ISSN: 1991-0037 (print), 2710-3285 (online)
SOUTH ASIAN JOURNAL OF AGRICULTURE
https://www.banglajol.info/index.php/SAJA
Agrotechnology Discipline, Khulna University
https://ku.ac.bd/discipline/at

OPEN ACCESS

South Asian J. Agric.

Research Article Vol. 11, No. 2, Dec., 2025: 89-99

Title: Performance of Maize (*Zea mays* L.) Varieties and Soil Amendment Strategies for Sustainable Cultivation in Coastal Saline Soils in Bangladesh

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Article Info:

Received: *November 30, 2025*
Accepted: *December 05, 2025*
Published: *December 20, 2025*

Keywords: *Integrated soil management, organic amendment, saline agriculture, varietal selection, and yield*

ABSTRACT

The expansion of salinity-affected coastal zones in Bangladesh intensifies pressure on arable land, necessitating the development of resilient agricultural systems. This study investigated the viability of maize (*Zea mays* L.) as an adaptive crop for these challenging environments, where productivity is limited by soil salinity, poor drainage, and low fertility. A two-stage field experiment was conducted to first identify a suitable maize variety among three candidates (Agro Vision, Lal Teer 'Hybrid Maize-Sultan', and BARI Hybrid Maize-6) and then to evaluate integrated soil amendment strategies. The varietal trial assessed germination, growth, and yield parameters, revealing BARI Hybrid Maize-6 as superior, with the tallest plants (168.33 cm at maturity) and highest grain yield (1.51 t ha^{-1}). Subsequently, this variety was grown under ten nutrient management regimes, including inorganic fertilizer (INF) applied alone or combined with graded levels of cowdung (CD), quick compost (QC), or sand. Results demonstrated that organic-inorganic combinations profoundly outperformed inorganic fertilizer alone. The highest grain yield (3.61 t ha^{-1}), plant height (181.74 cm), and cob count were achieved with the highest cowdung dose combined with INF (CD3+INF), representing a fourfold yield increase over the sole INF treatment (0.88 t ha^{-1}). Amendments with quick compost or sand also significantly enhanced growth and yield relative to the control. These findings advocate for an integrated soil management approach, specifically coupling the BARI Hybrid Maize-6 variety with cow dung amendment, to sustainably enhance maize productivity in coastal saline soils. Further multi-location and multi-season trials are recommended to confirm these promising results.

DOI: https://doi.org/10.3329/saja.v11i2.85958

To cite this article: Sultana, S., Ahmmad, M. S., & Islam, M. D. (2025). Performance of Maize (*Zea mays* L.) Varieties and Soil Amendment Strategies for Sustainable Cultivation in Coastal Saline Soils in Bangladesh. *South Asian Journal of Agriculture, 11*(2): 89-99.

INTRODUCTION

Bangladesh's coastal region, encompassing approximately 32% of the national landmass which is home to nearly 30% of the country's population. This densely inhabited zone is both agriculturally significant and ecologically vulnerable, lying at the interface of land and sea, where tidal flooding, salinity intrusion, and climate change impose serious constraints on agricultural productivity such as restricts cropping intensity, poor structure, low organic matter, and erosion, further reducing fertility and stability. The coastal population is projected to grow to about 60.8 million by 2050 (Islam and Ahmad, 2004). The major problems in coastal arable soils of Khulna, Bangladesh are (1) salinity and (2) late recession of flood water from the field because of poor internal drainage conditions of the soil. Broadly, rice varieties cultivated in this region in *Kharif*-I, the rest of the year remains under inundation with rainwater. To get the best output from the land we need to introduce another crop in the fallow season.

