Research Article

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Growth and yield responses of maize to different tillage practices and straw incorporation under different levels of gypsum in a saline-sodic soil

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ABSTRACT

Soil salinity is one of the significant issues in crop production and its adverse effects have been noticed at various stages of a crop life cycle therefore to assess the remedies for mitigation of soil salinity, the present study was conducted in Khipro district, Sanghar, Sindh, Pakistan during 2018-19. The experiment was laid out in Randomized Complete Block Design (RCBD), to evaluate the growth and yield responses of maize to different tillage practices and straw incorporation under different levels of gypsum in a saline-sodic soil. The factorial study was consisted of three factors including: Tillage practices (shallow tillage [ST] and deep tillage [DT], Wheat straw incorporation (3, 7, and 10 ton. ha^{-1}) and gypsum rates (13.5, 9 and 4.5-ton ha^{-1}). The comparative results showed that Deep Tillage DT with wheat straw incorporation at 10-ton ha^{-1} (DT_{WS10}) had significantly higher result in term of growth and yield traits followed by shallow tillage ST at 10-ton ha^{-1} (ST_{WS10}). Moreover, the lowest results regard growth and yield attributes were observed in Shallow tillage ST with no wheat straw incorporation (ST_{CK}) Additionally, It was also observed that gypsum application did not have significant effect ($P > 0.05$) on maize growth and yield, but it mitigated soil salinity and sodicity, contributing to improved crop growth and yield. Therefore, incorporating straw into saline-sodic soils can significantly ($P < 0.05$) enhance maize yield and its attributes, with notable effects observed after two years of treatment.

Keywords: Saline sodic soil, Tillage Practice, straw, gypsum, maize crop and yield

INTRODUCTION

Pakistan ranks as the third-largest maize-producing country globally, with an annual production of 10.6 million tons, utilizing an area of 1.7 million hectares. But the average maize yield of Pakistan remains comparatively low among maize-producing nations [3]. Therefore, enhancing yield per hectare is crucial for the country's agricultural development. Among the following challenges such as water shortages, climate change, and market policy issues soil salinity and sodification are major factors that adversely impact maize production. These saline–sodic soils are highly degraded and minimally productive due to the combined effects of salinity and sodicity on the soil's physical, chemical, and biological properties [9, 32]. High salinity hinders plant growth by causing osmotic imbalances and specific ion toxicities, while sodicity deteriorates soil structure through clay swelling and dispersion, leading to poor aeration and hydraulic conductivity. This condition results in the migration of fine clay particles, forming a crust on the soil surface, which impedes water infiltration and root penetration. Moreover, the presence of excess sodium can lead to nutrient deficiencies and low soil fertility, further reducing crop growth and yield [24].

Article History

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To address these issues, recent studies have explored the use of organic amendments, such as crop straw, manure, and compost, for improving saline soils. The application of straw has been shown to enhance soil salt leaching, increase microbial biomass and activity, and reduce soil salinity. Additionally, straw amendments can decrease soil bulk density and increase pore space, thus promoting better soil structure and aggregate stability [45, 46]. In many developing countries, including Pakistan, large amounts of crop residues like maize, rice, and cotton are often burned, contributing to environmental pollution and global warming. However, these residues contain a significant proportion of nutrients, with estimates suggesting that they retain 30%–35% of applied mineral nitrogen and phosphorus and 70%–80% of applied potassium. Utilizing these residues as organic amendments can thus offer a sustainable solution to improve soil health and enhance maize production [5, 19].

Moreover, the tillage application is considered a great practice in the reclamation of saline-sodic soils. It can increase infiltration and hydraulic conductivity rates, improve salt leaching to deeper layers. On the contrary, shallow tillage increases carbon sequestration, controls erosion, lessens the energy input [42] and improves soil quality and crop productivity, particularly in tropical cereal-based cropping systems [31]. Moreover, this approach has been shown to increase soil microbes [47] and reduce CO2 fluxes [51]. Deep tillage can cause an increase in soil hydraulic conductivity, improve soil drainage and aeration, and consequently enhance the effective root zone in saline-sodic soils [7]. Additionally, it can improve water use efficiency and crop production, as shown recently in soybean (*Glycine max* L.) [14].

Gypsum is the most often used additive for sodic soil reclamation and minimizing the detrimental impacts of high salt irrigation water in agricultural regions due to its solubility, cheap cost, availability, and simplicity of handling [5]. Studies on the effect of gypsum treatment on saline-sodic soil reclamation have revealed that soil receiving the most gypsum removes the most Na+ from the soil columns and significantly decreases Ece and SAR [12]. This approach, however, necessitates financial inputs in the buying and using of gypsum. Additionally, the accessibility of agricultural gypsum may be restricted in some areas, making this technique unfeasible. In these cases, it is critical to apply readily available techniques [18].

