the soil. This study suggested that farmers can maximise water use efficiency by compacting their furrows using 6-passes tractor trafficking.

Keywords: furrow/ridge storage efficiency, irrigation method, soil physical properties, tractor wheel trafficking, water use efficiency

INTRODUCTION

Various surface irrigation methods have been practiced for several decades, such as border, flood, and furrow irrigations. Farmers seem reluctant to adopt other methods due to their cost and required operational skills, whereas the efficiency of the surface irrigation method has been reported below 50% [Burt *et al.* 1997]. Therefore, it is mandatory to optimise its design and manage it efficiently to maximise production and save water. Among surface irrigation methods, the furrow irrigation method is employed by the majority of farmers. The furrow irrigation method is more important in comparison to costly modern irrigation methods with less know-how transferred to common farmers regarding automation and operation [Shirazi *et al.* 2011].

Furrow irrigation is one of traditional methods which is said to have poor water use efficiency compared to high-tech drip and sprinkler irrigation methods. It is usually because of non-uniform water distribution and percolation. Additionally, subsurface irrigation is one of the most efficient methods through which small quantity of water is supplied below the soil surface to the crop to reduce evaporation and deep percolation at the farm level [Siyal *et al.* 2011]. However, it is supposed to be a more efficient method compared to the basin and border irrigation methods [Burt *et al.* 1997]. In light textured soils, due to lower field capacity, productivity is low, there is less organic matter contents, and low soil fertility, while initially the intake of water is high. Therefore, there is a dire need for alternate strategies that facilitate water, fertiliser, and soil management. The furrow irrigation method may enable to achieve high irrigation efficiency and minimise nitrogen loss during leaching. Ghaffar *et al.* [2015] reported that owing to the increasing water scarcity, irrigation techniques always play an important role to boost agricultural production as they enhance the efficiency of irrigation.

In irrigated agriculture, the efficiency of applying water is a burning issue as water resources become increasingly scarce due to climate changes. As demonstrated by Iqbal *et al.* [1994], the measurement of water application efficiency requires irrigation advance data for volume analysis and hydrodynamic models or moisture calculations pre and post irrigation for which different methods are used [SHAIKH *et al.* 2017]. In other words, the water application efficiency measurement is based on the quantity of water stored in a root zone and water that is used by plants.

As regards the evaluation of soil compaction, although bulk density and porosity of soil are important factors to be measured, they cannot reflect changes in pore size and its continuity during the compaction of soil. The measurement of only the above-mentioned indicators may not be sufficient to predict the effect of water movement due to compaction. One of the prime threats is the reduction of soil quality by decreasing the pore volume and changes the pore geometry due to soil compaction [TOLÓN-BECERRA *et al.* 2012]. But in a furrow irrigation system where furrows are supposed to carry water and provide moisture to ridges where plants grow, water should be laterally delivered to ridges or beds with minimum vertical intake within furrows. To restrict the vertical entry of water in the furrow bed, its compaction is necessary.

The research relevant to water use efficiency of various soils under soil compaction is limited in published scientific studies. Therefore, this study has been conducted to determine the effect of tractor wheel compaction on the water use efficiency in a furrow irrigation system and resulting physical properties of different soil types. This study provides guidelines for farmers to achieve maximum water use efficiency while cultivating crops with a furrow irrigation method.

MATERIAL AND METHODS

LOCATION OF THE EXPERIMENTAL AREA

The study was conducted on three different soils in the Tandojam, Sindh, Pakistan. The experiment was managed in a split-plot design with randomised complete block design with three replications. Three sites were selected in accordance with required soil texture (i.e. clay loam (25°25'27.47" N; 68°32'38.44" E and 26 m a.m.s.l.), silty clay loam (25°25'3.44" N; 68°32'40.99" E and 26 m a.m.s.l.) and silty loam (25°24'58.25" N; 68°32'31.85" E and 26 m a.m.s.l.) in the vicinity of Tandojam (Fig. 1). The experimental area of each site was 500 m^2 (27.78 m × 18.00 m). The experimental layout is shown in Figure 2. The experiment was carried out in 2017–2018 and 2018–2019. In these months, there is no or nominal rainfall and temperature ranges from 9 to 25°C.

