Sustaining Yield of Wheat Crop Using Tractor Wheel Compaction and Fertilizer Placement at Ridge Bed Irrigation System

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ABSTRACT

The population of Pakistan is increasing at an alarming rate, leading to a high demand for more food and fiber production. To address this demand, effective land and water management is required, emphasizing improvement in irrigation and fertilizer use efficiencies of conventional irrigation methods. This study therefore aimed to determine the impact of various tractor wheel compaction and fertilizer placement at ridge bed irrigation method on different soil textures during 2017-18 and 2018-19 at Sindh Agriculture University, Tandojam, Pakistan. The several levels of compaction observed were, without compaction (T1), three-round tractor wheel compactions (T2), and six-round wheel compactions (T3), while the soil textures were clay loam (CL), silty clay loam (SCL), and silty loam (SL). The field trials were conducted in spilt plot in a randomized complete block design (RCBD) with three replications. The results showed that different treatments significantly affected plant growth, yield of wheat, water productivity, and net returns with ridge bed furrow irrigation method. Further, results showed that all parameters significantly increased with increasing soil compaction levels in all soil textures. Based on the results, it was concluded that T3 integrated with fertilizer application at the top of the ridge bed was the most promising method for enhancing the water and fertilizer use efficiency for the wheat crop.

Keywords: Ridge bed; soil compaction; soil textures; wheat

INTRODUCTION

Wheat is a major food crop in Pakistan, serving as an essential grain in meeting dietary by providing 60% of the protein and calories in a standard diet. The cultivation of wheat in the country covers an area of 8,825 thousand hectares producing 24,946 thousand tons, with an average yield of 2,827 kg ha-1 (GoP, 2020), which is less when compared to other countries (Dahri et al., 2018). Furthermore, wheat is considered an important grain crop, covering two-thirds of the food cropped annually (Bressani et al., 2004). However, the cultivation process faces challenges, as the increase in soil moisture adversely affects the yield (Uniyal et al., 2019). The season during wheat crop remains dry in terms of surface water availability through rainfall distribution from November to March. For that reason, half of the total wheat cultivating area remains without water, where it grows on residual moisture in the soil present from the previous season (Vaghefi et al., 2017).

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To address this limitation, flood irrigation is commonly practiced as a traditional method in Pakistan, flooding the entire soil surface without considering the actual crop consumptive requirement. This inefficient method has led to water logging and salinity, reducing crop irrigation efficiency (Raza et al., 2020). Based on estimates, approximately 30% of the total water losses are mainly associated with the practice of inefficient, traditional border, and basin irrigation methods (Siyal et al., 2016). Consequently, the use of micro-irrigation methods such as drip, sprinkler, bubbler, etc. has been advocated in Pakistan for the last few decades. Despite the potential benefits, the micro-irrigation methods have not gained significant attention from the common farmers in Pakistan due to the high cost of installation, operation, maintenance, and requirement for skilled labor (Shah et al., 2017). This phenomenon indicates the urgency to enhance irrigation efficiency of conventional methods, which are economical, easy to install and operate, and popular among farmers (Vistro et al., 2021).

Furrow irrigation is a conventional method, where gravity plays a role in providing enough water for plants to grow (Khan et al., 2015). It is usually prepared by calculating the ridge as part of the layout and furrow application which is the part of the field that allows the passage of water (Tian et al., 2014). Previous studies showed that furrow irrigation system has low water use efficiency when compared to high-tech micro-irrigation methods (Sial et al., 2011). Due to increased water scarcity, irrigation methods always has played a significant role in enhancing crop productivity by improving water use efficiency (Khan et al., 2015).

