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# Influence of straw incorporation-to-planting interval on soil physical properties and maize performance

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A b s t r a c t. Long-term soil disturbance due to regular tillage destroys the soil structure, particularly by reducing the soil organic matter content. This, in turn, can lead to declining crop yields. This study assessed the influence of wheat (*Triticum æstivum* L.) straw incorporation and timing prior to seeding at 6 Mg ha$^{-1}$ ($S^+$), relative to no straw ($S^-$), on maize (*Zea mays* L.) growth and yield parameters, as well as on soil characteristics. There were four intervals between straw incorporation and maize seeding, *i.e.* 60, 45, 30 and 15 days before sowing. Compared to the $S^-$ (control), soil dry bulk density increased ($p \leq 0.05$) under all $S^+$ treatments. A significantly greater proportion of undesirable small aggregates (<0.5 mm), and a lesser proportion of desirable medium sized (0.5-8.0 mm) aggregates, occurred under $S^-$ treatment, as compared to $S^+_{60}$ treatment. A similar, but less pronounced, trend was observed under $S^+_{45}$ treatment. This trend was also evident for the $S^+_{30}$ and $S^+_{15}$ treatments. Generally, incorporation of straw 60 days prior to sowing led to achieving the best soil structure in terms of aggregation. Compared to $S^-$, the soil organic matter showed a weakly significant ($0.05 \leq p \leq 0.06$) increase under straw amendment. Seedling emergence, plant height, cob length, the number of grain rows per plant, the number of grains per cob, as well as 1000 grain weight and yield were the highest under $S^+_{60}$, and the lowest under $S^-$. The present study suggests that more research is necessary over longer time periods between straw incorporation and seeding on different crops, and in different soil types, in order to study the effects on soil properties, and on the growth and yield of crops.

K e y w o r d s: maize yield, soil bulk density, soil organic matter, straw incorporation, timing

## INTRODUCTION

With rapid population growth and related environmental threats, global food security has become a significant issue (Poulsen *et al.*, 2015). Food security can be achieved, in part, by enhancing agricultural productivity. While conventional tillage practices loosen soils to allow for better crop harvests in the short term, long-term soil disturbance due to regular tillage destroys the soil structure, particularly by reducing the soil organic matter (SOM) content (Baker *et al.,* 2007). This, in turn, leads to lower crop yields. Accordingly, it is important to increase SOM in order to achieve higher crop yields (Koga and Tsuji, 2009). SOM refers to the material produced by living organisms that is returned to the soil and undergoes decomposition processes (Bot and Benites, 2005). It improves the physical, chemical and biological properties of the soil (Lal, 2004), provides nutrients to plants and improves water availability, all of which enhance soil fertility and ultimately improve food productivity. Moreover, SOM improves the structural soil stability by promoting aggregate formation which, together with pore size distribution, ensures sufficient aeration and water infiltration to support plant growth (FAO, 2017).

Soil organic matter can be replenished by providing organic amendments to the soil (Stewart *et al.*, 2007), through no-till farming, the incorporation of straw or crop residues, the amendment of soils with manure or sewage sludge, or the cultivation of permanent or bioenergy crops

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(Lal, 2004). Straw contains a sufficient quantity of organic matter and soil nutrients to be considered an important natural organic fertilizer (Duiker and Lal, 1999). The incorporation of straw into the soil helps to improve soil quality (Mulumba and Lal, 2008), soil aggregation and the stability of aggregates (Sonnleitner *et al.*, 2003), while maintaining the overall ecological balance of the crop production system (Tan *et al.*, 2007). Singh *et al.* (1992) reported that the incorporation of paddy straw three weeks before the sowing of wheat significantly increased the growth and yield components of the wheat crop in the Sonepat district (India) on a clay loam soil, while no such beneficial effect was observed on a sandy loam soil in Hisar (India). In contrast, a traditional burning of straw after harvest, or its removal and use for livestock feeding, was shown to create soil compaction and produce adverse effects on the growth and yield of subsequent crops (Mele and Crowley, 2008).