FIELD AND FURROW PREPARATION

At first, the field was cleaned by uprooting residues of previously cultivated crops and then ploughing with a disk plough. A soaking dose of 100 mm was applied and, after few days, field was ploughed with a cultivator and levelled. Furrows were prepared manually with the 40 cm furrow and 60 cm ridge under all schemes (Fig. 3). Furrows were prepared without compaction, with three passes of tractor (Massey Ferguson MF375, 2wd, 75hp) for tire wheel compaction and with 6 passes of tractor for compaction. The weight of a tractor on furrow was 1.22 Mg. The total weight of tractor was 2.44 Mg. The soil has its field capacity at the time of soil compaction. Thus, the compaction of furrows was carried out under favourable moisture condition.

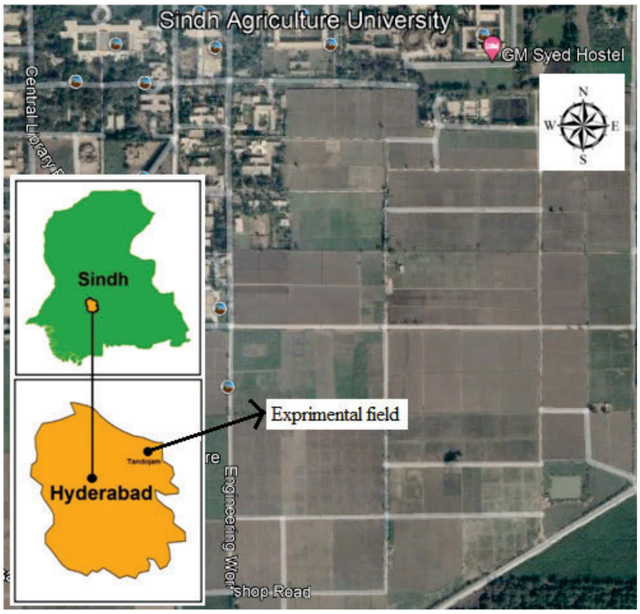

Fig. 1. Location map of the experimental site; source: own study

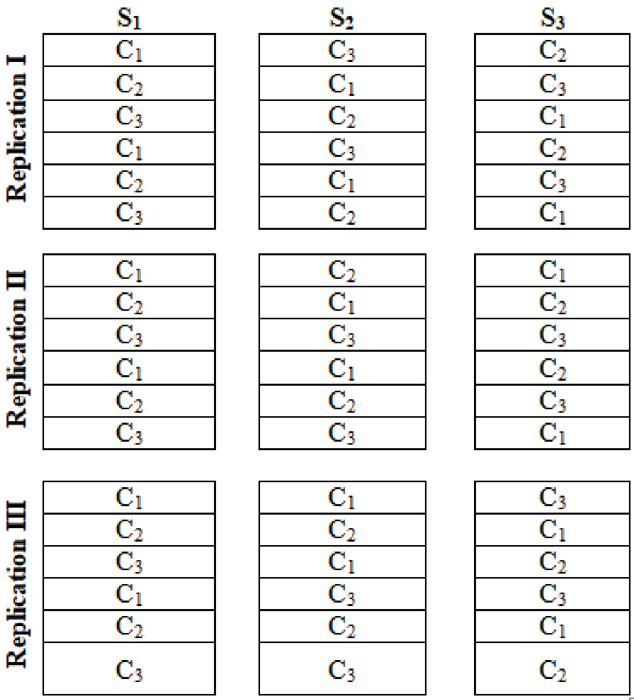

Fig. 2. Experimental layout and setup in the field; S_1 = clay loam soil, S_2 = silty clay loam soil, S_3 = silty loam soil; C_1 = control without compaction, C_2 = compaction with three rounds of tractor wheels passes; C_3 = compaction with six rounds of tractor wheels passes experimental plots; source: own elaboration

