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Evaluating the Synergistic Impact of Water Practices, Gypsum, and Silicon on Potato Productivity in Salt-Affected Soils in Ganges Tidal Floodplain (AEZ-13)

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IN BANGLADESH, the soil salinity is the main factor reducing the overall yield of potatoes grown in the southwestern area. We evaluated the effect of water management practices and gypsum combined with silicon on improving potato yield under saline conditions. The experiment was carried out at two locations viz. Sadar and Kaliganj upazila of Satkhira district, Bangladesh. Most of the yield contributing characters and yield were significantly influenced with the application of mulching + recommended irrigation + 150 kg ha^{-1} gypsum + 150 kg ha^{-1} silicon (M3G1S1) treatment in both locations. In Sadar and Kaliganj upazila, the M3G1S1 treatment yielded the maximum tuber yield (22.36 t ha-1 and 21.70 t ha-1) and the lowest proline content (1.27 mg g^{-1} and 1.99 mg g^{-1} fresh weight), respectively. Conversely, in Sadar upazila, highest Na+: K+ ratio (1.25) and proline content (5.22 mg g-1 fresh weight) were observed in M0G0S0 (no mulching + no gypsum + no silicon) treatment. In Kaliganj upazila, the same treatment (M0G0S0) resulted in the highest Na+: K+ ratio (1.42) and proline content (5.75 mg g-1 fresh weight). In case of principal component analysis (PCA), the first two principal components (PCs) accounted 78.5 % of the total variation among the parameters in Sadar upazila, while in Kaliganj upazila, they explained 74.1 % of the total variation So, it can be concluded that mulching with irrigation and gypsum with silicon fertilization is an effective way in enhancing potato productivity in saline-affected area.

Keywords: Potato, Gypsum, Silicon, Salinity, Tuber Yield.

Introduction

Potato (Solanum tuberosum L.) holds a prominent position among the world's essential crops for the global economy. Potato tubers contain proteins, vitamin C, starch, fats, reducing sugars, dietary fiber, ascorbic acid, riboflavin and other major nutrients, and mineral elements such as potassium, iron, zinc, calcium, magnesium and vitamins (Han et al., 2023). Over 20 million hectares of potatoes are grown in 150 countries, with a total production of about 360 million tons, as a result, potatoes play a significant role in food security and production is predicted to double over the next ten years (Mickiewicz et al., 2022). According to BBS (2024), the total production and area were 10.6 million metric tons and 0.46 million hectares, respectively. In the context of an expanding global population, the best possible cultivation and production of potatoes, a significant food crop, is crucial to ensuring food security (Fan et al., 2023 and Paul et al., 2017). For the best growth and yield, potatoes need exceptionally particular soil characteristics, like loose structure, sufficient ventilation, and a high organic matter concentration (Park and Noh, 2011). The ideal pH range for potatoes is between 5.0 and 5.5, and soil salinity severely reduces potato yield (Kafi et al., 2019).

Jaarsma et al. (2013) stated that some detrimental effects that salinity stress has on potato plants were reduced growth of the stem, leaves, and decreased tuber yield. Mulch helps to maintain a stable soil temperature and enhances soil conditions, particularly by lowering water evaporation (Kar and Kumar, 2007). According to Lambert et al., (2001) there was a 49.3% increase in potato yield in the

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saline soil because of mulch. Straw mulching promotes overall plant health, increases root growth, and makes it easier for nutrients to be absorbed, all of which lead to an increase in potato yield (Singh et al., 2021 and Hasan et al., 2018). Additionally, it raises the surface layer soil temperature, increases soil moisture which promotes early potato tuber germination and earlier crop growth with larger yields (Mia et al., 2024 and Wang et al., 2009). On the other hand, by using slow infiltration and small-scale irrigation, drip irrigation also eliminates excess salt from the root zone, providing a desalination zone close to the emitter that has sufficient water and less salt, so establishing a low-salinity microenvironment that is ideal for plants' typical growth (El-Ghobashy et al., 2020, Amoah and Berko, 2020 and Burt and Isbell, 2005). Additionally, by encouraging salt drainage and enhancing soil pore structure, irrigation also lessens mechanical resistance on root growth and deep saline soil compaction (Zhao et al., 2024 and Salem, 2020). A traditional commercial fertilizer that contains both S and Ca is gypsum, which is rapidly absorbed by plants and has a relatively high solubility. Wright (1995) mentioned that calcium which comes from gypsum in the soil is important for potato tuber development, skin quality, and lowering the risk of internal tuber diseases also to reduce the salinity effects. In addition, the high nutrient content of gypsum promoted plant growth and enhanced crop emergence and yield in saline-alkaline soils (Halder et al., 2024 and Tao et al., 2021). Plants absorb silicon from the soil in the form of H4SiO4 or Si (OH)4 (monosilicic acid/orthosilicic acid), which is available to plants (Zargar et al., 2019). Since silicon is essential for reducing plant stress caused by factors such as high temperatures, freezing temperatures, droughts, salt stress, disease, and insect stress, among others, using it as a bio stimulant can enhance plant growth in stressful environments and boost crop yields (Malik et al., 2021). Hence, altering soil and plant elements and increasing silicon availability can be an alternative for reducing salinity-induced changes in plants (Mahdy et al., 2023 and Kaur et al., 2021). According to Zhu and Gong (2014), the mechanisms of salt stress mitigation mediated by Si include the maintenance of the water supply, enhancement of photosynthesis and decrease of transpiration rates. Research revealed that the application of soil silicon (Ca and Mg silicate) to potato plants increased plant height, decreased stem lodging, and increased tuber weight (Crusciol et al., 2009). An increase in the Si contents was also observed when gypsum was applied which may have displaced silicate from the adsorption sites, increasing the availability of that nutrient (Crusciol et al., 2014). Demo & Asefa Bogale (2024) analyzed that mulching and silicon improved soil moisture retention, maintaining higher organic matter and soil fertility, and improved crop yield. According to Ali et al. (2022) depending on the salt level of that specific place, applying gypsum and mulch can boost the production of maize in Bangladesh's saline areas. In Bangladesh soil salinity is the major problem that adversely affects the potato yield in the south-western region. Inadequate management practices and limited knowledge about the fertilizer functioning under salinity stress, are the major constraints in potato production. Because of these limitations, a field study was undertaken to evaluate the impact of water management practices and the application of gypsum combined with silicon on alleviating salt stress in potato production in the south-western region of Bangladesh.