The vast majority of studies on the effects of straw incorporation on soil quality have addressed the productivity and yields of various crops (Sonnleitner *et al.*, 2003; Mulumba and Lal, 2008; Wilhelm *et al.*, 2007). However, little information is currently available on the proper time to incorporate straw into the soil in order to maximize its impact on the physical properties of the soil and crop yield. Our hypothesis was that if straw was incorporated into the soil before the crop was sown, it would not only improve the physical properties of the soil but also enhance crop yield. This study was carried out to investigate the influence of straw incorporation and its timing on some physical properties of the soil, and on maize crop yield parameters.

## MATERIALS AND METHODS

The study was carried out at an experimental site belonging to the Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, Hyderabad district, Sindh, Pakistan. At a lat. 25º25’28” N and long. 68º32’6” E, the study site was situated about 26 m above mean sea level. Prior to this experiment the field had been planted with mango (*Mangifera indica* L.) for five years and had received the recommended doses of fertilizers: 910 g N, 680 g $P_2O_5$ and 680 g $K_2O$ per tree. The complete dose of P and K and half the dose of N were applied in February, while the remaining N was applied in April (Raheel Anwar *et al.*, 2011). Based on the USDA soil particle size analysis (Bouyoucos, 1927), the soil was found to belong to the textural class of silt loam, with the sand (0.05-2.0 mm) fraction ranging from 25.0 to 33.0%, the silt (2-50 μm) fraction from 54.0 to 64.0%, and the clay (< 2μm) fraction from 11.0 to 15.2%, across the field.

The study assessed the influence of wheat (*Triticum æstivum* L.) straw incorporation and timing prior to the seeding at 6 Mg ha$^{-1}$ ($S^+$), relative to no straw ($S^-$), on maize (*Zea mays* L.) growth and yield parameters, as well as on soil characteristics. There were four intervals between straw incorporation and maize seeding, i.e. 60, 45, 30 and 15 days before sowing, designated as $S^+_{60}, S^+_{45}, S^+_{30}, S^+_{15}$, respectively. These four time intervals, together with $S^-$, gave five treatments.

All the five treatments were arranged in a randomized complete block design (RCBD) with three replications. The entire experimental field (50 × 14 m) was divided into three blocks (4 × 50 m), with 1.0 m strips separating them. Each block was divided into five randomly assigned treatment plots (4 × 10 m).

The nutrient content of the wheat straw was 7.22 kg N Mg$^{-1}$, 1.07 kg P Mg$^{-1}$ straw, and 9.20 kg K Mg$^{-1}$ (Tarkalson *et al.*, 2009). The wheat straw was chopped into 0.05 m pieces (Zhang *et al.*, 2014) and mixed into the top 0.25 m of the soil using ridge tillage: mouldboard ploughing to a depth of 0.25 m, followed by two passages of a disk harrow to a depth of 0.10 m (Farid Eltom *et al.*, 2015) and by a ridger. Maize (cv, Akbar) was sown during the first week of August 2016. The inter- and intra-row distances between plants were maintained at 0.75 and 0.30 m, respectively. The seeds were hand-drilled at a rate of 30 kg ha$^{-1}$ (Farmanullah *et al.*, 2010). The field capacity was determined using the gravimetric method. Upon seeding and throughout the growing season, irrigation water was applied through ridge-furrow irrigation when the soil water content dropped to 60% of the field capacity (Ministry of Food, Agriculture and Livestock, 1997). The soil water content ($\theta$) at 60% depletion (*SMD*) was determined using:

$$SMD = \theta_f - \theta_o, \tag{1}$$

$$\theta = \frac{W_w - W_d}{W_d} 100, \tag{2}$$

where: $\theta_f$ is the water content at field capacity (%), $\theta_o$ is the water content at 60% depletion, $\theta$ is soil water content (%), $W_w$ is the weight of moist soil (g), $W_d$ is the weight of dry soil (g).

Seedling emergence per square meter (one week after seeding), plant height at harvest, and mature cob length were measured in five different randomly selected sampling locations in each treatment plot, and the obtained values were then averaged. To record grain yield, after harvesting the plants at maturity, cobs were separated, sun-dried and threshed manually. Grain yield per plot was also recorded. To measure 1000-grain weight, five sets of 1000 grains were randomly sampled from each plot seed production. Then, they were weighed and the average values were calculated.