In addition to limited water availability, soil compaction is a major concern for farmers as it significantly reduces agricultural production. The impact due to the flood irrigation system is more evident in intensive farming, leading to growth retardation in the above-ground part and decreased root system development (Tolon-Becerra et al., 2011). During the soil development process, compaction is a decisive part, where it mostly occurs in tillage operations (De-Melo et al., 2022). Soil compaction is often experienced in mechanized farming, where several operations such as tilling, harvesting, chemical application, and fertilizer spreading are usually carried out using heavy-wheeled machines. Moreover, soil compaction by tractor wheels is categorized by reduced porosity (Kiani and Iqbal, 2021). In no-tillage practices, a small amount of the ground area experiences compaction due to heavy machine wheels (Mileusnić et al., 2022). While in minimum tillage, compaction usually exceeds 60%, while conventional may reach 100% in a cropping cycle. Heavy machine trafficking also induces compaction of subsoil, which varies based on type and climatic conditions (Mosaddeghi et al., 2000). The depth of compaction varies from 10-60 cm, more obviously on topsoil (10 cm). However, 16 to 76% compaction can occur in the first 40 cm surface layer, limiting the increase in bulk density to 15 cm depth (Balbuena et al., 2000). The soil compaction primarily causes a reduction in porosity, resulting in decreased bulk density. To address soil compaction, particularly in arid and semiarid areas, several strategies are required. These include organic matter addition, precise traffic, deep ripping, as well as rotation comprised of crops and pasture plants with strong tap roots that penetrate and break down compacted soil. High-pressure conventional field vehicles damage soil structure and increase cultivation inputs, when compared with zero traffic systems (Keller et al., 2019). This was also confirmed by Bouwman and Arts (2000), who studied the comparative response of winter and spring barley under zero and reduced ground pressure traffic systems. When compaction is restricted to the subsurface only, roots can grow more laterally or coil upward toward the less compacted layers without a significant decrease in yield (Liu et al., 2022). According to Ishaq et al. (2001), subsoil compaction in sandy clay loam caused a 38% reduction in wheat grain yield, while plant height and seed index remained unaffected. This study therefore aimed to determine the impact of various tractor wheel compaction and fertilizer placement at ridge bed irrigation method on different soil textures.

METHODS

Experimental Setup

This study was conducted to observe the effect of different soil compaction levels, textures, and ridge bed fertilizer applications on the growth, grain yield, and crop water productivity of wheat during 2017-18 and 2018-19. The experiments were conducted at the field station of the Sindh Agriculture University, Tandojam, Sindh, Pakistan. The soil textures selected were clay loam (25°25′27.47″ N, 68°32′38.44″ E), silty clay loam (25°25′3.44″ N, 68°32′40.99″ E), and silty loam (25°24′58.25″ N, 68°32′31.85″ E). The debris (straw and roots) of previously cultivated crops before experimentation was cleaned from selected plots, as shown in Figure 1. Subsequently, the plots were ploughed with a disk plough and irrigated with 100 mm as a soaking doze. After a few days, the plots were re-ploughed with a cultivator and leveled using the laser land leveler, followed by manual preparation of a 60 cm wide ridge bed (Soomro et al., 2017a).

Treatments

The experiment was conducted on three soil textures, namely clay loam (CL), silty clay loam (SCL),

(a)

(b)

(c)

(d)

Figure 1. Field preparation activities (a, b, and c showing different tillage practices, namely mold board plough, cultivator, and rotary tiller; d shows the preparation of bunds)

and silty loam (SL), with different soil compactions. These included control treatment without any compaction (T1), three-round tractor wheel (T2), six-round tractor wheel (T3), and on ridge bed fertilizer application. The split-plot design method was adopted using a randomized complete block design (RCBD), with three replications. A total of 27 sub-plots were arranged with an average plot size of 10x10 m^2. The selected wheat variety TD-1 was purchased from the Agriculture Research Institute, Tandojam Sindh, Pakistan. The NPK fertilizer was applied at the rate of 168-84-40 Kg ha^{-1}, as suggested by Tunio (2007).

Soil Compaction Levels

Previously prepared three plots were further divided into three sub-plots to make different soil compaction levels. The tractor Massey Ferguson MF-375 2wd, 75hp, having a total weight of 2445 Kg was selected, with each tire weighing 1222.5 Kg. As shown in Figure 2, the tractor was operated through the bottom of the furrows

(a)

(b)

Figure 2. Preparing different soil compaction levels

in each sub-plot for three and six rounds to achieve the required compaction levels.

Irrigation Water Consumption

Wheat was irrigated at six different intervals in one cropping season (2017-18 and 2018-19), except the soaking doze. Six irrigation applications of 75mm depth of water were applied to all treatments during the experimental period. For uniform depth of irrigation water, a cut-throat flume (8″ × 1.5″) was installed at the center of each channel to measure the irrigation water. Subsequently, the flow rate of the cut-throat flume was measured as suggested by Soothar et al. (2021).