Materials and Methods

Experimental site

The research was carried out at two locations: Labsa at Sadar upazila and Khamarpara at Kaligonj upazila of Satkhira district. The experimental field belongs to the non-calcareous grey floodplain soil under the AEZ-13 located in between 21°36' and 22°54' north latitudes and in between 88°54' and 89°20' east longitudes. Subsoils are neutral to mildly alkaline. General fertility level is high, with medium to high organic matter content.

Climate

The experimental area has a subtropical climate characterized by a hot season with high humidity from April to June, a hot, humid monsoon season with heavy rainfall from June to October, and a relatively cool and dry winter season from November to March. The average monthly air temperature, rainfall, relative humidity, and sunshine hour are presented in Table 1.

Sequencing

Amplified PCR products were purified using a PCR purification Kit (QIAquick®) according to the manufacturer's instructions. The Macrogen Company (South Korea) performed direct sequencing on the purified PCR product. The Gen Bank received the nucleotide sequence submissions. Using DNA-Man program V7, the arrangements were examined and compared with other sequences that were accessible in GenBank.

Table 1. Monthly record of temperature, relative humidity, rainfall and sunshine during the period from October 2023 to February 2024 at Satkhira district.

Month	Temperature			Average relative humidity %	Total rainfall (mm)	Sunshine(hrs)
	Maximum	Minimum	Average			
October	29.9°C	22.8°C	26°C	79%	135mm	11 h 37 m
November	28.2°C	7.81°C	22.9°C	70%	35mm	11 h 4 m
December	26°C	14.1°C	19.9°C	62%	6mm	10 h 46 m
January	25.4°C	12.6°C	19°C	54%	5.5mm	10 h 55 m

Source: Weather Station, Satkhira.

Treatments and design

The experiment comprised six levels of water management practices viz. no mulching (M_0), mulching (M_1), no mulching + one irrigation at stolon formation (M_2), mulching + recommended irrigation (during stolon formation and tuberization) (M_3), no mulching + recommended irrigation (M_4), mulching + one irrigation at tuberization (M_5), and four levels of gypsum combined with silicon fertilizer viz. no gypsum + no silicon (G_0S_0), no gypsum + 150 kg ha^{-1} silicon (G_0S_1), 150 kg ha^{-1} gypsum + no silicon (G_1S_0), 150 kg ha^{-1} gypsum + 150 kg ha^{-1} silicon (G_1S_1). The experiment was laid out in a split-plot design with three replications where water management is the main plot factor, and gypsum with silicon as sub-plot factor. The size of each plot was 10 m^2 (4 m × 2.5 m). The space between replication to replication was 1.0 m and plot to plot distance was 0.75 m. Same measurements were taken in both locations.

Soil sample collection and salinity level determination

The soil salinity level was measured by using the electrical conductivity (EC) method of Rhoades (1992). For the month of October, a representative soil sample was collected before tuber planting from both locations: Sadar upazila and Kaliganj upazila, ensuring it was free from large debris. For the rest of the month, soil data was collected at the end of each month till February. The sample was then mixed with distilled water in a 1:5 ratios in a beaker. The mixture was stirred thoroughly and allowed to settle for 30 minutes to extract soluble salts. After settling, the solution was filtered to obtain a clear extract. The EC meter was calibrated, and the electrical conductivity of the filtered solution was measured in deciSiemens per meter. The recorded EC value was analyzed to interpret the salinity level of the soil, with higher values indicating greater salinity. Salinity levels at both locations were monitored throughout the growing period (Figure 1).