Individually for each treatment plot, composite soil samples were collected at depths of 0-0.15 m, 0.16-0.30 m and 0.31-0.60 m. Soil samples were dried at 105ºC for 24 h. The dry bulk density ($\rho_d$, Mg m$^{-3}$) was determined using the gravimetric method (Blake and Hartge, 1986) as follows:

$$\rho_d = \frac{DW_{soil}}{V_{soil}}, \tag{3}$$

where: $DW_{soil}$ is the dry weight of the soil (Mg), and $V_{soil}$ is the total volume of the soil ($m^3$).

The soil organic carbon content was determined using the Walkley and Black (1934) method. Organic carbon was then converted into the soil organic matter content by multiplying it by Van Bemmelen's number a factor of 1.72.

To determine the extent of post-tillage soil aggregation, the disturbed soil samples were collected, placed in aluminium boxes and left to air-dry at room temperature for 15 days. The air-dried soil samples were then passed through a nest of nine sieve classes of various aperture sizes to obtain the aggregate fractions of the following size classes: 32-25, 25-12.5, 12.5-8, 8-2, 2-1.2, 1.2-0.5, 0.5-0.25 and 0.25-0.15, and 0.15-0.015 mm. The mass of the soil retained within each size class was collected, weighed, and then divided into the following three aggregate size ranges (Tagar *et al.*, 2017):

– 8 mm, large aggregates or clods;
– 0.5-8 mm, medium or desirable aggregates, and
– <0.5 mm, small, undesirable aggregates.

The effect of the straw incorporation timing on the physical properties of the soil, and on crop growth and yield parameters, was estimated by means of the balanced analysis of variance (ANOVA) model (Tables 1). Tukey's multiple comparison test served the purpose of ascertaining the differences among individual treatments. A normality test was performed using the Anderson-Darling normality test method, and the appropriate transformations were applied when necessary. All statistical tests were performed using the MINITAB Statistical Software-16 (Minitab, 2007). The organic matter content ($p > 0.25$), soil aggregation ($p > 0.20$), seedling emergence ($p > 0.95$), cob length and rows per cob ($p > 0.94$), as well as grain yield ($p > 0.50$) data were deemed normal ($p > 0.05$), while dry bulk density, plant height, grains per cob and 1000 grain weight data were non-normal ($p > 0.05$). To improve the normality of the data, it was transformed using the Johnson transformation.

## RESULTS AND DISCUSSION

The effects of the different timing of straw incorporation (*i.e.*, 60, 45, 30 and 15 days prior to seeding) on mean $\rho_d$ are illustrated in Fig. 1. Compared to the $S^-$ treatment, the value of $\rho_d$ declined significantly ($p < 0.05$) under all straw-amended treatments. The extent of the decline was the greatest for $S^+_{60}$ (9.2%) among the amended treatments although the decline was non-significant ($p > 0.05$), corresponding to 8.26% for $S^+_{45}$, 6.5% for $S^+_{30}$ and 5.6% for $S^+_{15}$ (Fig. 1).

These results are similar to those obtained by Mi *et al.* (2016), who reported that straw incorporation significantly reduced the dry bulk density of the soil by 8-11%. Dao (1996) concluded that tillage with no straw incorporation treatment initially decreased the dry bulk density, but the tillage with straw incorporation treatment resulted in a lower dry bulk density by the end of the growing season. Additionally, Zhu *et al.* (2010) reported that straw

**Table 1.** Analysis of variance (ANOVA) of the effect of different straw incorporation timings, relative to corn crop seeding or the absence of straw amendment on the physical properties of the soil, and on crop growth and yield parameters