Maize (*Zea mays* L.) is an important staple food crop and it provides bulk of raw materials for the livestock and many agro-allied industries in the world (Sanodiya et al., 2023; Yadesa and Diro, 2023). In coastal arable soils like Khulna, Maize cultivation in dry season can provide extra grains, fodders for cattle and bulk of raw materials for poultry and fish feed industry to meet the challenge for overgrowing population. Maize presents a promising alternative for coastal agriculture, as it shows considerable adaptability under salinity stress when paired with appropriate soil management strategies. For instance, inorganic fertilization has been shown to significantly mitigate the negative impacts of salinity on maize yield (Haque, 2020). In addition to mineral fertilization, organic amendments are also an effective strategy to ameliorate saline soil conditions. Studies showed that applying cowdung or quick compost under salt stress improved plant height, biomass, and K^+/Na^+ balance compared to unamended soils (Doulat et al., 2025). Similarly, controlled experiments in coastal saline–alkali soils demonstrate that different organic manures not only improve soil chemical properties—such as organic carbon, available nutrients, and pH—but also enhance soil microbial diversity, which correlates positively with maize growth (Huang et al., 2025). Moreover, soil erosion in these regions, exacerbated by silt-dominated soils and weak structure, can be reduced by organic soil amendments (Al Shoumik and Islam, 2020).

Previous research indicates that both inorganic fertilization and organic amendments like cowdung or compost can individually ameliorate saline soil conditions and improve crop growth. However, a critical research gap remains in the integrated, field-based evaluation of promising maize varieties in conjunction with combined soil amendment strategies specifically designed for the unique constraints of Bangladesh's coastal saline soils. While studies often test amendments or varieties in isolation, there is a lack of conclusive evidence on which specific variety performs best when supported by practical, locally available soil management practices to optimize both plant adaptation and yield under these challenging conditions. Therefore, this study was designed to bridge this gap by systematically evaluating varietal performance and the synergistic effects of combined organic-inorganic amendments in a coastal saline environment.

This study aims (i) to evaluate and compare the agronomic performance of three commercially available maize varieties (Agro Vision, Lal Teer (Hybrid Maize-Sultan), and BARI Hybrid Maize-6) under the saline soil conditions of the coastal Khulna region, (ii) to assess the efficacy of ten distinct soil amendment and fertilizer treatments, including inorganic fertilizer alone and its combinations with varying rates of cow dung, quick compost, and sand in enhancing maize growth and yield and (iii) to identify and recommend a sustainable cultivation package, comprising the most suitable maize variety and the most effective soil amendment strategy, for improving maize productivity in coastal saline soils of Bangladesh.

MATERIALS AND METHODS

The experiment was conducted in the experimental field of Soil, Water and Environment discipline at Khulna University, Khulna during the season of *Kharif*-I. GPS reading of the location is 22º48′11.88″ north latitude and 89 º 32′2.04″ east longitude. With tropical climate, the average annual temperature is 26.1°C and rainfall is 1736 mm in Khulna and falls in Agro ecological zone-13 (Ganges tidal floodplain). The experimental field was a flat land; land type was medium lowland with very late recession of water. Initial soil characteristics of experimental field is presented in Table 1.

At first, the varietal test experiment was conducted at field in *Kharif*-I with 3 varieties of maize seed with 3 replications respectively V1 (Agro Vision), V2 (Lal Teer (Hybrid Maize- Sultan)) and V3 (BARI Hybrid Maize-6) were planted and observe its growth (germination %, plant height at both vegetative and reproductive stage, number of leaves both at vegetative and reproductive stage, number of cobs) and yield. After varietal test, statistically the best performed variety of maize was selected for the next experiment. Here, 10 treatments respectively INF (Inorganic fertilizer-basal dose), CD1+INF (Cow dung 10 t ha^{-1} + Inorganic fertilizer- basal dose), CD2+INF (Cow dung 15 t ha^{-1} + Inorganic fertilizer- basal dose), CD3+INF (Cow dung 20 t ha^{-1} + Inorganic fertilizer- basal dose), QC+INF1 (Quick compost +Inorganic fertilizer- basal dose), QC+INF1.5 (Quick compost +Inorganic fertilizer- basal dose X 1.5), QC+INF2 (Quick compost+ Inorganic fertilizer- basal dose X 2), SAND1+INF (Sand 27%+Inorganic fertilizer- basal dose), SAND2+INF (Sand 54%+Inorganic fertilizer- basal dose) and SAND3+INF (Sand 81%+Inorganic fertilizer- basal dose) were applied to improve the growth and yield of maize at costal belt soil. Sand treatments were specially applied to control water recession problem in the experimental field. Control plots with no treatment were prepared to evaluate the growth performances for all treatments. Nutrient content of applied manures is listed in Table 2. Completely randomized numbers (CRD) with 3 replications were used to assign treatment to the plots because the experimental field contains uniform distribution of land and very low gradient of all considering factors.