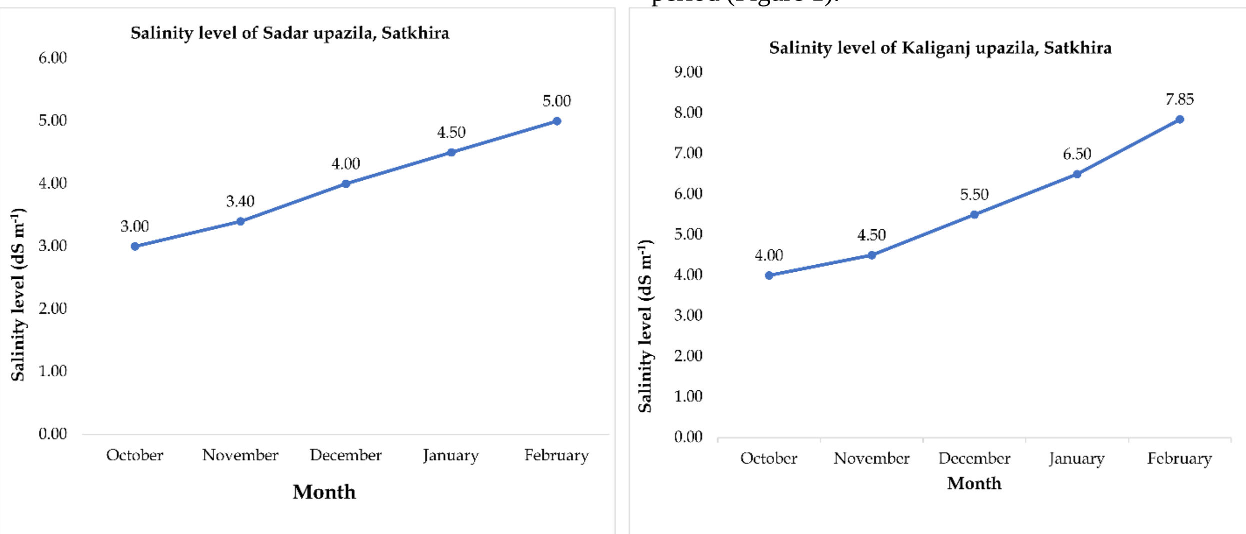

Fig. 1. Soil condition of the experimental field.
Source: Soil Resource and Development Institute (SRDI), Satkhira

Crop husbandry

The experimental land of two locations were first ploughed and cross ploughed with a tractor drawn disc plough and ploughed soil was brought into desirable tilth condition by the operations of harrowing. All kinds of uprooted weeds and previous crop residues were removed from the fields. After land preparation, it was fertilized with 275 kg ha-1 N, 290 kg ha-1 TSP, 60 kg ha-1 MoP, 7 kg ha-1 zinc sulfate, 6 kg ha-1 boric acid and 4 t ha-1 cowdung respectively. Paddy straw mulch was applied at a rate of 6 t ha^{-1} as per the experimental treatment (FRG, 2012). Gypsum and silicon fertilizer were applied at 150 kg ha^{-1} in the experimental plot, following the specific experimental treatment detailed in the layout during the final land preparation. The whole amount of TSP, MoP, and boron, zinc sulfate, boric acid and cowdung and two-third of urea were applied at the time of final land preparation. The rest amount of urea was applied in equal installment at 35 days after sowing (DAS) the potato tubers. Tubers of potato were sown in 2-3 cm deep furrows made by hand rake. After placement in furrow, tubers were covered with soil and followed by a light pressure by hand. Line to line spacing was 60 cm and seed to seed spacing was 15 cm in both locations. Weeding was controlled manually. Roguing And earthing up was done in the entire unit plots with special care. Irrigation was applied during stolon formation and tuberization which is recommended for potato cultivation. Haulm pulling was done manually and haulm yield was measured in the field carefully. After haulm pulling, the potatoes were in the field for 18 days to let the skins harden. Plants were infested with late blight (phytophthora infestans) to some extent which was successfully controlled by applying Robral (0.2%) @ 10 ml /10 L of water for 5 decimal lands.

Determination of Na+: K+ (ratio)

The Na+: K+ ratio in potato leaves under saline conditions was determined using a modified method of Kordrostami et al. (2017). Fresh, young expanded leaves were dried at 60–70°C for 48 hours, ground into a fine powder, and 1.0 g of the sample was digested with 10 mL concentrated nitric acid. After pre-digestion (30 min), the mixture was heated in a microwave digester until clear, cooled, and diluted with deionized water. Sodium (Na+) and potassium (K+) concentrations were measured using an atomic absorption spectrometer at 589 nm and 766 nm, respectively. The Na+: K+ ratio was calculated by dividing Na+ concentration by K+ concentration.

Determination of proline content (mg g-1 fresh weight)

The proline content in potato leaves under saline conditions was estimated using a modified method of Bates et al., (1973). Fresh, young expanded leaves (0.1 g) were homogenized in 10 mL of 3% sulfosalicylic acid, and the extract was centrifuged at 10,000 rpm for 10 minutes. A 2 mL supernatant aliquot was mixed with 2 mL of acid ninhydrin and 2 mL of glacial acetic acid, incubated at 100°C for 1 hour, then cooled in an ice bath. The chromophore was extracted with 4 mL of toluene, and absorbance was measured at 520 nm. Proline content was determined using a standard curve and expressed as mg g^{-1} fresh weight.

Harvesting

The maturity of the crop was determined when 80% of the leaf became yellowish brown. After 18 days of haulm pulling, harvesting was done manually on 5th February 2024 at Sadar upazila and on 6th February 2024 at Kaliganj upazila. All the precautions were taken during potato harvesting to avoid tuber injury at both locations.

Data collection parameter

Data on different growth parameters viz. plant height (ph), number of tubers plant-1 (tnpp), tuber length (tl), tuber periphery (tp), tuber weight plant-1 (twpp), tuber weight per m2 (twpms), haulm yield (hy), tuber yield (ty), Na: K (NaK) and proline content (pc) yield and yield contributing characters were recorded from both locations.