| Parameter | Mean square | | F-value | Probability |
|---|---|---|---|---|
| | Treatment (d.f. = 4) | Error (d.f. = 10) | | |
| Soil physical characteristics | | | | |
| Dry bulk density (Mg m$^{-3}$) | 0.008 | 0.002 | 24.1 | 0.000 |
| Soil organic matter (% w/w) | 0.005 | 0.001 | 3.31 | 0.057 |
| Soil aggregates | | | | |
| Large >8.0 mm | 2.302 | 6.821 | 0.34 | 0.847 |
| Medium 0.5-8.0 mm | 87.30 | 6.526 | 13.4 | 0.000 |
| Small <0.5 mm | 62.51 | 6.671 | 9.37 | 0.000 |
| Crop growth and yield | | | | |
| Seedling emergence | 148.4 | 5.575 | 26.62 | 0.000 |
| Plant height | 469.7 | 4.267 | 110.0 | 0.000 |
| Length of cob | 6.579 | 1.080 | 6.09 | 0.009 |
| Grain rows per cob | 5.190 | 1.028 | 5.05 | 0.017 |
| Grains per cob | 7493 | 6.460 | 1161 | 0.000 |
| 1000-grain weight | 12307 | 4.400 | 2773 | 0.000 |
| Grain yield | 6.209 | 0.373 | 16.66 | 0.000 |

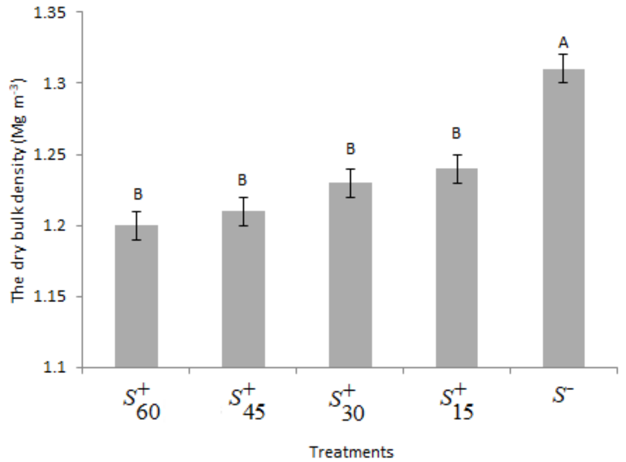


**Fig. 1.** Mean values of dry bulk density under different straw incorporation timing regimes ($S^+_{60}$, $S^+_{45}$, $S^+_{30}$, $S^+_{15}$: 60, 45, 30 and 15 days before seeding, respectively) or no straw ($S^-$). Error bars denote standard error (n = 3). Values with common letters are not significantly different (p > 0.05), based on Tukey's multiple comparison test.

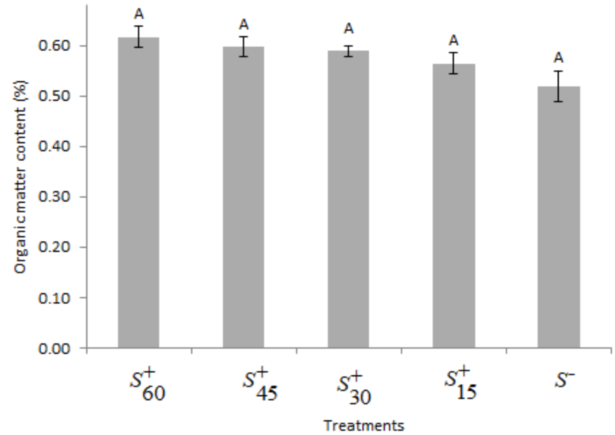


**Fig. 2.** Mean values of the soil organic matter under different straw incorporation timing regimes ($S^+_{60}$, $S^+_{45}$, $S^+_{30}$, $S^+_{15}$: 60, 45, 30 and 15 days before seeding, respectively) or no straw ($S^-$). Explanations as in Fig. 1.

incorporation significantly improved the soil water-holding capacity and dry bulk density, while Chaudhary *et al.* (2014) concluded that straw incorporation could improve soil fertility and reduce bulk density in a sandy clay loam soil. In contrast, Lindqvist (2015) showed that there were non-significant differences in dry bulk density between the plots with straw incorporation and straw removed.

The quantity of the soil organic matter content was only marginally ($0.05 \leq p \leq 0.06$) affected by the straw incorporation timing (Table 1, Fig. 2). The increase in SOM, relative to the non-amended control sample, was the highest for $S^+_{60}$ (18.75%) and declined in a non-significant ($p > 0.05$) trend to 15% for $S^+_{45}$, 13.33% for $S^+_{30}$ and 8.62% for $S^+_{15}$.