The purpose of this study is to evaluate how different tillage practices, straw incorporation, and gypsum application levels affect maize growth and yield in saline-sodic soils. It aims to identify the most effective tillage methods and straw management techniques for improving soil structure and fertility, and to determine the optimal gypsum application rates for enhancing soil conditions and maize productivity. The study also seeks to understand the specific interactions between these practices and soil properties to provide practical recommendations for optimizing crop yield and soil health in challenging environments.

MATERIALS AND METHODS

Experimental Site: The present study was carried out in a farmer's field in Khipro district, Sanghar, Sindh, Pakistan (lat. 25°45'0" N, long. 69°23'15" E, elev. 13 m AMSL; Figure 1).

The experimental site had been barren for more than 20 years due to salinity/sodicity problems and unavailability of water. Across all treatment plots and based on United States Department of Agriculture (USDA) soil particle size analysis by Bouyoucos method. Table 1 shows the physical properties of experimental soil.

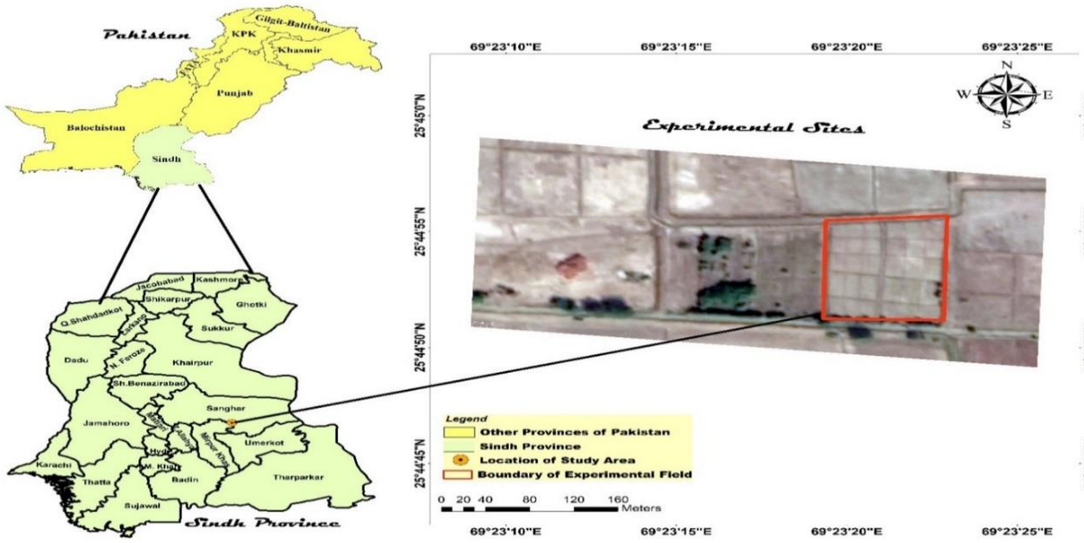


Table 1. Physical and Chemical Properties of Soil

Soil depth (cm)				Textural class	ECe (dS m-1)	pH	SAR	ESP
	Sand	Silt	Clay					
0-15	24.8	60.2	15	Silty loam	9.9	6.5	18.9	22.1
15-30	25.1	59.4	15.5	Silty loam	9.7	7.1	18.9	21.9
30-45	23.8	61.1	15.1	Silty loam	9.3	6.9	21.9	23.7

Respectively, the monthly average minimum and maximum temperatures were 18.21^{0}C and 41.55^{0}C during 2018-19 and 16.90^{0}C and 40.57^{0}C during 2019-20. The average monthly minimum and maximum rainfall was 2.2 mm and 4.2 mm in 2018 and 2.1 mm and 5.2 mm in 2019, respectively.

Experimental design: The treatments were arranged in a Randomized Complete Block Design (RCBD) with four replications as follows:

T1	Shallow tillage + control	T14	Deep tillage+ control
T2	Shallow tillage + Gypsum 4.5 ton /ha +NPK	T15	Deep tillage + Gypsum 4.5 ton /ha +NPK
T3	Shallow tillage + Gypsum 9 ton /ha +NPK	T16	Deep tillage + Gypsum 9 ton /ha +NPK
T4	Shallow tillage + Gypsum 13.5 ton /ha +NPK	T17	Deep tillage + Gypsum 13.5 ton /ha +NPK
T5	Shallow tillage + straw incorporation 3ton/ha + Gypsum 4.5ton/ha	T18	Deep tillage + straw incorporation 3ton/ha + Gypsum 4.5ton/ha
T6	Shallow tillage + straw incorporation 3 ton /ha + Gypsum 9 ton /ha	T19	Deep tillage + straw incorporation 3 ton /ha + Gypsum 9 ton /ha
T7	Shallow tillage + straw incorporation 3 ton /ha + Gypsum 13.5 ton /ha	T20	Deep tillage + straw incorporation 3 ton /ha + Gypsum 13.5 ton /ha
T8	Shallow tillage + straw incorporation 7 ton /ha + Gypsum 4.5 ton /ha	T21	Deep tillage + straw incorporation 7 ton /ha + Gypsum 4.5 ton /ha
T9	Shallow tillage + straw incorporation 7 ton /ha + Gypsum 9 ton /ha	T22	Deep tillage + straw incorporation 7 ton /ha + Gypsum 9 ton /ha
T10	Shallow tillage + straw incorporation 7 ton /ha + Gypsum 13.5	T23	Deep tillage + straw incorporation 7 ton /ha + Gypsum 13.5
T11	Shallow tillage + straw incorporation 10 ton /ha + Gypsum 4.5 ton /ha	T24	Deep tillage + straw incorporation 10 ton /ha + Gypsum 4.5 ton /ha
T12	Shallow tillage + straw incorporation 10 ton /ha + Gypsum 9 ton /ha	T25	Deep tillage + straw incorporation 10 ton /ha + Gypsum 9 ton /ha
T13	Shallow tillage + straw incorporation 10 ton /ha + Gypsum 13.5 ton /ha	T26	Deep tillage + straw incorporation 10 ton /ha + Gypsum 13.5 ton /ha

Tillage

The tillage treatments included Shallow Tillage (ST) to a depth of 0.10 m with two passes of a disk harrow, and Deep Tillage (DT), which involved moldboard ploughing to a depth of 0.25 m, followed by two passes of a disk harrow similar to ST.

Wheat Straw Amendments

The wheat straw amendments applied were at rates of 3 ton.ha-1 (WS_3), 7 ton.ha^{-1} (WS_7), and 10 ton.ha^{-1} (WS_{10}), while gypsum amendments were applied at rates of 4.5 ton.ha^{-1}, 9 ton.ha^{-1}, and 13.5 ton.ha-^{1}. In addition, Conventional Practice (CK) involved no straw, with only NPK and gypsum, and a control treatment (CTRL) with neither straw nor gypsum.

Gypsum Amendments

The gypsum salt was mixed into the will following rates including 4.5 $ton.h^{-1}$, 9 $ton.h^{-1}$ and 13.5 $ton.h^{-1}$

The gypsum requirement was calculated using the formula:

$$GR=0.344\ \rho\ d\ ([Ca^{2+}]g-[Ca^{2+}+Mg^{2+}]_f)$$

where GR is the soil gypsum requirement (Mg ha^{-1}), $[Ca^{2+}]g$ content of a saturated gypsum solution (me L^{-1}), $[Ca^{2}+Mg^{2+}]_f$ content of the filtrate (me L^{-1}), d is the soil depth (m), and ρ is the soil bulk density (Mg m^{-3}).

Crop Management

Maize was sown on 02 August 2018 during Kharif season. The inter- and intra-row distances between plants were maintained at 0.75 m and 0.30 m. Fertilizers were applied according to [26] recommendations 120 kg N and 50 kg P_2O_5 ha^{-1} were applied to the maize crop. Full P and half of the N were applied at sowing, and the remaining half of N was applied at the first irrigation. All other agronomic and plant protection practices were kept normal for all treatments.

Growth and Yield Parameters

Seedling emergence was calculated at five different locations in each plot using following relation [36]

$$\text{Seedling emergence} = \frac{\text{Number of seedlings emerged}}{\text{Number of seeds sown}} \times 100$$

Five plants were randomly selected from five different randomly selected locations in each plot to measure height of plant, rows per cob at harvest. Plant height (cm) was measured from ground level to the tip of cob with the help of staff rod.

To measure of thousand grain weight and yield the cobs were separated from the sundried bundles of plants, threshed and cleaned manually. Five sets of thousand grains were randomly sampled from each plot's seed production and weighed with the help of weight balance (0.0001 g). The grain yield (kg) per plot was calculated with the help of weight balance (0.0001 g). Finally, the grain yield data were converted into ton. ha^{-1}.