Table 1. Characteristics of the experimental soil

pH	EC (dS/m)	OM (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g soil)
7.89	2.87	1.19	0.09	3.50	0.36

The experimental field was ploughed, leveled and plots of 2 m×1.5 m dimensions had been prepared for the experiment. Seeds were sown maintaining a constant seed to seed spacing of 20 cm (Ahmmed et al., 2018). Germination percentage was calculated by dividing the number of seeds that germinate by the total number of seeds sown, multiplying by 100. Height of the maize plant was measured with scaling tape from the ground level up to tip. The average height of all plants was considered the height of the plant for each plot. The number of leaves counted for each plant, compute average and was considered as the number of leaves of the plant for each plot. Plant height and number of leaves were counted twice during the vegetative and reproductive stages of maize plants, respectively. The total number of cobs was counted manually for each plant and summed up for each plot. For yield, maize ears were harvested and kernels were separated and the weight was recorded after proper drying in the sun. Weights of per plot converted into t ha^{-1}. Soil pH was measured using a glass electrode pH meter with a soil-to-water ratio of 1:2.5 (McLean, 1982). Electrical conductivity (EC) was assessed at a 1:5 soil-to-water ratio using an EC meter (USDA, 2004). At first organic carbon was determined by Walkley and Black's wet oxidation method as given by (Jackson, 1962). Then organic matter was estimated multiplying the percent value of organic carbon by the conventional Van-Bemmelene's factor of 1.724 (Piper, 1966). Total nitrogen was analyzed following the Micro-Kjeldahl procedure, in which samples were digested with sulfuric acid and a catalyst mixture, then subjected to alkali distillation and titration (Bremner and Mulvaney, 1982). Available phosphorus was extracted using 0.5 M $NaHCO_3$ (Olsen method) at pH 8.5 and quantified with the ascorbic acid blue color method in a sulfuric acid system at 882 nm using a spectrophotometer (Olsen et al., 1954). Exchangeable potassium (K^+) was extracted with ammonium acetate (pH 7.0) and measured with a flame photometer following Jackson (1973). Statistical analysis of the data was done by using the statistical software SPSS (version 27.0) and graphs were drawn by using Microsoft Excel. The level of significance at 5% for the different treatment means was calculated by Duncan's new multiple range test (DMRT) (Zaman et al., 1982).

Table 2. Nutrient content of organic amendments (Ahmmed et al., 2018)

Organic Amendment	N (%)	P (%)	K (%)
Cowdung	1.0±0.1	0.3±0.03	0.46±0.05
Quick-compost	0.75±0.07	0.6±0.06	1.0±0.1

RESULTS AND DISCUSSION

Varietal Test

All varieties V1 (87%), V2(83%) and V3(93%) resulted high germination percentage (Figure 1). Among all, BARI Hybrid Maize-6 (V3) produced highest germination percentage but not significantly ($p<0.05$) higher than Agro Vision (V1) and Lal Teer (Hybrid Maize-Sultan) (V2).