Procedure of Data Collection
Plant height (cm)

Plant height was measured from the ground level to the tip of the longest stem at physiological maturity. Five plants were chosen at random from each plot unit and mean value was calculated.

Number of tubers plant-1

The number of tubers plant-1 was counted from each unit plot. Data were recorded from plants selected at random from the row of each plot during harvesting.

Tuber length (cm)

Tuber length of selected plants from each plot were counted and then mean were expressed as plant-1 basis. Data were recorded as the average of five plants selected at random from the inner rows of each plot.

Tuber periphery (cm)

Tuber periphery data was taken from randomly selected five plants from each plot and the mean periphery length was expressed on plant-1 basis.

Tuber weight plant-1 (g)

Tuber weight plant-1 was recorded from randomly selected five plants at the time of harvest. Data were recorded as the average of five tubers from each plot.

Tuber weight (kg m^{-2})

Tuber weight of 1 m2 area were counted from each unit plot, and weights were converted into kg m^{-2}.

Tuber yield (t ha-1)

Tubers collected from 10 m2 (4.0 m × 2.5 m) of each plot was cleaned. The tuber's weight was taken and converted into the yield in t ha-1.

Haulm yield (t ha-1)

For calculating haulm yield, from each individual plot, 10-meter land was selected from where the tubers are weighed for tuber yield and the plant covered in 10 meter was weighed for haulm yield. The 10-meter haulm yield then converted into ton per hectare.

Data analysis

Data were compiled and tabulated in proper form for statistical analysis which was carried out in the statistical software R version 3.4.1. Data management and graph preparation were done using MS Office Excel®. Various statistical tests such as the two-factor ANOVA test, mean performance, correlation coefficient, and PCA analyses were performed through opensource statistical platform 'R' (R Core Team, 2022).

Results:

Plant Height (cm)
Effect of water management practices

In Sadar upazila, plant height was found to increase significantly with the water management parameters. The highest plant height (52.77 cm) was observed in M3 (mulching + recommended irrigation) treatment and the lowest plant height (43.58 cm) was observed from M0 (no mulching) treatment (Table 2 and Table 6). Similarly, in Kaliganj upazila, plant height was found to increase significantly with the water management parameters. The highest plant height (58.88 cm) was recorded and the lowest plant height (53.64 cm) was recorded from the same treatment as Sadar upazila (Table 2 and Table 7).

Effect of gypsum with silicon

In Sadar upazila, highest plant height (50.85 cm) was observed in G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and the lowest plant height (47.40 cm) was observed from G1S0 (150 kg ha-1 gypsum + no silicon) treatment. which was statically identical with G0S0 (no gypsum + no silicon) treatment (Table 3 and Table 6). In Kaliganj upazila, the highest plant height (61.21 cm) was recorded from the application of G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and the lowest plant height (52.84 cm) was found in control treatment G0S0 (no gypsum and no silicon) (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the highest plant height (54.44 cm) was found from the M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. And the lowest plant height (40.38 cm) was observed from the control M0G0S0 (no mulching + no gypsum + no silicon) treatment (Table 4 and Table 6). In Kaliganj upazila, the highest plant height (54.44 cm) was found and the lowest plant height (40.38 cm) was observed from the same treatment as Sadar upazila (Table 5 and Table 7).

Number of Tubers Plant-1
Effect of water management practices

In Sadar upazila, the maximum number of tubers plant-1 (6.40) was recorded from the application of M3 (mulching + recommended irrigation) treatment. The minimum number of tubers plant-1 (3.55) was recorder from the control M0 (no mulching) treatment (Table 2 and Table 6). In Kaliganj upazila, the maximum number of tubers plant-1 (5.28) was found and the minimum number of tubers plant-1 (3.86) was found from the same treatment as Sadar upazila (Table 2 and Table 7).

Effect of gypsum with silicon

In Sadar upazila, application of gypsum with silicon significantly increases the number of tubers plant-1. The application of G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted in the maximum number of tubers plant-1 (5.53). The minimum number of tubers plant-1 (4.46) was found with the application of control (G0S0) (no gypsum + no silicon) treatment (Table 3 and Table 6). Whereas, in Kaliganj upazila, the maximum number of tubers plant-1 (5.14) and the minimum number of tubers plant-1 (4.12) was found from the following treatments (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the number of tubers plant-1 of potato were influenced by the interaction effect of water management practices and gypsum with silicon. The treatment M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) resulted the maximum number of tubers plant-1 (7.25). The minimum number of tubers plant-1 (3.25) was observed from M0G0S0 (no mulching + no gypsum + no silicon) treatment (Table 4 and Table 6). Whereas, in Kaliganj upazila, the highest number of tubers plant-1 (6.60) and the lowest number of tubers plant-1 (3.46) was observed from the following treatments (Table 5 and Table 7).

Tuber Length (cm)
Effect of water management practices

In Sadar upazila, the treatment M3 (no mulching) showed the highest tuber length (10.56 cm) and the lowest tuber length (7.58 cm) was observed from M0 (no mulching) treatment (Table 2 and Table 6). whereas, in Kaliganj upazila, the highest tuber length (9.16 cm) and the lowest tuber length (7.97 cm) was found from following treatment (Table 2 and Table 7).