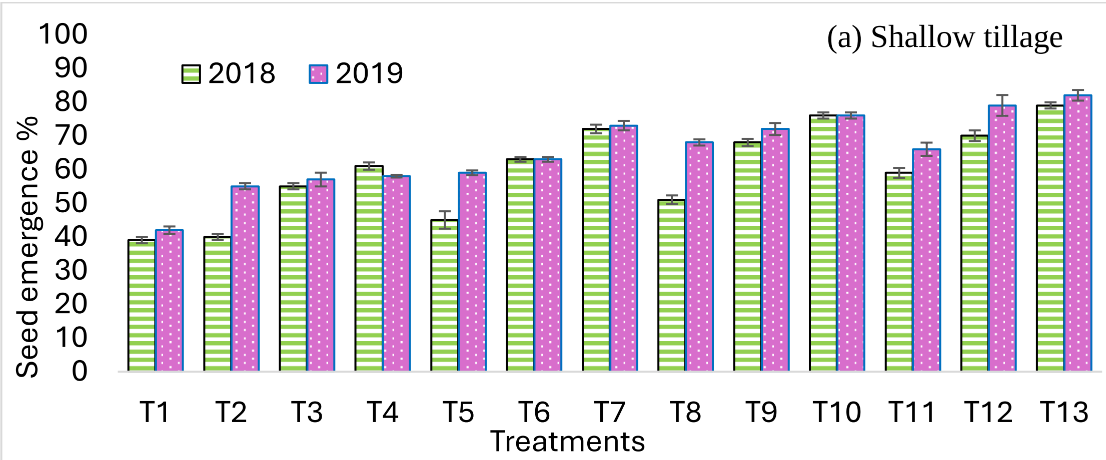
Statistical Analysis

The ANOVA test was conducted using statistics- 8.1 [3] package. Tukey's test was used to calculate Least Significant Difference (LSD) among treatments.

Results

Seed emergence (%)

The analysis of variance showed that seed emergence (%) was significantly affected by tillage practices, straw incorporation and gypsum applications (Fig-1a &1b). Moreover, the combined result revealed that under the Deep Tillage (DT), the maximum seed emergence (89% and 84%) was depicted by T_{26} in both growing years 2018-2019, followed by T_{10} (shallow tillage + straw incorporation 7 ton /ha + gypsum 13.5) and T1 (deep tillage+ control) which showed 82% and 81% regards seed emergence. Furthermore, the results showed that the lowest seed emergence percent 39 % was observed shallow tillage without straw incorporation and gypsum application.



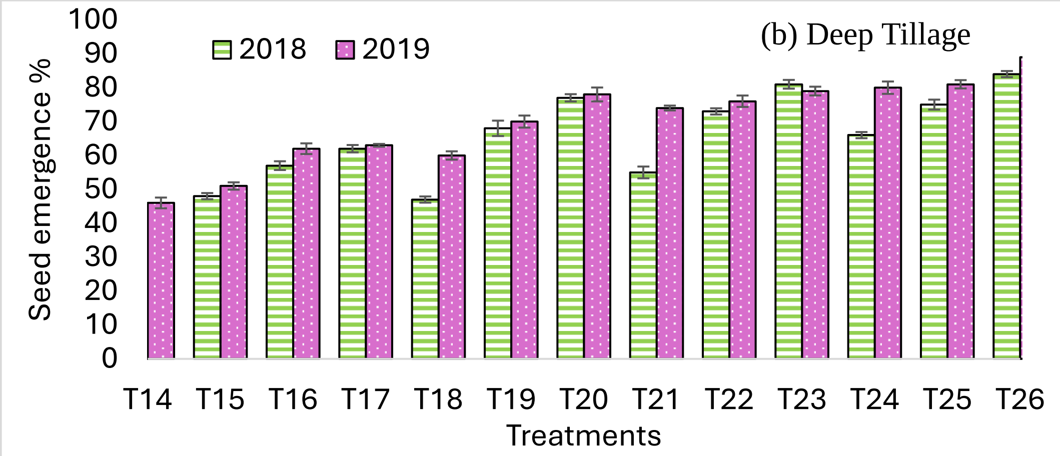
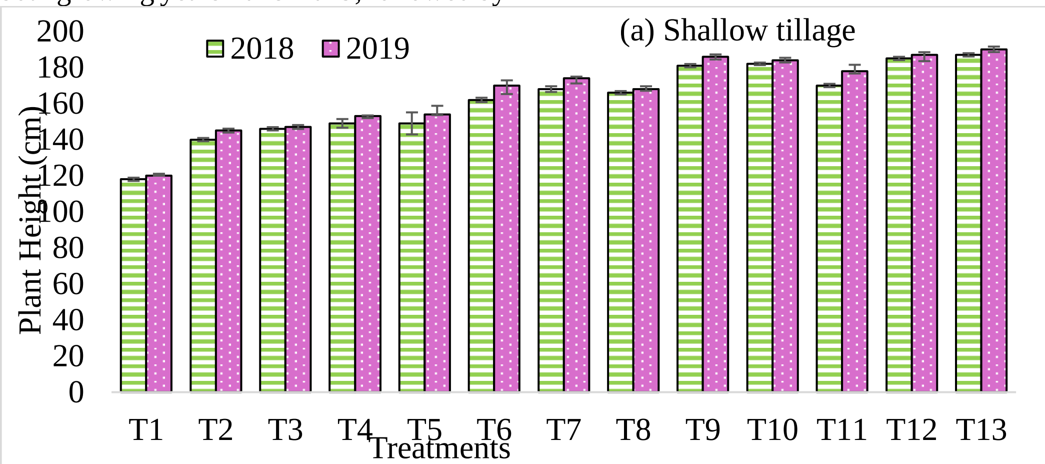