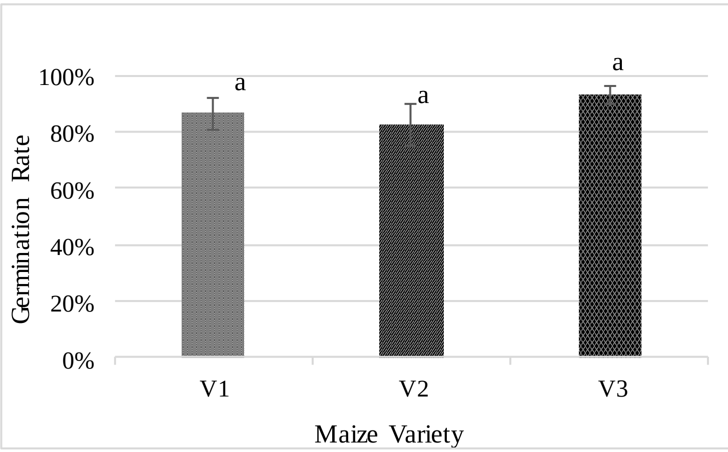

Figure 1. Effect of maize seed variety on germination rate

Mean plant height values obtained at vegetative growth stage for V1, V2, and V3 varieties were 76.27 cm, 70.7 cm and 88.97 cm (Figure 2a) and 147.32 cm, 123.07 cm and 168.33 cm in reproductive growth stage (Figure 2b) respectively. At both growth stages, variety V3 (BARI Hybrid Maize-6) managed to produce significantly ($p<0.05$) higher plant height than V1 (Agro vision) and V2 (Lal Teer (Hybrid Maize-Sultan)) grown in the coastal belt soil of late recession type.

In the case of leaf number, although variety V3 (11.0) performed significantly ($p<0.05$) better than V2 (8.3) at the vegetative stage (figure 3a) but at reproductive stage (figure 3b) it produced insignificant result compared to other varieties. At both growth stages the lowest leaf number was obtained with V2 variety.

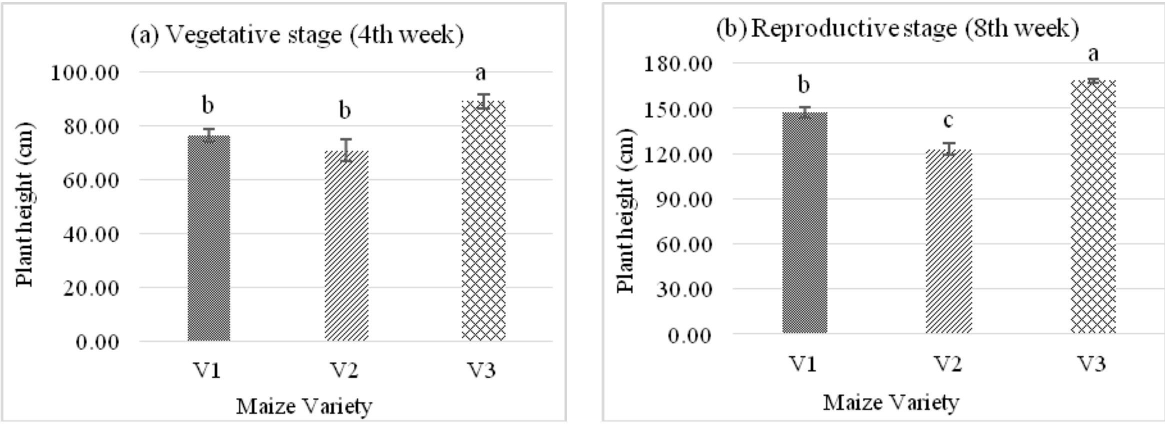

Figure 2. Changes of plant height at the vegetative stage (a) and reproductive stage (b) caused by maize varieties

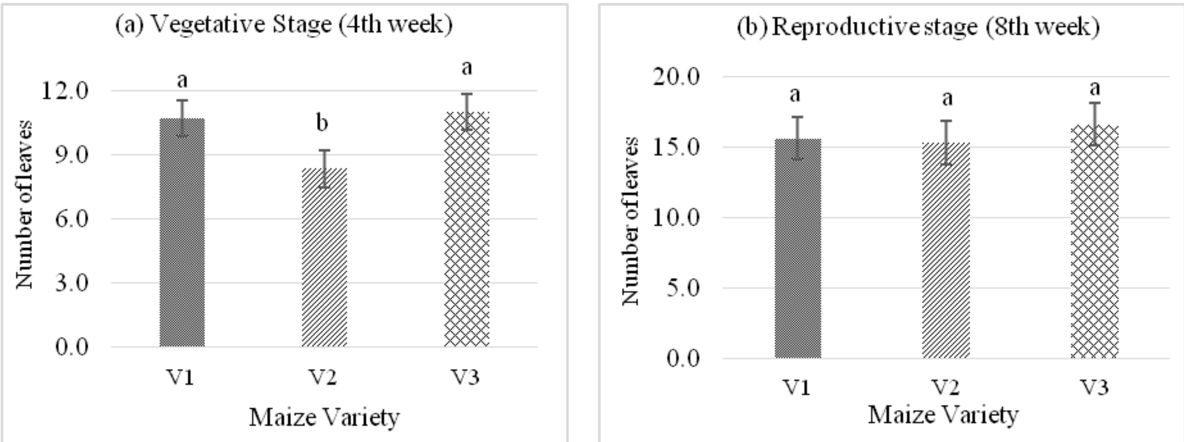

Figure 3. Effect of maize seed variety on the number of leaves at the vegetative stage (a) and the reproductive stage (b)