Growth and Yield Parameters

The parameters observed included plant height (cm), tillers per plant, spike length (cm), grain weight per spike, and grain yield (kg ha^{-1}). The plant height was measured from ground level to the tip of the flag leaf using a measuring tape. Tillers per plant were measured at physiological maturity and before harvesting time of wheat from each treatment by random counting. Furthermore, the grain weight per spike was collected from the seed per spike lot of each sub-plot and weighed using an electric balance after sun drying. The total grain yield was measured using Equation 1.

$$\text{Grain yield (Kg ha}^{-1}) = \frac{\text{Grain yield (kg)}}{\text{Plot size } (m^2)} \times 100 \qquad (1)$$

Crop Water Productivity

The crop water productivity was measured using Equation 2 (Soothar et al., 2021).

$$\text{Crop water productivity (Kg m}^{-3}) = \frac{\text{Grain yield (kg ha}^{-3})}{\text{Total water applied } (m^2 \text{ ha}^{-1})} \qquad (2)$$

Net Returns

Net returns values were determined based on the amount received from the physical productivities of wheat such as the value of grain yield achieved from the crop and straw using Equation 3. The entire costs right from the land preparation to the crop harvest was accumulated as the cost of production.

$$\text{Net returns} = \frac{\text{Output cost}}{\text{Input cost}} \times 100 \qquad (3)$$

Statistical Analysis

The data was statistically analyzed using the analysis of variance (ANOVA) and the average values were compared using Duncan's multiple range test at $p<0.05$ significant level. All statistical analyses were performed by using the SPSS 18.0.

RESULTS AND DISCUSSION

Plant Height

The analysis of variance ($p<0.05$) for plant height of wheat during 2017-18 and 2018-19 cropping seasons is shown in Figure 3. Based on the results, Figure 3a shows the average plant height values for T_1* CL, T_1* SCL, and T_1* SL treatments which were observed to be 66±0.2 cm, 63±3 cm, and 60±5 cm. For T_2* CL, T_2* SCL, and T_2* SL treatments the values observed were 68±3 cm, 65±5 cm and 64±3 cm, while for T_3* CL, T_3* SCL, and T_3* SL treatments the data was 68±3 cm, 67±3 cm and 64±3 cm respectively during 2017-18. A significant increase in plant height with high soil compaction levels was also observed under all soil textures. Similar results were observed for the cropping season 2018-19, as shown in Figure 3b. The plant height in T_1* CL, T_1* SCL, and T_1* SL treatments were 66±0.5 cm, 64±1 cm, and 64±3

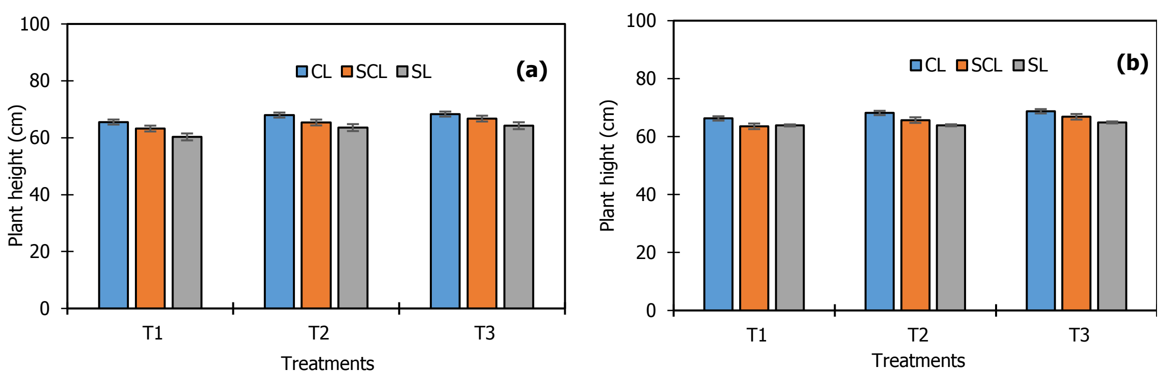

Figure 3. Plant height of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018-19 cropping seasons