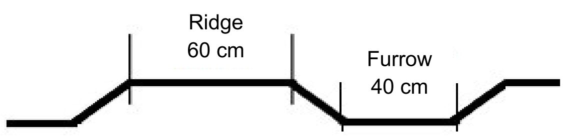

Fig. 3. Dimensions of furrow in the furrow irrigation method; source: own elaboration

ASSESSMENT OF COMPACTION

Basis properties, such as soil texture, bulk density, field capacity, soil porosity, infiltration rate, water use efficiency, ridge storage efficiency, and furrow storage efficiency, were assessed to evaluate the effect of tractor wheel compaction on vertical movement of water. The five soil samples from each experimental unit were collected at random up to the depth of 60 cm.

A few glimpses of field activities are illustrated in Photo 1. The wheat (TD-1) crop was planted on Nov. 2017 and Nov. 2018 in both seasons for to determine water use efficiency. Six irrigation of 75 mm each were applied at the interval of 21 days as per the recommendation of the research department for the study area. The crop was harvested, and grain yield was determined to compute water use efficiency.

Photo 1. Field and laboratory activities (phot. *R. B. Vistro*)

STATISTICAL ANALYSIS

The collected data were analysed statistically through Statistic ver. 8.1. To compare the superiority of treatments, the *LSD* test was applied for the study at the significance level of 0.05.

RESULTS AND DISCUSSIONS

BULK DENSITY

The tractor wheeling intensity while operating in the field cause rearrangement of soil particles. It brings particles closer and enhance bulk density regardless the type of soil. Figure 4 illustrates that in our study, bulk density increased significantly ($p < 0.05$) with increase in the number of tractor wheel passes. The bulk density of clay loam in comparison to the control (1.343 g·cm^{-3}) increased considerably under 3-wheel passes (1.450 g·cm^{-3}) and 6-wheel passes (1.520 g·cm^{-3}) tractor wheel passes, showing increase in bulk density by 8% and 13%, respectively. In the same manner, the bulk density of silty clay loam increased under 3-wheel passes (1.420 g·cm^{-3}) and 6-wheel passes (1.490 g·cm^{-3}), showing increase in bulk density by 7% and 12%, respectively over control (1.33 g·cm^{-3}).The same trend of increment in bulk density was observed in silty loam increased under 3-wheel passes (1.380 g·cm^{-3}) and 6-wheel passes (1.470 g·cm^{-3}) by 5 and 12%, respectively over control (1.33 g·cm^{-3}). The *LSD* test suggested a linear increase in bulk density with consecutive tractor wheel passes ($p < 0.05$). This suggested quantitative degree of soil compactness that is defined by the ratio of recorded bulk density compared to the control bulk density. The study also indicates that the soil bulk density of clay loam was originally larger than silty clay loam and silty loam soil. A linear and significant ($p < 0.05$) increase in the soil bulk density was recorded when the

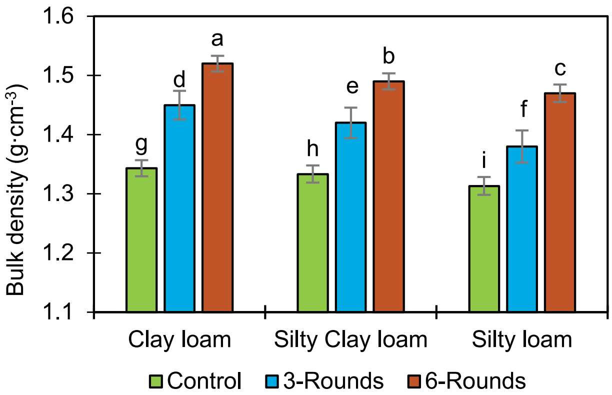

Fig. 4. Bulk density of different types of soil as affected by different compaction intensities; small letters on bars indicate statistical difference; the same letters show no difference and different letters show difference among treatments; source: own study