Effect of gypsum with silicon

In Sadar upazila, analysis of variance showed that tuber length was significantly influenced by the treatments. The highest tuber length (9.13 cm) was recorded from G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and the lowest tuber length (8.00 cm) was observed from the treatment G0S0 (no gypsum + no silicon) (Table 3 and Table 6). In kaliganj upazila, the highest tuber length (8.97 cm) was recorded from the application of G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. The lowest tuber length (8.14 cm) was found in G1S0 (150 kg ha-1 gypsum + no silicon) treatment which was statistically identical with G0S0 (no gypsum + no silicon) treatment (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the maximum tuber length (12.48 cm) was found from M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and the minimum tuber length (9.55 cm) was found from M0G0S0 (no mulching + no gypsum + no silicon) treatment (Table 4 and Table 6). Whereas, in Kaliganj upazila, the highest tuber length (10.22 cm) and the lowest tuber length (6.7 cm) was observed from the following treatments (Table 5 and Table 7).

Tuber Periphery (cm)
Effect of water management practices

In Sadar upazila, potato tuber periphery resulted highest (15.51 cm) when M3 (mulching + recommended irrigation) treatment was applied. And the lowest tuber periphery of potato was observed when M0 (no mulching) treatment was applied which resulted (10.54 cm) tuber periphery (Table 2 and Table 6). In Kaliganj upazila, also the highest tuber periphery (15.38 cm) was recorded and the lowest tuber periphery (12.04 cm) was recorded from the same treatment (Table 2 and Table 7).

Effect of gypsum with silicon

In Sadar upazila, the maximum tuber periphery (14.16 cm) was found from G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and minimum tuber periphery (12.81 cm) was found from G0S0 (no gypsum + no silicon) treatment (Table 3 and Table 6). In Kaliganj upazila, the highest tuber periphery (15.54 cm) was recorded and the lowest tuber periphery (13.80 cm) was found from the same treatment (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the treatment M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted the highest tuber periphery (17.48 cm) and the lowest tuber periphery (9.55 cm) was observed from M0G0S0 (no mulching + no gypsum + no silicon) treatment (Table 4 and Table 6). In Kaliganj upazila, the highest tuber periphery (16.44 cm) was observed, and the lowest tuber periphery (10.89 cm) was observed from the same treatment as Sadar upazila (Table 5 and Table 7).

Tuber Weight Plant-1 (g)
Effect of water management practices

In Sadar upazila, application of M3 (mulching + recommended irrigation) treatment produce the maximum tuber weight plant-1 (411.91 g). Also, with the application of M0 (no mulching) treatment resulted the minimum tuber weight plant-1 (255.58 g) (Table 2 and Table 6). In Kaliganj upazila, in this experiment the significant variation of tuber weight plant-1 (g) was observed due to different levels of water management practices. The highest tuber weight plant-1 (340.91 g) was recorded and the lower tuber weight plant-1 (184.58 g) was recorded from the same treatment as Sadar upazila (Table 2 and Table 7). From the observed data, in Sadar upazila 61.16% and in Kaliganj upazila 84.69% increased tuber weight plant-1 was found with the application of mulching with recommended irrigation (M3) treatment over control (M0).

Effect of gypsum with silicon

In Sadar upazila, G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted the maximum tuber weight plant-1 (325.72 g) and the application of G0S0 (no gypsum + no silicon) treatment showed the minimum tuber weight plant-1 (294.55 g). Similarly, in Kaliganj upazila, the highest tuber weight plant-1 (g) (254.72 g) and the lower tuber weight plant-1 ((223.55 g) was recorded from the following treatments (Table 3 and Table 6). In Sadar upazila 10.58% increased tuber weight plant-1 was found with the application of 150 kg ha-1 gypsum with 150 kg ha-1 silicon (G1S1) treatment and in Kaliganj upazila 13.94% increased tuber weight plant-1 found in the same treatment over control (G0S0) (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the maximum tuber weight plant-1 (436.67 g) was found from M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. The minimum tuber weight plant-1 (232.66 g) was found from M0G0S0 (no mulching + no gypsum + no silicon) treatment (Table 4 and Table 6). In Kaliganj upazila, M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted the highest tuber weight plant-1 (365.67 g) and the lowest tuber weight plant-1 (161.66 g) was observed from the same treatment as Sadar upazila (Table 5 and Table 7). With the applicaton of mulching with recommended irrigation and 150 kg ha-1 gypsum with 150 kg ha-1 silicon (M3G1S1) resulted 87.68% increased tuber weight plant-1 in Sadar upazila and 126.19% increased tuber weight plant-1 in Kaliganj upazila over control (M0G0S0).

Tuber Weight (kg m-2)
Effect of water management practices

In Sadar upazila, application of M3 (mulching + recommended irrigation) treatment produced the maximum tuber weight (1.82 kg m-2). And with the application of M0 (no mulching) treatment resulted in the minimum tuber weight (1.15 kg m-2) (Table 2 and Table 6). In Kaligang upazila, with respect to the tuber weight (kg m-2) of potato, significant variation was observed due to different level of water management practices. The highest tuber weight (1.57 kg m-2) was recorded and also the lowest tuber weight (1.14 kg m-2) was recorded from the same treatrment as Sadar upazila. (Table 2 and Table 7). From the observed data, in Sadar upazila 58.26% and in Kaliganj upazila 37.72% increased tuber weight per m2 was found with the application of mulching with recommended irrigation (M3) treatment over control (M0).