Figure 1a & 1b Seed emergence under tillage practice straw, incorporation, fertilizer and gypsum application

Plant height (cm)

The plant height (cm) was significantly affected by tillage practices, straw incorporation and gypsum applications (Fig-2a & 2b). Moreover, the interactive result revealed that under Deep Tillage (DT) had maximum plant height (204 cm and 201cm) was showed in both growing years 2018-2019, followed by T25 (deep tillage + straw incorporation 10 ton /ha + Gypsum 9 ton /ha) and T19 (deep tillage + straw incorporation 3 ton /ha + gypsum 9 ton /ha) which showed 200cm and 100cm regards plant height. Furthermore, the results showed that the lowest plant height (cm) 118 was observed in shallow tillage without straw incorporation and gypsum application.



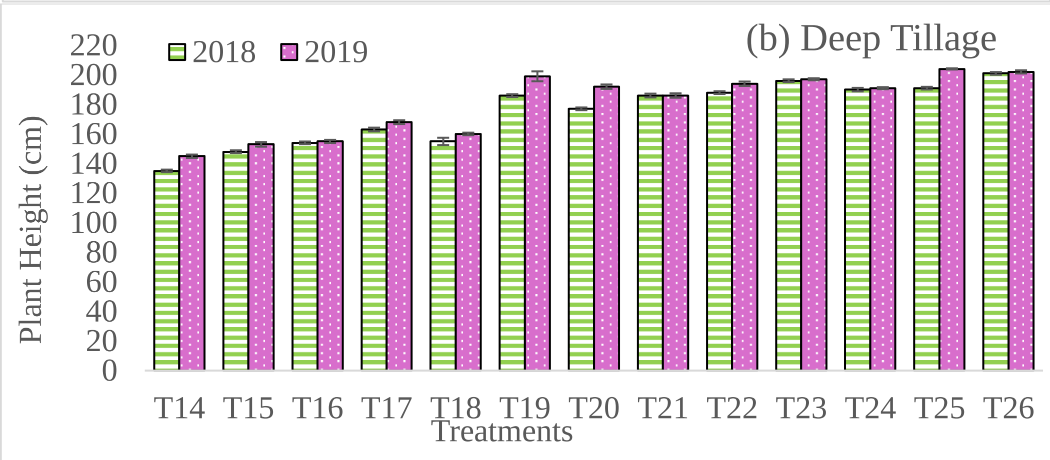
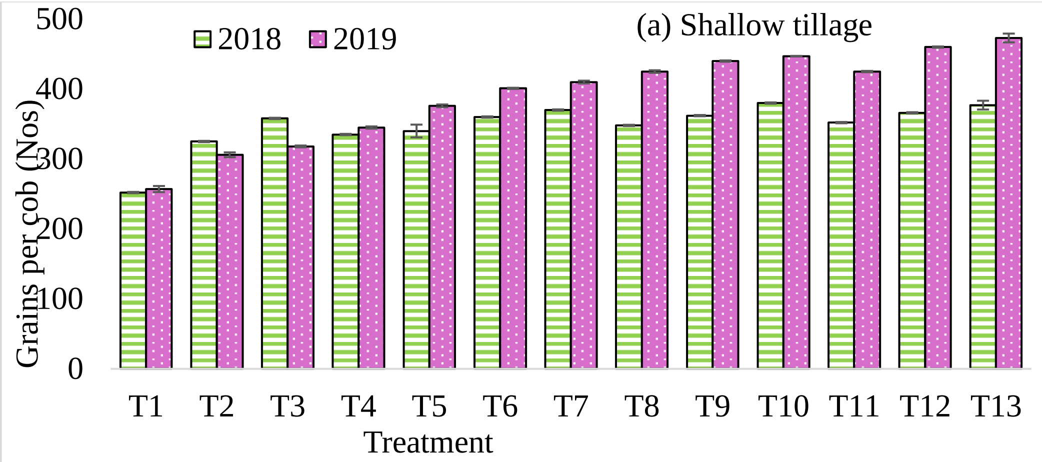