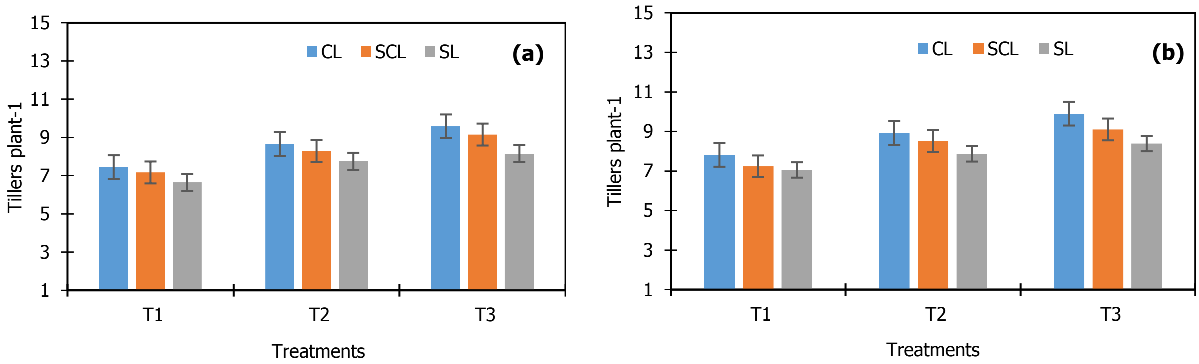

Figure 4. Tillers plant^{-1} of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018-19 cropping seasons

cm, respectively. For T_2* CL, T_2* SCL, and T_2* SL treatments the values were observed to be 68±0.6 cm, 66±0.4 cm, and 64±1.1 cm, while T_3* CL, T_3* SCL, and T_3* SL treatments had 69±1 cm, 67±1.2 cm, and 65±1.0 cm, respectively. Furthermore, it was observed that soil compaction at the bottom of the furrow, and the fertilizer application on the top of the ridge bed increased the plant height. These results varied significantly compared to non-compacted soil and ridge bed fertilizer application under ridge bed irrigation method during both cropping years.

Tillers Plant^{-1}

The results of tillers per plant for both cropping seasons are shown in Figure 4. For T_1* CL, T_1* SCL, and T_1* SL treatments during 2017-18, the values obtained were 7±0.3, 7±0.2, and 7±0.5, respectively, as shown in Figure 4a. The recorded values for T_2* CL, T_2* SCL, and T_2* SL treatments were observed to be 9±0.4, 8±0.5 and 8±0.5, while T_3* CL, T_3* SCL, and T_3* SL treatments had values of 10±0.4, 9±0.5 and 8±0.2. The values obtained during 2018-19 are represented in Figure 4b, which had a similar trend as of 2017-18. Tillers per plant in T_1* CL, T_1* SCL, and T_1* SL treatments were observed to be 8±0.1, 7±0.1, and 7±0.2 tillers plant^{-1} respectively. For T_2* CL, T_2* SCL, and T_2* SL treatments, the data was observed to be 9±0.1, 9±0.1 and 8±0.2, while for T_3* CL, T_3* SCL, and T_3* SL treatments the data was observed to be 10±0.4, 9±0.2 and 8±0.1, respectively.

Spike Length (cm)

The results of spike length for both cropping seasons are shown in Figure 5. Based on the results, Figure 5a illustrates the regression analysis for 2017-18 cropping season. The values of spike length under T_1* CL, T_1* SCL, and T_1* SL treatments were 10±0.4, 9±0.1 and 8±0.2, while the data for T_2* CL, T_2* SCL, and T_2* SL treatments were 10±0.5, 10±0.2, and 9±0.1, respectively. Meanwhile, for T_3* CL, T_3* SCL, and T_3* SL treatments, the values observed were 11±0.2 cm, 11±0.1 cm, and 9±0.1. The values for control were observed to be less when compared with other treatments. The results of spike length for 2018-19 had