Effect of gypsum with silicon

In Sadar upazila, the tuber weight was influenced by all treatments over control. The highest tuber weight (1.69 kg m-2) was recorded from the treatment G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) and the lowest tuber weight (1.45 kg m-2) was recorded from the G0S0 (no gypsum + no silicon) treatment (Table 3 and Table 6). In Kaliganj upazila, the highest tuber weight (1.53 kg m-2) was recorded and the lowest tuber weight (1.30 kg m-2) was recorded from the same treatment (Table 3). In Sadar upazila 16.55% increased tuber weight per m2 was found with the application of 150 kg ha-1 gypsum with 150 kg ha-1 silicon (G1S1) treatment and in Kaliganj upazila 17.69% increased tuber weight per m2found in the same treatment over control (G0S0) (Table 3 and Table 7).

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment produced the maximum tuber weight (2.23 kg m-2). On the other hand, M0G0S0 (no mulching + no gypsum + no silicon) treatment resulted in the minimum tuber weight (1.09 kg m-2) (Table 4 and Table 6). In Kaliganj upazila, the highest tuber weight (1.93 kg m-2) was recorded and the lowest tuber weight (1.09 kg m-2) was observed from the same treatment as Sadar upazila (Table 5 and Table 7). With the applicaton of mulching with recommended irrigation and 150 kg ha-1 gypsum with 150 kg ha-1 silicon (M3G1S1) treatment resulted 104.58% increased tuber weight per m2 in Sadar upazila and 77.06% increased tuber weight per m2 in Kaliganj upazila over control (M0G0S0).

Haulm Yield (t ha-1)
Effect of water management practices

In Sadar upazila, application of M3 (mulching + recommended irrigation) treatment produced the maximum haulm yield (2.92 t ha-1) and with the application of M0 (no mulching) treatment resulted the minimum haulm yield (1.85 t ha-1) (Table 2 and Table 6). In Kaligang upazila, the highest tuber haulm yield (2.36 t ha-1) was recorded and also the lowest haulm yield (1.79 t ha-1) was recorded from the same treatment (Table 2 and Table 7).

Table 2. Effect of water management practices on yield and yield contributing parameters of potato at a) Sadar upazila and b) Kaliganj upazila.

	Sadar upazila							Kaliganj upazila						
Water management practices	Plant height (cm)	Tuber plant^{-1} (no.)	Tuber length (cm)	Tuber periphery (cm)	Tuber weight plant^{-1} (g)	Tuber weight (kgm^{-2})	Haulm Yield (t ha^{-1})	Plant height (cm)	Tuber plant^{-1} (no.)	Tuber length (cm)	Tuber periphey (cm)	Tuber weight plant^{-1} (g)	Tuber weight (kg m^{-2})	Haulm Yield (t ha^{-1})
M0	43.58c	3.55e	7.58d	10.54e	255.58d	1.15e	1.85d	53.74c	3.86c	7.97c	12.04c	184.58d	1.14c	1.79c
M1	51.67a	4.43d	8.50bc	14.15bc	337.41b	1.49d	2.39c	58.63ab	4.62b	8.70ab	15.38a	266.41b	1.48a	2.25a
M2	47.14b	4.88c	8.69b	12.51d	249.58d	1.55cd	2.49c	56.31abc	4.71ab	8.05bc	15.33a	178.58d	1.37b	2.09b
M3	52.77a	6.40a	10.56a	15.51a	411.91a	1.82a	2.92a	58.88a	5.28a	9.16a	15.07a	340.91a	1.57a	2.36a
M4	48.25b	5.70b	7.66cd	14.44b	278.33c	1.62bc	2.6b	56.02bc	4.54b	8.13bc	13.95b	207.33c	1.37b	2.10b
M5	46.94b	5.56b	8.55bc	13.60c	336.00b	1.68b	2.7b	58.59ab	4.26bc	8.66ab	15.81a	265.00b	1.48a	2.25a
Level of significance CV (%)	** 5.18	* 15.68	* 8.69	** 8.30	** 3.82	** 7.08	***4.86	** 3.62	** 3.44	** 11.49	** 5.48	** 2.94	** 5.10	**6.39

* = Significant at 5% level of probability, ** = Significant at 1% level of probability, NS = Not significant, M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization.

Effect of gypsum with silicon

In Sadar upazila, the haulm yield was influenced by all treatments over control. The highest haulm yield (2.71 t ha-1) was recorded from the treatment G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon). The lowest haulm yield (2.32 t ha-1) was recorded from the G0S0 (no gypsum + no silicon) treatment (Table 3 and Table 6). In Kaliganj upazila, the highest haulm yield (2.27 t ha-1) was recorded and the lowest haulm yield (2.03 t ha-1) was recorded from the same treatment (Table 3 and Table 7).

Table 3. Effect of gypsum with silicon on yield and yield contributing parameters of potato at Sadar upazila and Kaliganj upazila.