There's no significant difference found in cob numbers obtained for the varieties V1 (5.33), V2 (5.33) and V3 (6) of maize (Figure 4a). Although variety V3 (BARI Hybrid Maize-6) managed to produce a higher number of cobs than V1 (Agro vision) and V2 (Lal Teer (Hybrid Maize-Sultan)). V2 produced the lowest cob numbers per plot. Mean grain yield values obtained for the varieties were V1 (1.1 t ha^{-1}), V2 (0.99 t ha^{-1}) and V3 (1.51 t ha^{-1}). The highest and lowest grain yields were obtained with the V3 and V2 varieties (Figure 4b). BARI Hybrid Maize-6 (V3) produced significantly ($p<0.05$) higher grain yield compared with V1 and V2 but between these two varieties insignificant yield difference was found.

In the varietal test, BARI Hybrid Maize-6 resulted highest values at every growth and yield parameter among which plant height at both vegetative and reproductive stages, leaf number at vegetative stage and grain yield were significantly higher than Agro vision and Lal Teer (Hybrid Maize- Sultan). Agro Vision also produced significantly better values both in leaf number at the vegetative stage and plant height at the reproductive stage than Lal Teer (Hybrid Maize- Sultan). In literature, BARI Hybrid Maize-6 recorded with 9.0-9.5 t ha^{-1} in Rabi and 7.0-7.5 t ha^{-1} grain yield in *Kharif* season (Mia, 2017). In this experiment the estimated yield was much lower, which might be the impact of salinity, lower nutrients' availability and persistent water stagnation of the experimental field. These abiotic stresses impair essential physiological processes like water absorption, photosynthesis, respiration and nutrient uptake, ultimately leading to stunted growth and reduced grain production (Alomar and Jena, 2022; Iqbal et al., 2020). Waterlogging often exacerbates soil salinity problems, particularly in low-lying coastal areas, as poor drainage allows salts to accumulate in the root zone. The combination of water stress and salt stress can have more severe impacts on crop production. Liao et al. (2024) reported simultaneous occurrence of water stress and salt stress can impose compounded limitations on maize growth because both factors restrict water uptake and disrupt physiological processes such as reductions in photosynthesis, nutrient balance, and overall plant productivity. Although the yield did not match the general estimation, among all three varieties, the overall results in the varietal test experiment suggested BARI Hybrid Maize-6 as the better variety for coastal belt soil.

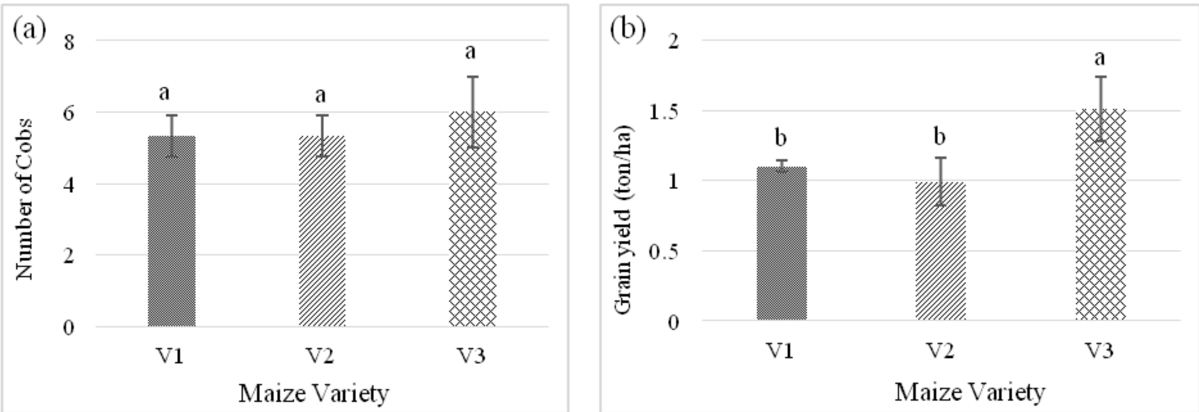

Figure 4. Changes in cob number (a) and grain yield (b) caused by different maize varieties