number of tractor wheel passes increased. The soil compaction rearranges and brings solid particles closer, as consequence bulk density of soil is increased [Nawaz *et al.* 2013]; however, the soil compactness is well defined by the fraction of bulk density observed to reference or control bulk density [Lipiec, Hatano 2003]. Moreover, soil compaction also depends on the soil structure that affects physical, biological, and chemical behaviour of soil [Ahmadi, Ghaur 2015; Nawaz *et al.* 2013]. In a past study, Smith *et al.* [1997] tested a wide range of soil textures applying vertical stress on soils by graded pressure, and then measured bulk density depending on the texture of soil. Having low colloid content, the silt loam soil is assumed to be more susceptible to compaction than loamy textured and clayey soils.

SOIL POROSITY

Soil consists of particles of different type and size and space between these particles. The overall space between particles is represented by porosity. This is a significant measurement particularly for agricultural related studies and activities. Figure 5 demonstrates that soil porosity is significantly ($p < 0.05$) affected by tractor wheel trafficking, and the increasing number of tractor wheel passes results in the decrease of the soil porosity. The soil porosity of clay loam, silty clay loam and silty loam in the control treatment was 49.7, 40.0, and 48.7%. In soil receiving 3-tractor wheel passes, soil porosity was 46.0, 45.7 and 45.3%, indicating a decrease of 7.44, 6.73 and 6.98%; while porosity of the soil receiving 6-tractor wheel passes was 43, 43 and 41%, respectively, showing decrease by 13, 12 and 16%, respectively over the control scheme. The soil porosity showed highly significant difference ($p < 0.01$) between soil types in control and 6-round compaction treatment; while at 3-round compaction treatment, the difference in porosity was significant at $p < 0.05$ level. Thus, the compaction of soil resulted in the increased bulk density and decreased soil porosity. Hence, these modified soil parameters are responsible to influence on soil compaction in terms of soil chemical characteristics, soil physics and diversity. With the increased trafficking during mechanical operation in crops, soil porosity increases proportionaly. Apart from the compaction treatment, the silty clay loam and silty loam have greater soil porosity than clay loam textured soil. After mechanical operations with tractor, decrease in soil porosity was found by

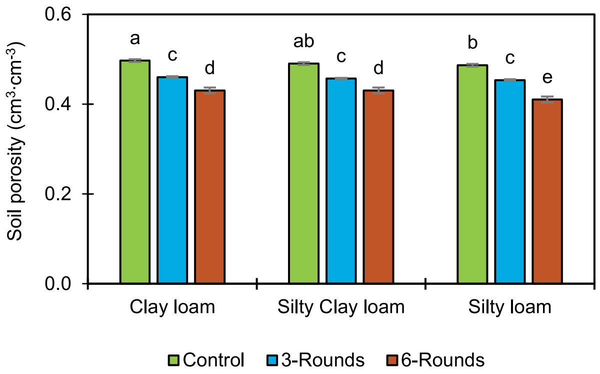

Fig. 5. Soil porosity of different types of soil as affected by different compaction intensities; note as at Fig. 4; source: own study

many researchers [Ramezani *et al.* 2017; Silva *et al.* 2008]. An increased contact pressure of 100 kPa resulted in the decrease of soil porosity of 5.7% at soil depth of 15 cm after 24 tractor wheel passes in sandy humus rich forest soil [Sakai *et al.* 2008].