Figure 2a & 2b. Plant height under tillage practice straw, incorporation, fertilizer and gypsum application

Grains per cob

The results of grains per cob (was significantly varied by tillage practices, straw incorporation and gypsum applications (Fig-3a &3b). Moreover, the combined result revealed that under Deep Tillage (DT), the maximum grains per cob (488 and 395) was recorded in both growing years 2018-2019, followed by T26 and T18 which showed 473 and 460 regards grains per cob. Furthermore, the results showed that the lowest grains per cob 252 was observed shallow tillage without straw incorporation and gypsum application



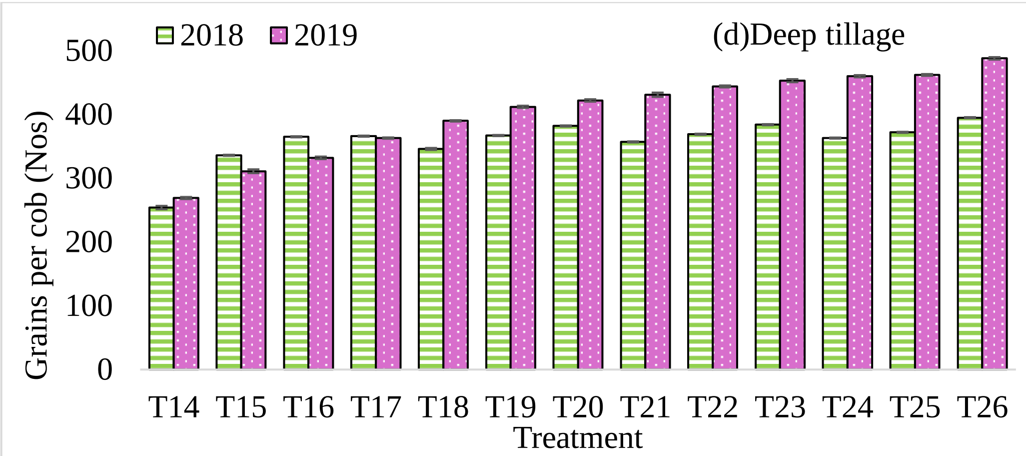
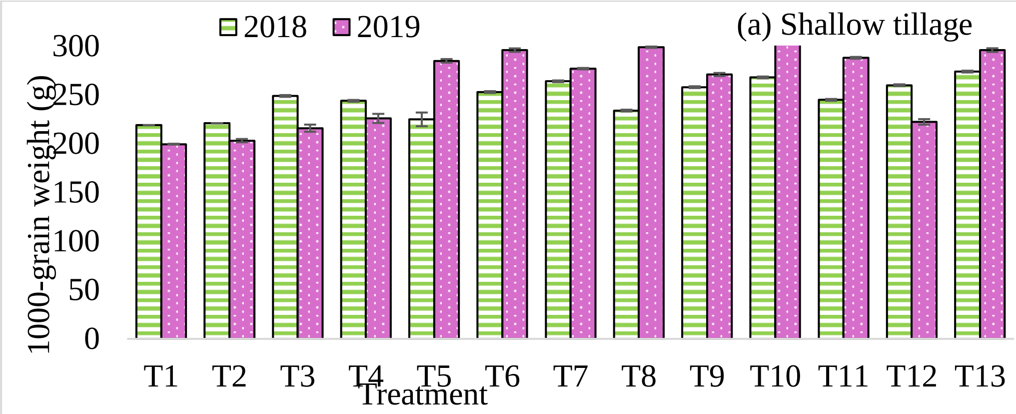


Figure 3a & 3b. Grains per cob under tillage practice straw, incorporation, fertilizer and gypsum application

1000-grain weight (g)

The data relating to 1000 - grain weight (g) was significantly higher by tillage practices, straw incorporation and gypsum applications (Fig-4a &4b). Moreover, the combined result revealed that under Deep Tillage (DT), the maximum 1000 - grain weight (g) (319 and 272) was measured by T26 in both growing years 2018-2019, followed byT25 and T23 which showed 311 and 310 regards 1000 - grain weight (g). Furthermore, the results showed that the lowest 1000 - grain weight (g) 199.6 was observed in shallow tillage without straw incorporation and gypsum application