These results concur with those presented by Memon *et al.* (2018), who demonstrated that straw incorporation significantly increased the SOM level by 3.08-17.07%, compared to treatments without straw, after two rice growing seasons. Poeplau *et al.* (2015), who carried out their research in Sweden, found little or no positive effect of straw incorporation, possibly due to the shorter time of straw incorporation, among the treatments.

In this study, the soil structure in terms of soil aggregates was considered to be good when more than 50% of post-tillage aggregates were of medium size and small aggregates were at a minimum (Abbaspour-Gilandeh and Sedghi, 2015; Tagar *et al.,* 2016). Straw incorporation and its timing had highly significant ($p \leq 0.01$) effects on the proportion of medium (0.5-8.0 mm, desirable) and small (<0.5 mm, undesirable) aggregates, but no significant effect ($p > 0.05$) on large aggregates (Fig. 3). A significantly greater proportion of undesirable small (<0.5 mm) aggregates, and a lower proportion of desirable medium sized (0.5-8.0 mm) aggregates (46.92 and 35.82%, respectively), were found under the $S^-$ treatment, as compared to the $S^+_{60}$

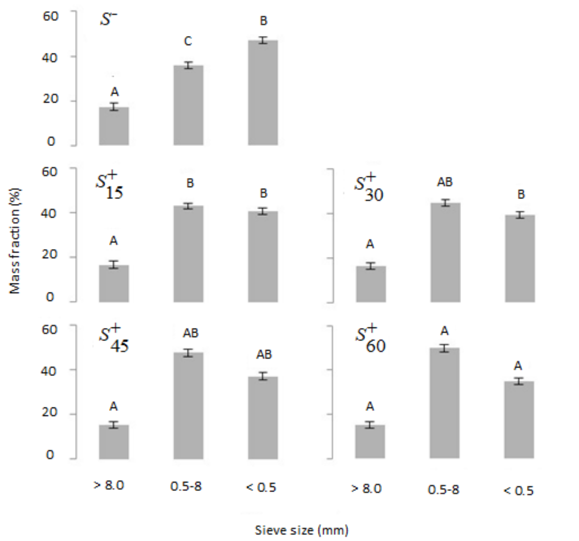


**Fig. 3.** Mass fraction (%) in different soil aggregate size ranges, with no straw amendment ($S^-$), or with straw amendment 15, 30, 45 or 60 days prior to seeding ( $S^+_{15}$, $S^+_{30}$, $S^+_{45}$, and $S^+_{60}$, respectively. Explanations as in Fig. 1.

treatment (34.88 and 49.91%, respectively). A similar, but less pronounced, trend was observed under the $S^+_{45}$ treatment (37.11 and 47.59%, respectively). This trend was also evident for the $S^+_{30}$ and $S^+_{15}$ treatments.

Coppens *et al.* (2006) also reported that straw incorporation significantly increased the formation of aggregates, even in the short-term. Similarly, Zhang *et al.* (2014) found straw incorporation to produce significantly more and larger soil aggregates as compared to the control sample receiving no straw. They attributed these changes to the fact that straw releases a number of organic C fractions into the soil during its decomposition, which accelerates soil aggregation from micro-aggregates to macro-aggregates (Hbirkou *et al*., 2011). In contrast, Nuttall *et al.* (1986) reported that the incorporation of straw had little or no effect on SOM, soil water content and soil aggregation.

The maximum seedling emergence (82.85%) occurred under $S^+_{60}$, while the minimum and significantly lower ($p \leq 0.05$) seedling emergence (64.52%) occurred in the non-amended control ($S^-$) (Table 1, Fig. 4). Among the amended treatments, emergence increased significantly with the extending time period between the amendment and seeding (68.48% < [73.82, 75.82%] < 82.85%, for $S^+_{15}$, $[S^+_{30}, S^+_{45}]$ and $S^+_{60}$, respectively).

Straw incorporation resulted in significantly ($p \leq 0.05$) taller plants, compared with those undergoing no straw amendment, while longer incorporation-to-seeding periods ($S^+_{60}$ and $S^+_{45}$) resulted in greater plant height than shorter periods ($S^+_{30}$ and $S^+_{15}$) (Table 1, Fig. 5A). The tallest plants (2.28 m) occurred under $S^+_{60}$, while the shortest ones (1.96 m) occurred under the non-amended $S^-$ control.