INFILTRATION RATE

The infiltration under field conditions was inversely ($p < 0.05$) associated to the number of tractor wheel passes (Fig. 6). Infiltration rate was significantly ($p < 0.05$) reduced by increased tractor wheel trafficking and increasing number of tractor wheel passes resulted in a decreased infiltration rate. The infiltration rate of clay loam, silty clay loam, and silty loam in the control treatment was 31.163, 33.510, and 34.487 mm·h^{-1}; the soil receiving 3-tractor wheel passes had infiltration rate of 28.560, 29.630, and 30.710 mm·h^{-1}, which shows a decrease of 8, 12 and 11%, respectively over the control scheme; while infiltration rate of the soil after 6-tractor wheel passes was further reduced to 26.570, 27.120 and 27.710 mm·h^{-1}. This showed a decrease of 15, 19 and 20%, respectively over the control scheme. The *LSD* test suggests a linear ($p < 0.05$) decrease in infiltration due to each increased unit of soil compactness. Naturally, the infiltration is higher in silty loam as compared to silty clay loam and clay loam soils. Thus, regardless soil texture, soil compaction results in a decreased infiltration rate. According to Ramezani *et al.* [2017], the discoloured area, corresponding to the water intake rate index, declined by 77.5% when the tractor passed eight times as compared to the control scheme. In this study, the compaction of a furrow bed restricted the vertical infiltration and caused stagnant water to move laterally towards a ridge area and make moisture available for plants.

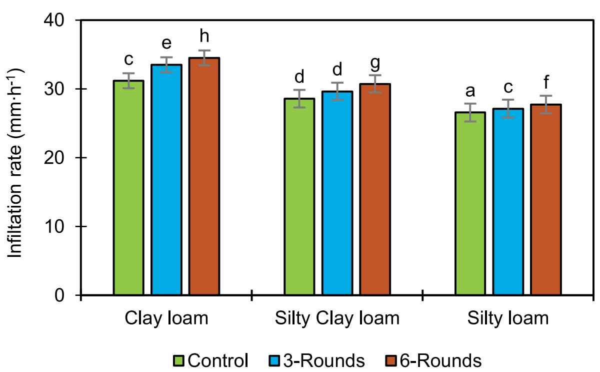

Fig. 6. Infiltration rate of different types of soil as affected by different compaction intensity; note as at Fig. 4; source: own study

FIELD CAPACITY (Θ_{fc})

The field capacity of different soil textures as affected by soil compaction is illustrated in Figure 7. The field capacity considerably ($p < 0.05$) increased with the increase in the tractor wheel trafficking. The field capacity of clay loam, silty clay loam, and silty loam in the control treatment was 0.367, 0.350 and 0.347; the soil after 3 tractor passes had field capacity of 0.400, 0.383 and 0.383, showing 9.0, 9.4 and 10.0% increase over control; while field capacity of the soil receiving 6 tractor passes was 0.427, 0.414 and 0.413, respectively suggesting increase of 16.0, 18.0 and 19.0% over the control area. The *LSD* test suggested a linear significant ($p < 0.05$) increase with increase in the soil compactness. Generally, the clay loam and silty loam received less damaging impact regarding field capacity due to tractor wheel trafficking as compared to silty clay loam. However, soil compaction resulted in an adverse effect on field capacity by altering soil parameters. Beutler *et al.* [2008] indicated that the tractor moving on dryer soil caused reduction in field capacity due to increased compaction. Similar findings have also been reported by Soracco *et al.* [2015] and Ramezani *et al.* [2017].

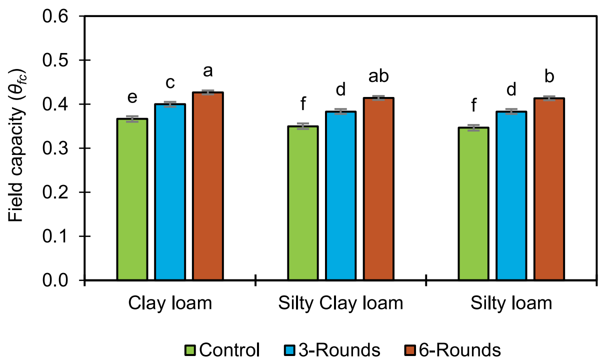

Fig. 7. Field capacity of different types of soil as affected by different compaction intensities; note as at Fig. 4; source: own study

FURROW STORAGE EFFICIENCY (%)