	Sadar upazila							Kaliganj upazila						
Gypsum with silicon	Plant height (cm)	Tuber plant^{-1} (no.)	Tuber length (cm)	Tuber periphey (cm)	Tuber weight plant-1 (g)	Tuber weight (kg m-2)	Haulm Yield (t ha^{-1})	Plant height (cm)	Tuber plant-1 (no)	Tuber length (cm)	Tuber periphey (cm)	Tuber weight plant^{-1} (g)	Tuber weight (kg m-2)	Haulm Yield (t ha^{-1})
G0S0	47.86b	4.46c	8.00b	12.81c	294.55d	1.45c	2.32c	52.84c	4.12c	8.31b	13.80b	223.55d	1.30c	2.03c
G0S1	47.46b	5.13b	8.27b	13.30bc	308.94c	1.51c	2.42c	57.02b	4.43bc	8.36ab	14.10b	237.94c	1.37b	2.11b
G1S0	47.40b	5.22b	8.96a	13.56ab	316.66b	1.57b	2.52b	57.06b	4.51b	8.14b	14.95a	245.66b	1.41b	2.15b
G1S1	50.85a	5.53a	9.13a	14.16a	325.72a	1.69a	2.71a	61.21a	5.14a	8.97a	15.54a	254.72a	1.53a	2.27a
Level of significance CV (%)	**5.92	**3.47	**9.05	**6.59	**3.29	**5.77	***5.77	**4.67	**10.16	**11.36	**7.62	**4.27	**7.21	**6.10

* = Significant at 5% level of probability, ** = Significant at 1% level of probability, NS = Not significant, G_0S_0 = No gypsum + no silicon, G_0S_1 = No gypsum + 150 kg ha^{-1} silicon, G_1S_0 = 150 kg ha^{-1} gypsum + no silicon, G_1S_1 = 150 kg ha^{-1} gypsum + 150 kg ha^{-1} silicon.

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment produced the maximum haulm yield (3.58 t ha-1). On the other hand, M0G0S0 (no mulching + no gypsum + no silicon) treatment resulted the minimum haulm yield (1.76 t ha-1) (Table 4 and Table 6). In Kaliganj upazila, highest tuber weight (2.82 t ha-1) and the lowest tuber weight (1.76 t ha-1) was observed from the same treatments as Sadar upazila (Table 5 and Table 6).

Table 4. Interaction effect of water management practices and gypsum with silicon on yield and yield contributing parameters of potato at Sadar upazila.

Water management practices	Gypsum × Silicon	Plant height (cm)	Tuber plant-1 (no.)	Tuber length (cm)	Tuber periphery (cm)	Tuber weight plant-1 (g)	Tuber weight (kg m-2)	Haulm Yield (t ha^{-1})
M0	G0S0	40.38i	3.25q	7.00l	9.55i	232.66k	1.09k	1.76j
	G0S1	40.56i	3.52pq	7.88g-l	10.47hi	253.33ij	1.13k	1.82j
	G1S0	45.85fgh	3.63op	7.88g-l	10.67hi	263.00hi	1.18k	1.89j
	G1S1	47.54c-g	3.82no	7.55jkl	11.49gh	273.33gh	1.21k	1.94j
M1	G0S0	51.11a-e	3.98mn	7.77h-l	13.61c-f	325.66ef	1.41j	2.26i
	G0S1	50.56a-f	4.19m	8.11f-l	13.55c-f	335.00def	1.45ij	2.33hi
	G1S0	52.90ab	4.62l	8.88c-i	14.56bcd	340.00de	1.48hij	2.38ghi
	G1S1	52.11abc	4.94jk	9.22b-f	14.88bc	349.00d	1.62c-h	2.59c-g
M2	G0S0	46.56efg	4.14m	8.54d-j	12.40fg	239.00jk	1.49g-j	2.39ghi
	G0S1	48.67b-g	5.18hij	9.11b-g	12.48fg	243.33jk	1.52f-j	2.44f-i
	G1S0	46.11fgh	4.93jk	9.00b-h	12.52fg	252.67ij	1.56e-i	2.51e-h
	G1S1	47.24d-g	5.28ghi	8.11f-l	12.65fg	263.33hi	1.63c-h	2.60c-g
M3	G0S0	52.56ab	5.44gh	9.71bcd	13.66c-f	374.00c	1.60d-i	2.56d-h
	G0S1	52.66ab	6.26c	9.85bc	15.33b	413.33b	1.70b-e	2.73b-e
	G1S0	51.44a-d	6.64b	10.22b	15.55b	423.67ab	1.76bc	2.82bc
	G1S1	54.44a	7.25a	12.48a	17.48a	436.67a	2.23a	3.58a
M4	G0S0	47.66c-g	4.88kl	7.33jkl	13.33def	274.00gh	1.53f-j	2.44f-i
	G0S1	47.22d-g	5.88de	7.44jkl	14.22b-e	276.67gh	1.60d-i	2.56d-h
	G1S0	46.44efg	5.95de	8.33e-k	14.66bcd	279.00gh	1.70b-e	2.73b-e
	G1S1	51.66a-d	6.10cd	7.55jkl	15.55b	283.66g	1.66b-f	2.66b-f
M5	G0S0	48.88b-g	5.08ijk	7.66i-l	14.33b-e	322.00f	1.58e-i	2.54e-h
	G0S1	45.11ghi	5.78ef	7.22kl	13.77c-f	332.00def	1.63c-g	2.61c-g
	G1S0	41.67hi	5.55fg	9.44b-e	13.44c-f	341.66de	1.74bcd	2.79bcd
	G1S1	52.11abc	5.83def	9.89bc	12.89efg	348.33d	1.79b	2.87b
	Level of significance	*	**	**	*	*	**	**
	CV (%)	5.92	3.47	9.05	6.59	3.29	5.77	5.77

* = Significant at 5% level of probability, ** = Significant at 1% level of probability, M_0 = No mulching, M_1 = Mulching, M_2 = No mulching + one irrigation at stolon formation, M_3 = Mulching + recommended irrigation, M_4 = No mulching + recommended irrigation, M_5 = Mulching + one irrigation at tuberization, G_0S_0 = No gypsum + no silicon, G_0S_1 = No gypsum + 150 kg ha^{-1} silicon, G_1S_0 = 150 kg ha^{-1} gypsum + no silicon, G_1S_1 = 150 kg ha^{-1} gypsum + 150 kg ha^{-1} silicon.