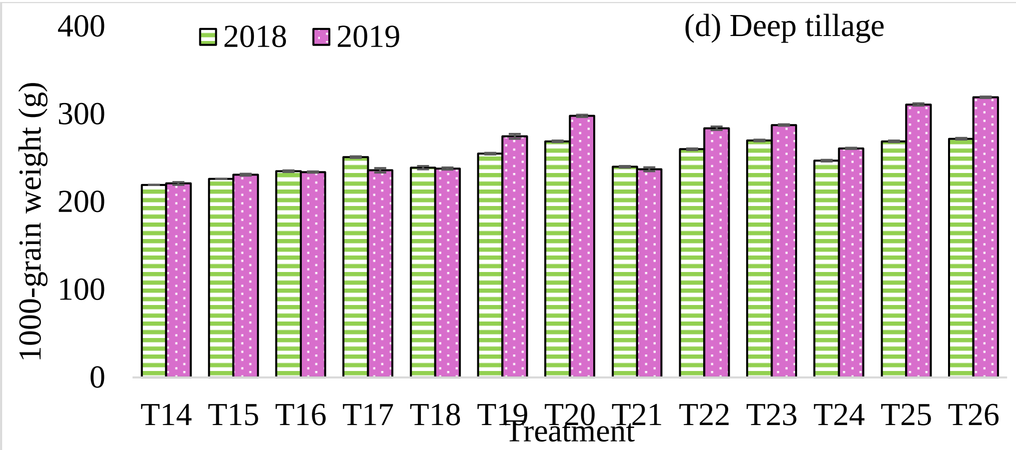
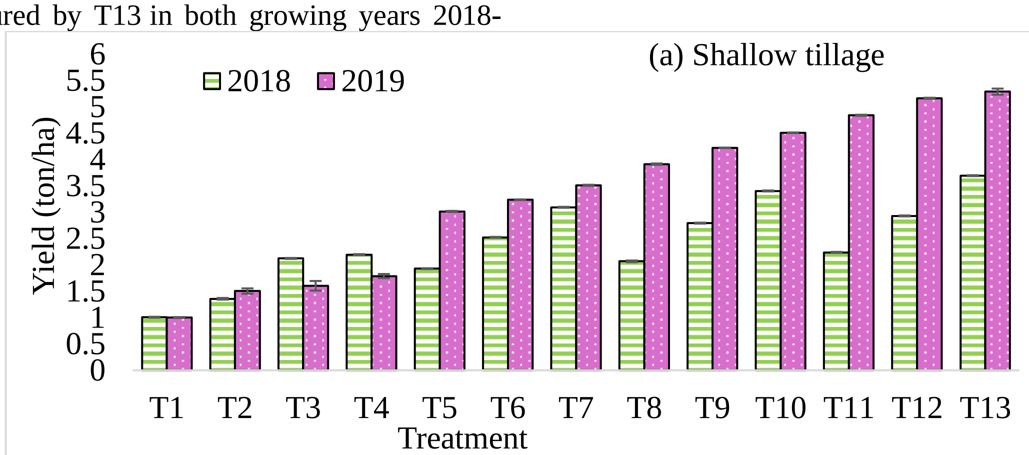


Figure 4a & 4b. 1000-grain weight under tillage practice straw, incorporation, fertilizer and gypsum application.

Yield (ton. ha^{-1})

The results on grain yield (ton. ha^{-1}) were significantly higher than tillage practices, straw incorporation and gypsum applications (Fig-5a &5b). Moreover, the combined result revealed that under Deep Tillage (DT), the maximum yield (ton. ha^{-1}) (5.639 and 3.971) was measured by T13 in both growing years 2018-2019, followed by T12 (DT) and T13 (ST) which showed 5.4 and 5.290 regards 1000 - grain weight (g). Furthermore, the results showed that the lowest yield (ton. ha^{-1}) 1.002 was observed in shallow tillage without straw incorporation and gypsum application T_1



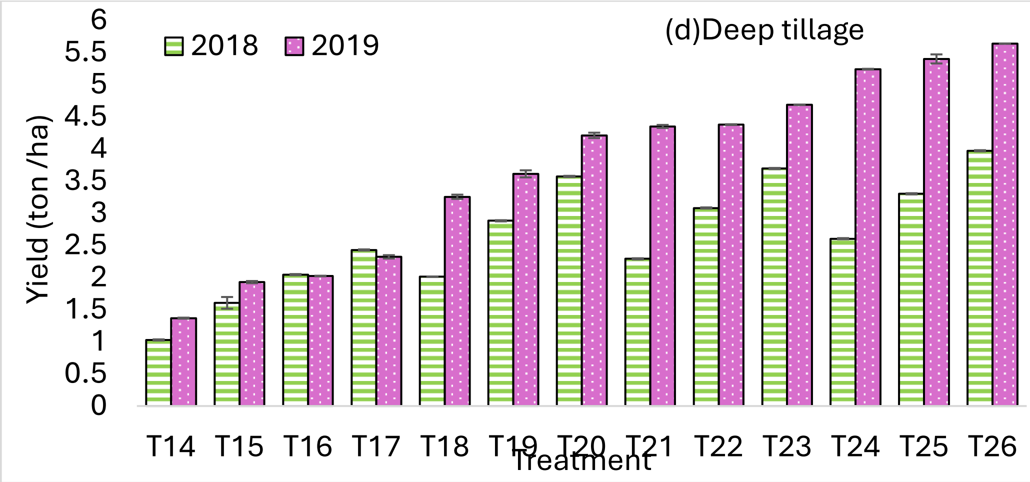


Figure 5a & 5b. Yield under tillage practice straw, incorporation, fertilizer and gypsum application.