The irrigation efficiency is the irrigation critical performance that measures farm field irrigation. Particularly, irrigation efficiency below the outlet is of prime significance as it is entirely dependent on farm management. The furrow storage efficiency in soils of different textural classes as affected by soil compaction is demonstrated in Figure 8. The soil compaction due to tractor wheel trafficking after mechanical operation affected the furrow storage efficiency significantly ($p < 0.05$). In clay loam, silty clay loam, and silty loam soil textures without compaction (control), the furrow storage efficiency was 79, 78%, and 77%. After 3 round tractor wheel compaction, the furrow storage efficiency decreased to 51, 50, and 49% that indicates a decrease of 35, 36, and 36%; while at 6 round tractor wheel compaction, the efficiency was further reduced to 46.55, 45.75, and 45.72%, showing decrease of 41, 41%, and 40%, respectively. The *LSD* demonstrated a linear decrease ($p < 0.05$) with the increasing soil compactness. Generally, the furrow storage of clay loam was less affected by tractor wheel trafficking as compared to silty clay loam and silty loam. However, the data clearly indicate that the traveling of tractor may alter soil parameters and furrow storage efficiency

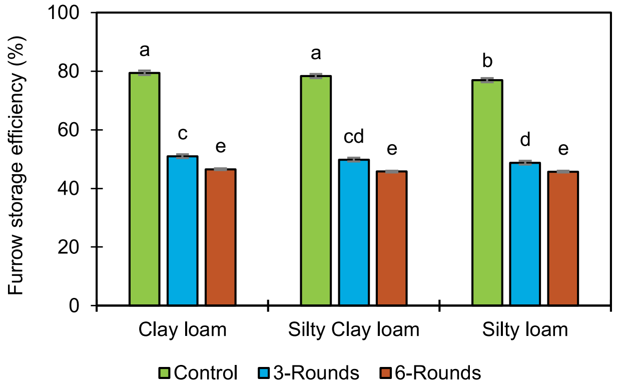

Fig. 8. Furrow storage efficiency in different types of soil as affected by tractor wheel passes; note as at Fig. 4; source: own study

can be adversely affected. Hamza and Anderson [2005] have also reported similar results from their studies. In a recent study, it was noted that soil compaction has a considerable effect on the water storage efficiency [Kimaro 2019].

RIDGE STORAGE EFFICIENCY

The ridge storage efficiency was affected significantly ($p < 0.05$) by the intensity of soil compaction due to various mechanical operations in the furrow (Fig. 9). The ridge water storage efficiency in clay loam, silty clay loam, and silty loam soils in the control scheme was 20.7, 19.8, and 18.5% at 3-passes of tractor wheels, and the ridge storage efficiency increased to 56.5, 55.5, and 54.5% which shows an overwhelming increase of 58.83, 57.96, and 56.76%; while at 6-wheel passes, the ridge water storage efficiency further increased to 171.91, 179.58, and 193.53%. This indicates an increase of 183, 192, and 205%, respectively over the control area. In silty clay loam and silty loam textures, the *LSD* test showed that the differences in ridge storage efficiency were negligible under 3- and 6-tractor wheel passes ($p > 0.05$), but difference was significant ($p < 0.05$) with clay loam. Hamza and Anderson [2005] reported that the ridge water storage efficiency improved with increased compaction intensity; and similar results have been achieved by Liu *et al.* [2018] and Kimaro [2019]. Zhang *et al.* [2014] reported that the furrow water storage efficiency due to compaction by mechanical operations in the field increased, and the ridge water storage efficiency significantly increased.