Effect of organic and inorganic fertilizer treatments on plant height

At the vegetative stage, all treatments except Sand1+INF and Sand3+INF resulted significantly ($p<0.05$) higher plant height compared to the control (Figure 5a). The maximum plant height was marked on CD3+INF (118.13 cm) which was also significantly higher than all the other treatments. Overall, different doses of cowdung applied with inorganic fertilizer plots recorded taller plants than other treatments. Control plots recorded with the shortest plant height (55.85 cm). At the reproductive stage, a similar trend was noticed with the tallest plant (181.74 cm) found in CD3+INF and overall taller plants at Cowdung applied with inorganic fertilizer plots (Figure 5b). Cowdung significantly improved maize plant height due to enhanced soil organic matter, greater water-holding capacity, improved root penetration and aeration. Under late recession of water, maize plants with cowdung maintain higher turgor pressure and continue internode elongation longer than the control which leads to taller and more vigorous plants. Similar observation was reported by Ederigbe et al., (2024) and recommended that combination of organic amendment with inorganic fertilizer resulted best growth for the maize plant.

Among quick compost with inorganic fertilizer applied plots, with increasing rate of inorganic fertilizer increased plant height was observed. QC+INF 2 also produced statistically similar results compared to cowdung applied plots. Here, again the shortest plant height (117.59 cm) was found in control plots. Quick compost provided partially decomposed organic matter and faster nutrient availability which stimulated rapid root, shoot and leaf growth. AyanfeOluwa (2019) reported that higher rates of accelerated compost consistently enhanced maize N, P, and K uptake. Rasul et al. (2025) also reported the combined use of biochar and compost significantly enhanced maize growth by increasing root and shoot fresh weight, total plant biomass, plant height, leaf number, leaf area, stem diameter, and dry weight. The authors also reported improvements in physiological traits, including chlorophyll content, reactive oxygen species, total free amino acids, and phenolic content (Rasul et al., 2025).

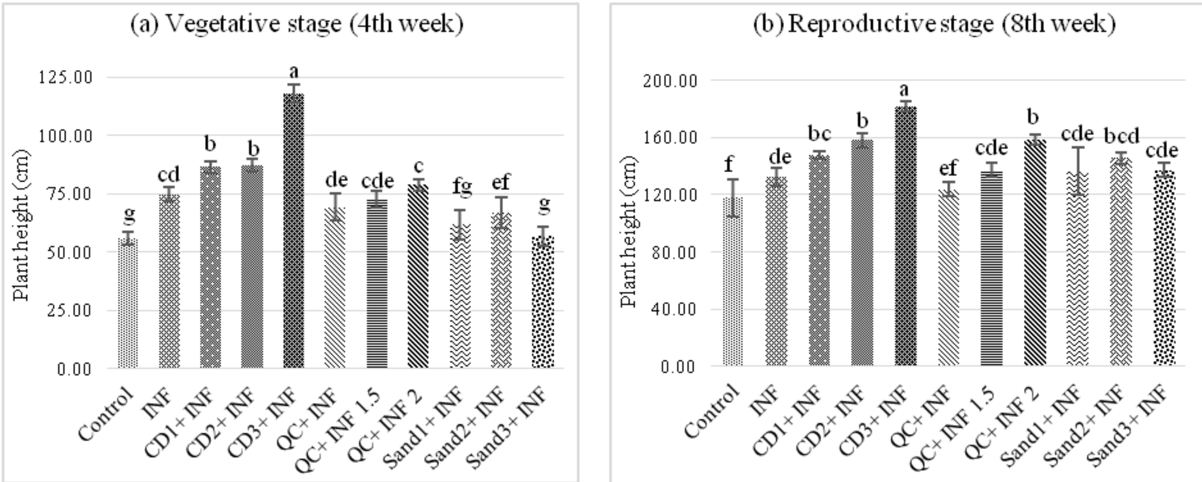

Figure 5. Effects on plant height at the vegetative stage (a) and reproductive stage (b) caused by treatments