Cob length, rows per cob, and grain per cob (Fig. 5B,C,D, respectively) were significantly higher ($p \leq 0.05$) for straw-amended plots than for non-amended ones (Table 1). The extending incorporation-to-seeding time significantly ($p \leq 0.05$) increased grains per cob (Fig. 5D), showing similar but non-significant ($p > 0.05$) trends for cob length and rows per cob. The maximum cob length (194 mm), grain rows per plant (16) and grains per cob (647.6) were found under $S^+_{60}$, whereas their respective minima (156 mm, 13, and 522.2) were obtained with the non-amended $S^-$ control.

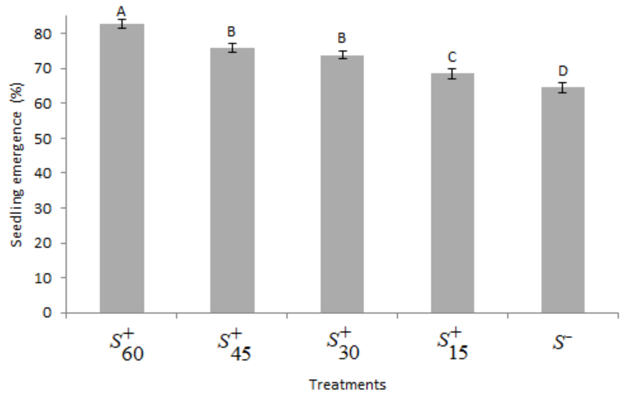


**Fig. 4.** Seedling emergence under different straw amendment treatments: no straw amendment ($S^-$), or with straw amendment 15, 30, 45 or 60 days prior to seeding ($S^+_{15}$, $S^+_{30}$, $S^+_{45}$, and $S^+_{60}$, respectively). Explanations as in Fig. 1.