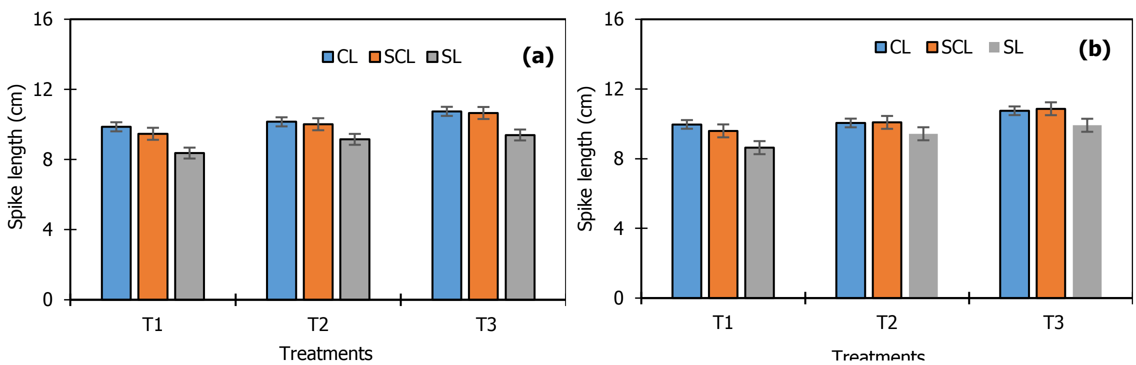

Figure 5. Spike length of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018-19 cropping seasons

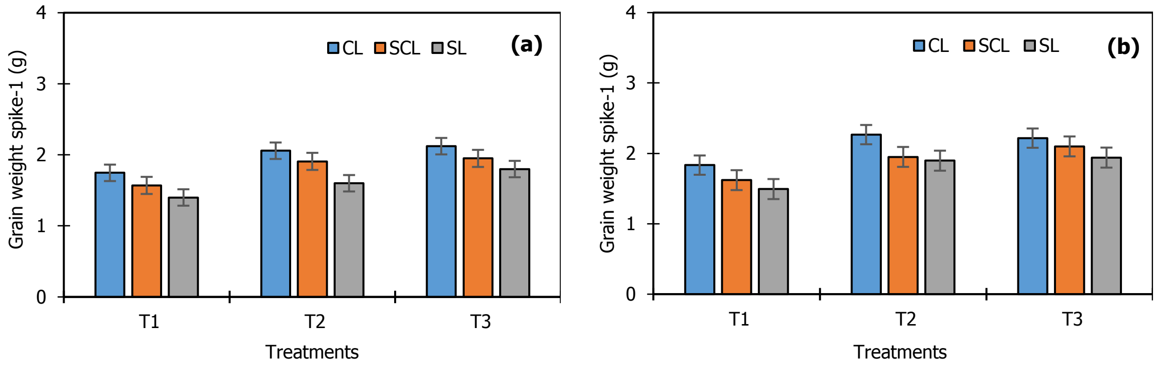

Figure 6. Grain weight spike^{-1} of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018-19 cropping seasons

a similar trend as of 2017-18. Spike length in T_1* CL, T_1* SCL, and T_1* SL treatments were observed to be 10±0.4, 10±0.3, and 9±0.1, respectively. T_2* CL, T_2* SCL, and T_2* SL treatments had 10±0.4, 10±0.3 and 9±0.1, while for T_3* CL, T_3* SCL and T_3* SL treatments the data was observed to be 11±0.6 cm, 11±0.6 cm and 10±0.4 cm, respectively.

Grain Weight Spike^{-1} (g)

The results of grain weight per spike for both cropping seasons are shown in Figure 6, while regression analysis for 2017-18 is presented in Figure 6a. Grain weight per spike for T_1* CL, T_1* SCL, and T_1* SL treatments were observed to be 1.7±0.1, 1.6±0.1 and 1.4±0.4 g, for T_2* CL, T_2* SCL, and T_2* SL treatments the data was observed to be 2.1±0.1, 2±0.2 and 2±0.1 g, and for T_3* CL, T_3* SCL, and T_3* SL treatments, the values were observed to be 2.1±0.2, 2±0.1, and 1.8±0.1. A similar trend for grain weight per spike was also observed for 2018-19 cropping season. The grain weight per spike in T_1* CL, T_1* SCL, and T_1* SL treatments for 2018-19 was observed to be 1.8±0.1, 1.6±0.1 and 1.5±0.1 g. For T_2* CL, T_2* SCL, and T_2* SL treatments, the grain weight per spike was 2.3±0.1, 2.0±0.1, and 1.9±0.1 g, while for T_3* CL, T_3* SCL, and for T_3* SL treatment the data was observed to be 2.2±0.1, 2.1±0.1, and 1.9±0.1, respectively.