Effect of organic and inorganic fertilizer treatments on leaf number

At the vegetative stage, although every treatment produced higher leaf numbers than control, only CD3+INF plots recorded (11.3) significant difference (Figure 6a). The lowest number of leaves was recorded (8) in control plots. Significant differences were observed at the reproductive stage too (Figure 6b) where again CD3+INF plots resulted highest leaf number (18.33) and the lowest value was recorded at the control (14.67). Both cowdung and quick compost associated with inorganic fertilizer similarly impacted on leaf numbers. At the reproductive stage, sand mixed with inorganic fertilizer-treated plot resulted better than quick compost. Sand-mix treatments were used to improve aeration which increased oxygen availability for root respiration, prevented root rot and improved early vigor. Wang et al. (2025) also reported how proper aeration impacted on plant's root-system health and improved growth and yield in their research. Organic amendments (cowdung/quick-compost) enhanced root–rhizosphere interactions, stimulating hormone production that promoted leaf development. Other hand, inorganic fertilizers ensured immediate nitrogen availability necessary for chlorophyll synthesis and leaf expansion. Together, they support the plant's physiological and biochemical processes needed for leaf formation, resulting in more leaves during both vegetative and reproductive stages compared to using inorganic fertilizer alone. Ananthi and Vennila (2021), also reported under the combined application of manure and recommended fertilizer dose improved growth parameters including greater plant height, more leaves per plant and higher leaf area index.

Effect of organic and inorganic fertilizer treatments on cob number and yield

Plots of cowdung applied with inorganic fertilizer recorded significantly ($p<0.05$) higher cob number and yield among all treatments (Figure 7a and 7b). With increasing doses of cowdung both cob number and yield increased accordingly. CD3+INF plots recorded the highest value for cob number per plot (8.33) and yield (3.61 t ha^{-1}) where control plots resulted in the lowest values of cob number (3.67) and yield (0.48 t ha^{-1}). CD2+INF (1.67 t ha^{-1}) and Sand2+INF (1.63 t ha^{-1}) both recorded statistically similar yields but significantly higher than quick compost with different doses of inorganic fertilizer applied to plots. In this study, integrated organic–inorganic fertilization increased cob number and maize yield. Organic matter improves soil structure, microbial activity, and nutrient-use efficiency, while inorganic fertilizers provide immediately available N and P for early vegetative and reproductive growth. The organic component (cowdung) enhanced cation exchange capacity and moisture retention, reducing nutrient losses and sustaining nutrient release during cob formation. This synergy optimized root development, promoted stronger tassel–silk synchronization, and ultimately resulted in more cobs and higher grain productivity than inorganic fertilizer alone. Germay and Gedebo (2020), Sachan et al. (2021), Bhattacharjya et al. (2024) all reported similarly that combination of organic manure with inorganic fertilizer yielded greater than organic or inorganic fertilizer alone.