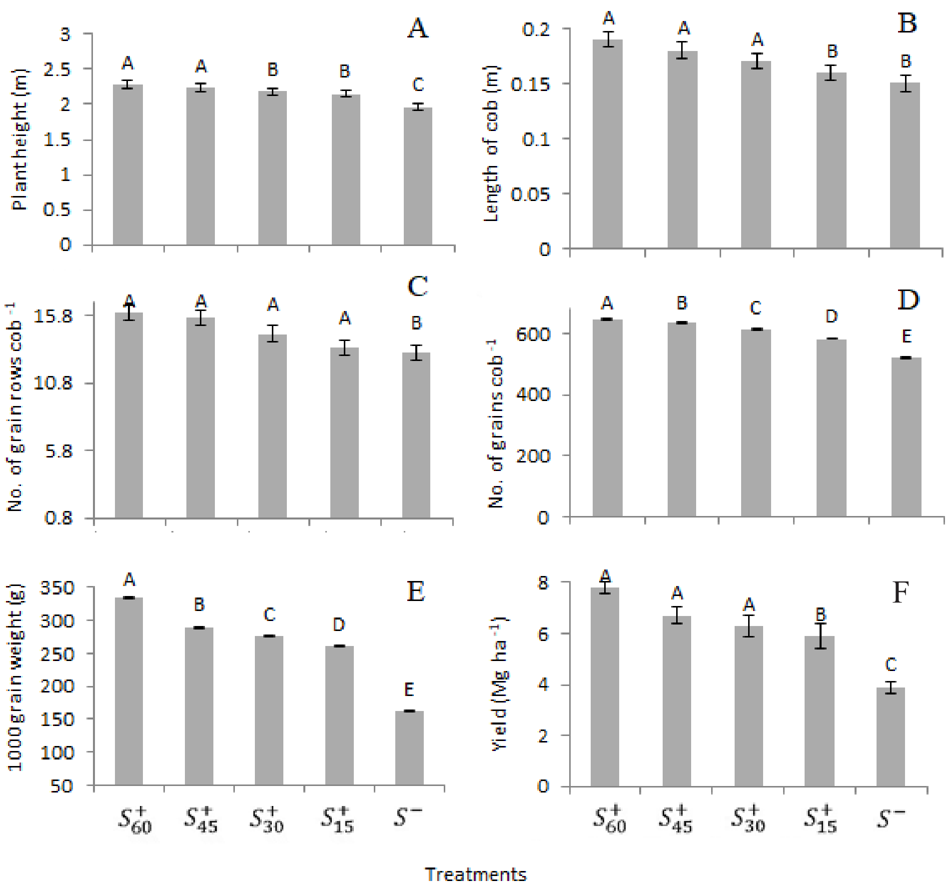


**Fig. 5.** The effect of no straw amendment ($S^-$), or with straw amendment 15, 30, 45 or 60 days prior to seeding ($S^+_{15}$, $S^+_{30}$, $S^+_{45}$, and $S^+_{60}$, respectively) on (A) plant height, (B) length of cob, (C) the number of rows per cob, (D) the number of grains per cob, (E) 1000 grain weight, and (F) the overall grain yield. Explanations as in Fig. 1.

Straw amendment significantly ($p \leq 0.05$) increased 1000 grain weight under all straw amendment treatments, compared to treatments with no straw amendment ($S^-$), and 1000 grain weight increased significantly at each interval between straw incorporation and maize seeding (Table 1, Fig. 5E). The maximum 1000 grain weight (335.5 g) was obtained under the $S_{60}^{+}$ treatment and the minimum weight (161.6 g) under the $S^-$ control.

Straw amendment significantly ($p \leq 0.05$) heightened grain yield over the non-amended treatment ($S^-$), and while yields for the $S_{30}^{+}$,$S_{45}^{+}$, and $S_{60}^{+}$ treatments did not differ significantly, they were significantly greater than those for the $S_{15}^{+}$ treatment (Table 1, Fig. 5F). However, the straw incorporation timing was the same for all treatments, corresponding to 15 days. The maximum grain yield (7.8 Mg $ha^{-1}$) was achieved under $S_{60}^{+}$, and the minimum (3.9 Mg $ha^{-1}$) under the $S^-$ control.

The present results are supported by Su *et al.* (2014), who reported that the incorporation of straw into the soil after the previous year harvest significantly increased crop yields. Likewise, Karami *et al.* (2012) showed that straw incorporation had positive effects on soil productivity and crop yields, and Wang *et al.* (2014) concluded that the incorporation of straw significantly increased the yield of a maize crop. However, some studies have reported little or no effect of straw application on crop yields. Yadvinder-Singh *et al.* (2004) conducted a field experiment to investigate the effects of residue decomposition on productivity and soil fertility on a sandy loam soil for a period of 7 years in a rice wheat rotation system. They demonstrated that residue incorporation 10 to 40 days before the establishment of the succeeding crop had no effect on wheat yields, while rice yields increased (0.18-0.39 Mg $ha^{-1}$) when wheat residue was incorporated with green manure. Similarly, Rydberg (1987) conducted field experiments in light clays, stiff clays, organic soil and sandy soils in the southern and central parts of Sweden. These experiments showed uneven levels of plant establishment and, therefore, lower yields. He recommended that straw should be chopped well, evenly spread on the field and mixed into the topsoil immediately after harvest. Lindqvist (2015) also suggested that if the straw was to be incorporated, it needed to be chopped finely and spread evenly over the field.

## CONCLUSIONS

1. This study has shown that amending an agricultural soil with straw, and doing so with different delays (*i.e.*, 60, 45, 30, 15 days) between straw incorporation and crop seeding, could have significant ($p < 0.05$) effects on the physical properties of the soil, as well as on the growth and yield of a subsequent maize crop. However, the straw amendment had only a marginal ($0.05 \leq p \leq 0.06$) positive effect on SOM.

2. Growth and yield parameters for the maize crop significantly ($p < 0.05$) increased under the 60 days before sowing treatment – and with varying levels of significance under the 45, 30, and 15 days before sowing treatments – compared to the non-amended $S^-$ control.

3. To reduce dry bulk density and improve soil aggregation, straw should be incorporated 60 days prior to the sowing of the crop.

4. To achieve greater growth and yield parameters for maize, straw should be incorporated 60 days prior to the sowing of the crop.

**Conflict of interest:** The Authors do not declare conflict of interest.

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