Grain Yield

The results of grain yield for both cropping seasons are presented in Figure 7. The grain yield for 2017-18 cropping season was 8038±70, 7820±81, and 7711±343 kg ha^{-1} for treatment T_1* CL, T_1* SCL, and T_1* SL. For T_2* CL, T_2* SCL, and T_2* SL treatments, the values were observed to be 9534±641, 9344±300 and 9234±73 kg ha^{-1}, while T_3* CL, T_3* SCL, and T_3* SL had 9810±447, 9679±625 and 9538±120 kg ha^{-1} values, respectively. As shown in Figure 7b, the results of grain yield for 2018-19 cropping season are in line with 2017-18. The grain yield in T_1* CL, T_1* SCL, and T_1* SL treatments was observed to be 8054±70, 7860±135, and 7970±70 kg ha^{-1} grain yield. For T_2* CL, T_2* SCL, and T_2* SL the values were observed to be 9588±598, 9360±255, and 9264±63 kg ha^{-1}, while for

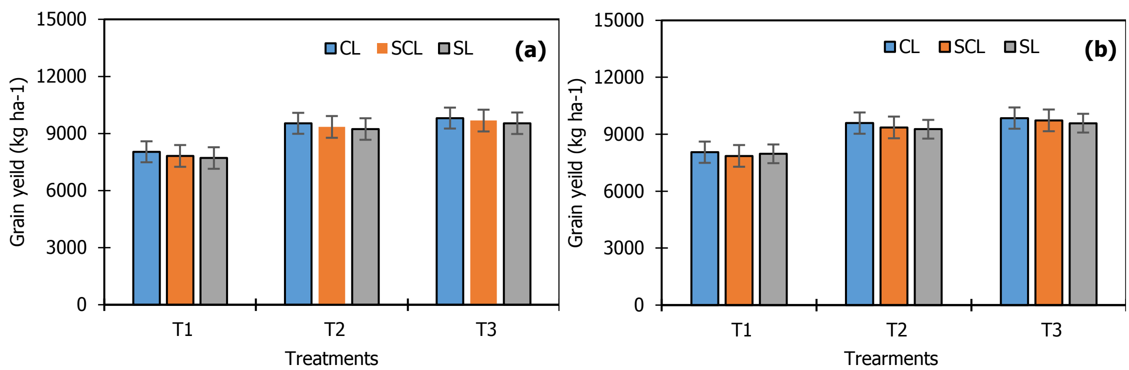

Figure 7. Grain yield of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018- 19 cropping seasons

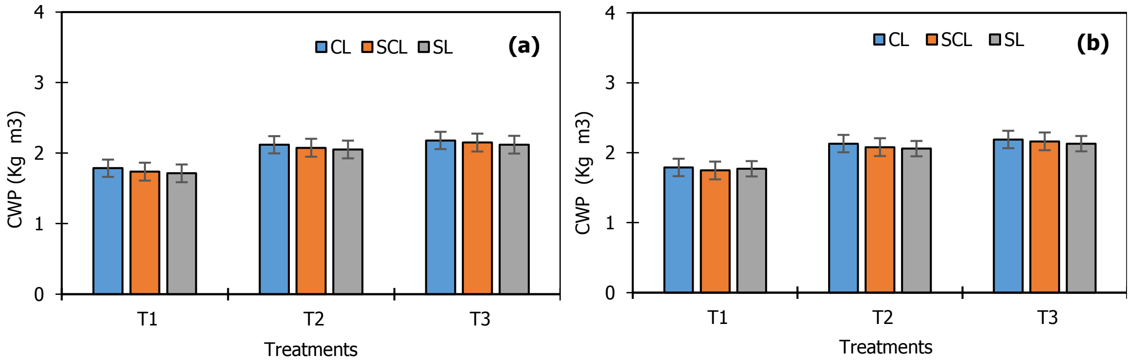

Figure 8. Crop water productivity of wheat crop cultivated under different treatments (a) 2017-18, and (b) 2018-19 cropping seasons