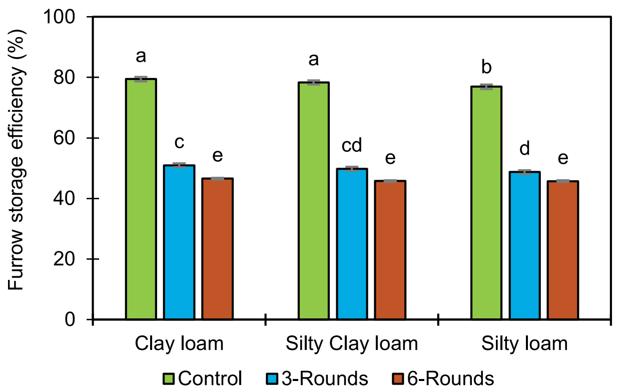

Fig. 9. Ridge storage efficiency in different types of soil as affected by different compaction intensity; note as at Fig. 4; source: own study

WATER USE EFFICIENCY *(WUE)*

This study examined the *WUE* of different soil types under the influence of different compaction intensity and results are shown in Figure 10. The water use efficiency in clay loam, silty clay loam, and silty loam soils without compaction (control) was 1.09, 1.09, and 1.07 kg·mm^{-1}. At 3-passes of tractor wheels, the *WUE* increased to 1.271, 1.261, and 1.249 kg·mm^{-1} showing an increase of 16.7, 16.0, and 16.7%, while at 6-wheel passes the *WUE* increased to 1.3, 1.3, and 1.3% indicating an increase of 19.0, 18.8, and 20.5%, respectively over the control area. The highest *WUE* among soil compaction procedures was observed under 6 rounds; followed by 3 rounds and the lowest *WUE* was determined in soil without compaction treatment regardless of soil type. The *LSD* test showed that there were tiny differences ($p > 0.05$) in the *WUE* between different soil textures under 6 round wheel passes; while similarity ($p > 0.05$) between clay loam and silty loam for the *WUE* was noted under 3-tractor wheel passes, while clay silty loam responded adversely to the *WUE*. Kimaro [2019] reported that the *WUE* may increase in compacted soil, while Tron *et al.* [2015] indicated that the plant water use efficiency may slightly be improved with the increasing of compaction intensity.

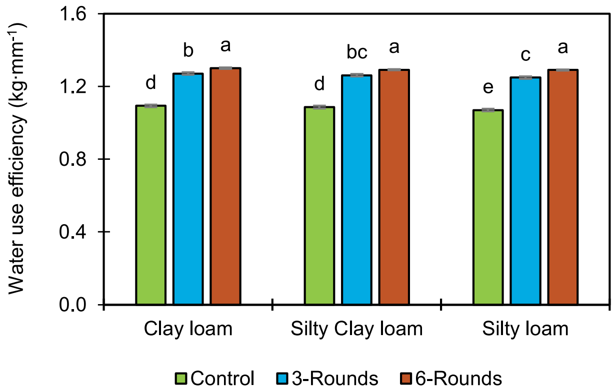

Fig. 10. Water use efficiency in different types of soil as affected by different compaction intensities; note as at Fig. 4; source: own study

CONCLUSIONS

Soil bulk density and porosity of clay loam was originally greater than silty clay loam and silty loam soil, and a significant increase in both indicators was recorded when the number of tractor wheel passes increased. Naturally, a higher infiltration was observed in the silty loam as compared to silty clay loam and clay loam soils. Regardless of soil texture, the soil compaction resulted in decreased infiltration rate in the furrow bed and compelled water to move towards ridge sides. The field capacity considerably increased ($p < 0.05$) with the increase in the tractor wheel trafficking; clay loam and silty loam received less damaging impact regarding field capacity due to tractor wheel trafficking as compared to silty clay loam. The tractor passes during mechanical operation affected furrow and ridge storage efficiency significantly and it altered soil parameters which in turn affected the furrow and right storage efficiency. In silty clay loam and silty loam textures, differences in ridge storage efficiency were negligible under 3- and 6-tractor wheel passes, but the difference was remarkable when compared to clay loam. The highest *WUE* and water storage efficiency among soil compaction treatments were observed under six rounds of compaction; followed by three rounds and the least *WUE* was determined in soil without compaction treatment regardless of the soil type. Based on the results regarding the efficiency of the furrow irrigation method, farmers are advised to use soil compaction in clay loam and the compaction could be even more beneficial when applied to sandy soils to achieve greater irrigation efficiency in furrow irrigated soils.

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