DISCUSSION

Saline-sodic soils negatively impact crop growth and yield due to their poor fertility and high rate of salt accumulation [20, 22]. Techniques for enhancing these soils involve physical modifications such as plowing and subsoiling [20], alongside chemical treatments like gypsum [19], sulfuric acid [20], basic oxygen furnace slag [28] and/or polyacrylamide [32, 17]. Integrating these amendments with tillage practices in arid environments has received insufficient attention. Alternatively, organic amendments could replace chemical ones in reclaiming saline-sodic soils [40]. In developing countries, large quantities of crop straw (wheat, rice, maize, cotton) are often burned, leading to environmental pollution and contributing to global warming [17]. These straws contain significant nutrients left over from cultivation, including about 30%–35% of applied mineral nitrogen and phosphorus, and 70%–80% of applied potassium [4]. Additionally, Amezketa, (2005) reported that increases in SOM from straw incorporated into the soil improved the soil physical properties and nutrient status [5], as well as impacting on the soil microbial biomass [29], which in turn enhanced the growth and yield of crop. Indeed, Nan, (2016) reported that tillage, combined with organic material and gypsum, improved the grain and straw yield of wheat [33].

In the present study revealed that highest results regarding yield attribute were significantly noted in T_{14}. This is consistent with Haq, (2001) who concluded that gypsum and wheat straw improved the wheat grain yield over gypsum and rice straw treatments [13]. This finding can be attributed to Bogunovic (2017) who observed that the gypsum requirement for all gypsum-treated pot soils dropped to zero after the wheat crop, whereas it ranged from 1.04 to 9.12 Mg/ha after the rice crop [8]. These results are also supported by Qadir, (2001) who stated that increasing the straw application rates increased the maize yield [41]. Medium and high straw rates significantly increased maize yield as compared to that of low straw treatments in the three years. This is consistent with Dixit, (2019) who demonstrated that the effective spike number and average thousand grain weight were observed high under 60% and 30% of straw addition as compared to control treatment [10]. The differences may be attributable to the increasing soil nutrients [39] and improved soil fertility [42] with the passage of time. In addition, Noy-Meir, (1973 and Hamza (2003) suggested that the enhanced crop yield following the application of crop straw can be primarily attributed to improvements in soil quality [36, 12]. In this study yield and yield attributes of maize were higher under deep tillage treatments i.e.T5-T13 (DT), T4, T3, T2 and T1(DT) than under shallow tillage treatments T5-T13 (ST), T4, T3, T2 and T1(ST) Hejazi, (2010) reported similar findings, noting that deep tillage using a moldboard plow significantly increased wheat yields by 15% to 52%, with an average yield increase of 25% compared to the cultivator[15]. These results are consistent with Ahmad, (1990) who also observed that the average grain yield of 2903 kg/ha obtained from moldboard plowing was significantly higher than the grain yield of 2512 kg/ha achieved with cultivator treatments [1]. On the other hand, Aynehband, (2017) found that straw incorporation led to increased grain yield, whether using rotary or deep tillage methods [6]. These results align with the conclusions drawn by [38, 41].

CONCLUSION

The present study revealed that all the studied traits i.e., germination, growth and yield significantly ($P < 0.05$) varied under tillage practices, fertilizer application, straw incorporation, and gypsum levels during both growing years 2018-19. Moreover, based on the results it has been concluded that promised results for all the parameters were found in T_{26} (deep tillage + straw incorporation 10 ton /ha + gypsum 13.5 ton /ha). However, the lowest results for germination, growth and yield traits were demonstrated by T_1 (Shallow tillage + control).

RECOMMENDATIONS

Based on the findings of the present study its can be recommended that gypsum application should be incorporated to mitigate the adverse soil sodic conditions in maize growing areas. Moreover, the combined application of fertilizers, straw incorporation and gypsum application with deep tillage practices should be followed for better growth and yield of maize crop. Further studies should be conducted to assess the maize crop under various mulching sources fertilizer application and tillage practices, to explore the more improved cultural practices for quality crop production.

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