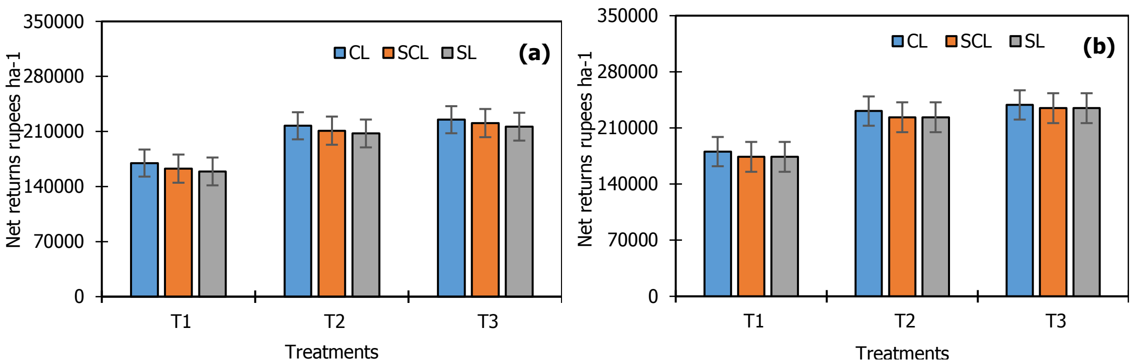

Figure 9. Net returns of wheat crop cultivated under different treatments during (a) 2017-18, and (b) 2018-19 cropping seasons

T_3* CL, T_3* SCL, and T_3* SL treatments the data was observed to 9852±388, 9732±609 and 9584±114 kg ha^{-1}, respectively.

Crop Water Productivity

The results of crop water productivity for both cropping seasons are presented in Figure 8. As shown in Figure. 8a, the values obtained for cropping season 2017-18, were 1.79±0.1, 1.74±0.2, and 1.71±0.1 for T_1* CL, T_1* SCL, and T_1* SL treatments. Crop water productivity for T_2* CL, T_2* SCL, and T_2* SL treatments was observed to be 2.12±0.2, 2.08±0.1 and 2.05±0.1, and the data for T_3* CL, T_3* SCL, and T_3* SL treatments was observed to be 2.18±0.1, 2.15±0.3 and 2.12±0.1 kg m^{-3}. Figure 8b shows the crop water productivity for 2018-19, which had a similar trend as of 2017-18. The crop water productivity for T_1* CL, T_1* SCL, and T_1* SL treatments was observed to be 1.79±0.2, 1.75±0.1 and 1.77±0.1 kg m^{-3}, for T_2* CL, T_2* SCL, and T_2* SL the values were observed to be 2.13±0.1, 2.08±0.3 and 2.06±0.1 kg m^{-3}, and for T_3* CL, T_3* SCL, and T_3* SL treatments, the values for crop water productivity were observed to be 2.19±0.2, 2.16±0.3, and 2.13±0.1 kg m^{-3} respectively.

Net Returns

The results of net returns for both cropping seasons are presented in Figure 9. As shown in Figure 9a, net returns for T_1* CL, T_1* SCL, and T_1* SL treatments in 2017-18, were 169884±80, 162799±91, and 159237±353 rupees ha^{-1}, respectively. Net returns for T_2* CL, T_2* SCL, and T_2* SL treatments were calculated to be 217271±651, 211096±312, and 207521±83 rupees ha^{-1}, while for T_3* CL, T_3* SCL, and T_3* SL treatments were calculated to be 225007±457, 220729±635, and 216166±130 rupees per ha^{-1}, respectively. The result for 2018-19 cropping season had a similar trend as of 2017-18, where net returns in T_1* CL, T_1* SCL, and T_1* SL treatments were 180472±90, 173924±155, and 173924±90 rupees ha^{-1}. For T_2* CL, T_2* SCL, and T_2* SL treatments, the values observed were 231012±618, 223316±275, and 223316±80 rupees per ha^{-1}, while T_3* CL, T_3* SCL, and T_3* SL treatments had 238687±408, 234637±629 and 234637±124 rupees per ha^{-1}.