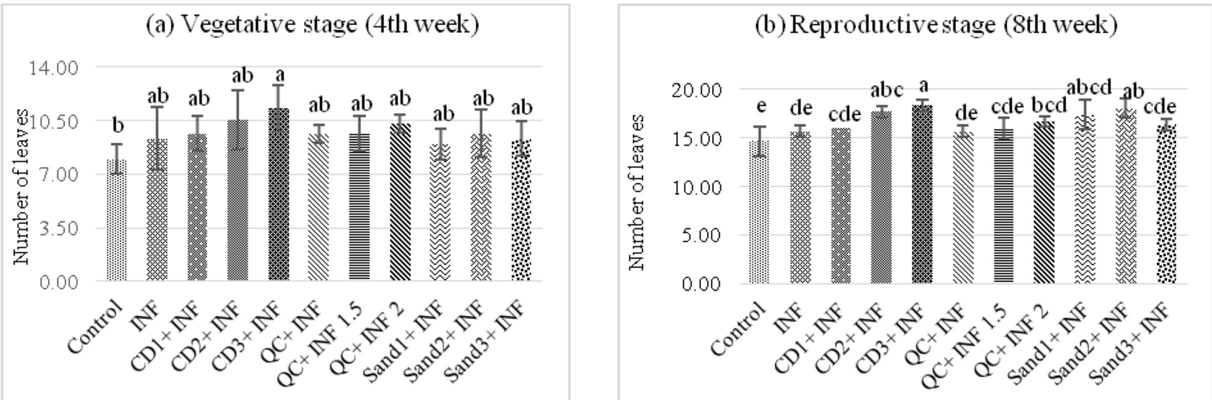

Figure 6. Effects on number of the leaves at the vegetative stage (a) and the reproductive stage (b) caused by treatments

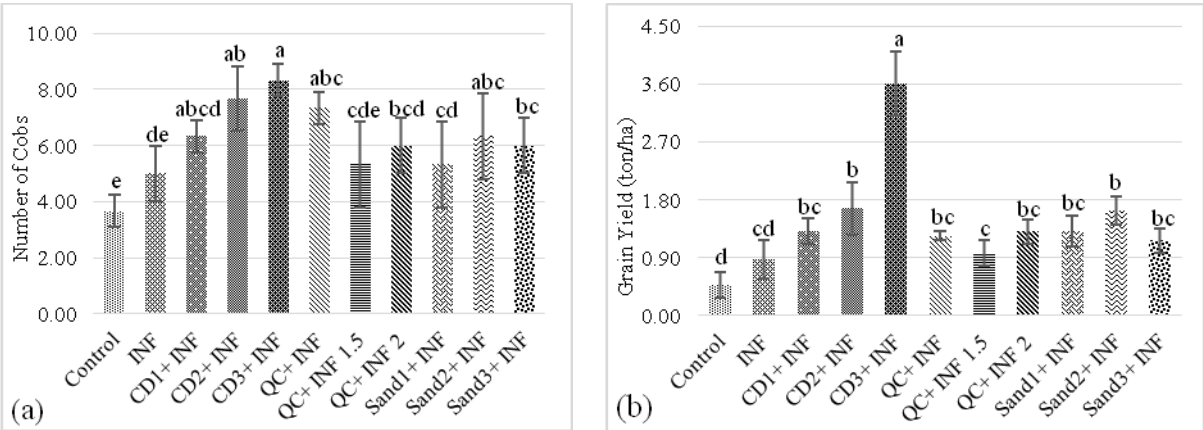

Figure 7. Effects on the number of cob (a) and yield (b) caused by treatments

CONCLUSION

Maize variety test reveals that 'BARI Hybrid Maize-6' produced higher growth (88.97 cm at vegetative stage and 168.33 cm at reproductive stage) and higher grain yield (1.51 t ha^{-1}). In both cases the performances of 'BARI Hybrid Maize-6' significantly differed from the performances of Agro Vision and Lal Teer (Hybrid Maize- Sultan). The study evaluating various treatments applied to BARI Hybrid Maize-6 found that combinations of cowdung and inorganic fertilizers significantly ($p < 0.05$) enhanced plant growth and yield compared to the other treatments. CD3+INF recorded best at all factors (plant height 118.13 cm and 181.74 cm, leaf number 11.33 and 18.33 at vegetative and reproductive stage respectively; cob number 8.33 and yield 3.61 t ha^{-1}). Next to 'cowdung plus inorganic fertilizers', quick compost plus inorganic fertilizer produced significantly higher growth (plant height, 158.33 cm) and Sand with inorganic fertilizer produced higher grain yield (1.63 t ha^{-1}) with reference to the growth (plant height) and yield of inorganic fertilizer only. Where only inorganic fertilizer produced 0.88 t ha^{-1} yield, combination of different doses of cowdung with inorganic fertilizer increased this rate by 1.5 to 4-fold. This much improvement happened on the growth and yield of maize by cowdung + inorganic fertilizer in only one season. With proper implementation of management treatment, the rate of growth and yield of maize can be increased manifold. Therefore, BARI Hybrid Maize-6 variety treated with cowdung+ inorganic fertilizer could be an option for coastal soil. Successive further studies on the field in different crop seasons should be conducted to establish this variety in the coastal region.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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