DISCUSSION

The agronomical parameters of wheat cultivated under different soil compactions and fertilizer treatments using the ridge bed furrow irrigation method in both cropping seasons showed significant variations, as shown in Figures 3-7. The results of agronomic parameters for soil without and with compaction (three and six tractor wheel phases soil compaction) treatments were significant, while the results for different soil textures were non-significant in both cropping seasons. Furthermore, it was observed that the agronomical parameters increased with high compaction levels. Previous studies have shown that moist soil is vulnerable to compaction but the impact of soil compaction has not been widely explored (Devine et al., 2022). Some investigations reported that wheat grain yield improved proportionately to the level of soil compaction, regardless of soil texture. Chan et al. (2006) compared the soil compaction between wheel tracks (1000 kPa and 1.25–1.29 Mg m^3, and 0.187–0.226 m^3) in 0.05 - 0.10 m soil layer under wheel tracks. The results showed that a significantly higher penetrometer resistance (>2000 kPa), bulk density (1.5–1.58 Mg m^3), and lower air-filled porosity (0.07–0.09 m^3), with similar wheat yields (5.3–5.5 t ha^{-1}) on wheel track in clay soil. This indicated that the advantages and disadvantages of soil compaction are correlated with the type of soil, realizing the importance of controlled traffic. Parvin et al. (2022) stated that farm machinery has a strong relationship with porosity, bulk density, and soil tolerance, significantly affecting crop yield due to the extensive usage of agricultural equipment, tillage, and soil compaction. The results suggested the initial removal of the hardpan of the soil developed by continuous farming practices without operating deep ploughing. Ramzan et al. (2014) reported that the penetrometer resistance and bulk density increased with increasing levels of compaction ($p<0.05$), emphasizing soil compaction as an influencing factor in cereals. The natural changes in soil at the precipitation level for different types of soil were also observed to cause a significant deviation in wheat yield (Soomro et al., 2017b). Similarly, the direction of change on compaction is associated with soil textures as a function of soil moisture level (Sunusi et al., 2020). This phenomenon results in various influences of water quantity on soil texture and development of cereals root system, which usually occurs in wheat yield during drought and waterlogging conditions (Vistro et al., 2022). Consequently, wheat yield may be influenced by soil texture, moisture content, compaction, and clay content at nutrient supplements (Zahid et al., 2022). Effect on soil resistance also depends on the depth of the compacted layer, variety, root characteristics, crop root growth, susceptibility to compaction, soil moisture, and climatic factors (Nawaz et al., 2013). Shahid et al. (2015) concluded that ridge and furrows formed with a ridge on the top, or the side resulted in increased germination and yield when compared to flat planting. This increase occurred because the raised bed and ridge planting method of wheat planting saved 22% irrigation water over the flat method. The ridge planting for wheat had an improvement of 23% in yield, and 40% in saving irrigation water compared to the farmer's technique of broadcasting (Ali et al., 2007). In this study, the water use efficiency, and net returns in rupees ha^{-1} of the wheat cultivated under different soil compaction and fertilizer treatments applied on top of the ridge bed furrow irrigation methods in both cropping seasons were significantly affected among the treatments, as shown in Figures 8-9. The results of crop water productivity and net returns for soil without and with compaction (three and six tractor wheel passes) treatments were found to be significantly different, while various soil textures were non-significant in both cropping seasons. The water productivity and net return increased with increasing compaction level. The results are in line with the findings of Sheikh et al. (2022). Sivarajan et al. (2018) stated that yield data showed a significant difference between the soil transects, but there were no variations observed between the highest and lowest tillage practices. These fluctuations are depended on the soil types and application of soil amendments. Attar et al. (2020) investigated the quality coefficient related to return flow and observed different values in different periods, namely 0.85 in August, while 1.0 was recorded between November and December.

CONCLUSION

This study investigated the effect of various tractor wheel compactions and fertilizer placement at ridge bed irrigation method under different soil textures by cultivating wheat during two cropping seasons 2017-18 and 2018-19. The treatments included without compaction (T_1), three-round tractor wheel compactions (T_2), and six-round tractor wheel compactions (T_3), while the soil textures were clay loam (CL), silty clay loam (SCL), and silty loam (SL). The results showed that different treatments significantly affected the yield of wheat, water productivity, and net returns with ridge bed irrigation method, where the optimal value was observed in T_3 treatment with clay loam soil. This showed that six-round tractor wheel compactions, integrated with fertilizer application at the top of the ridge bed was the most promising method, enhancing the water and fertilizer use efficiency for wheat.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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