Tuber Yield (t ha^{-1})

Effect of water management practices

In Sadar upazila, application of M3 (mulching + recommended irrigation) treatment produce the maximum tuber yield (18.27 t ha-1). Also, with the application of M0 (no mulching) treatment resulted the minimum tuber yield (11.57 t ha-1) (Figure 2a and Table 6). In Kaligang upazila, with respect of tuber yield of potato, significant variation was observed due to different level of water management practices. The highest yields were obtained in the M1, M3, and M5 treatments, which were statistically similar. The highest tuber yield (18.17 t ha-1) was recorded from the M3 (mulching + recommended irrigation) treatment. In addition, the lowest (13.82 t ha-1) tuber yield was recorded from M0 (no mulching) treatment (Figure 2b and Table 7). From the observed data, in Sadar upazila 57.90% and in Kaliganj upazila 31.38% increased tuber yield was found with the application of mulching with recommended irrigation (M3) treatment over control (M0).

Table 5. Interaction effect of water management practices and gypsum with silicon on yield and yield contributing parameters of potato at Kaliganj upazila.

Water Management practices	Gypsum ×Silicon	Plant height (cm)	Tuber plant^{-1} (no.)	Tuber length (cm)	Tuber periphery (cm)	Tuber weight plant^{-1} (g)	Tuber weight (kg m^{-2})	Haulm Yield (t ha^{-1})
M0	G0S0	50.60m	3.46h	6.77h	10.89g	161.66k	1.09l	1.76k
	G0S1	51.68lm	3.73fgh	8.44b-g	11.00fg	182.33ij	1.11l	1.81jk
	G1S0	52.92j-m	3.80fgh	7.66d-h	12.07efg	192.00hi	1.15kl	1.74k
	G1S1	59.78b-g	4.26defg	9.00a-e	14.22bcd	202.33gh	1.21jkl	1.88ijk
M1	G0S0	56.22f-k	3.66gh	8.67a-g	14.88abc	254.66ef	1.45c-i	2.27b-f
	G0S1	60.11b-f	4.40d-g	9.06a-d	15.44ab	264.00def	1.46c-i	2.20c-h
	G1S0	61.78abc	4.86cde	8.55b-g	16.11a	269.00de	1.50b-f	2.21c-h
	G1S1	57.44c-i	5.77b	8.54b-g	15.11abc	278.00d	1.53b-e	2.31b-e
M2	G0S0	51.60lm	4.46def	8.44b-g	15.44ab	168.00jk	1.33g-j	2.06f-i
	G0S1	56.22f-k	5.40bc	7.33fgh	14.77abc	172.33jk	1.35f-j	2.15c-h
	G1S0	56.56e-j	4.40d-g	7.44e-h	14.77abc	181.67ij	1.40d-i	2.04ghi
	G1S1	60.88b-e	4.60de	9.67ab	16.33a	192.33hi	1.40d-i	2.13d-h
M3	G0S0	53.44i-m	5.00cd	7.22gh	13.37cde	303.00c	1.31h-k	2.02hij
	G0S1	56.33f-j	4.13e-h	8.88a-f	14.91abc	342.33b	1.49c-g	2.25c-g
	G1S0	58.77b-h	5.40bc	8.33b-h	15.55ab	352.67ab	1.57bc	2.36bc
	G1S1	66.00a	6.60a	10.22a	16.44a	365.67a	1.93a	2.82a
M4	G0S0	51.81klm	4.40d-g	8.67a-g	11.98efg	203.00gh	1.33g-j	2.04ghi
	G0S1	55.66g-l	4.66cde	7.11gh	12.83def	205.67gh	1.37e-j	2.10e-h
	G1S0	55.33h-l	4.33d-g	8.00c-h	15.33ab	208.00gh	1.32h-k	2.24c-g
	G1S1	61.27bcd	4.80cde	8.11b-h	15.66ab	212.66g	1.48c-h	2.03ghi
M5	G0S0	53.36i-m	3.73fgh	9.44abc	16.22a	251.00f	1.30ijk	2.01hij
	G0S1	62.11ab	4.26d-g	9.33abc	15.64ab	261.00def	1.44c-i	2.20c-h
	G1S0	57.00d-j	4.26d-g	9.55abc	15.88ab	270.66de	1.54bcd	2.32bcd
	G1S1	61.92ab	4.80cde	8.33b-h	15.51ab	277.33d	1.66b	2.48b
	Level of significance	*	**	*	*	*	*	**
	CV (%)	4.67	10.16	11.36	7.62	4.27	7.21	6.10

* = Significant at 5% level of probability, ** = Significant at 1% level of probability, NS = Not significant, M_0 = No mulching, M_1 = Mulching, M_2 = No mulching + one irrigation at stolon formation, M_3 = Mulching + recommended irrigation, M_4 = No mulching + recommended irrigation, M_5 = Mulching + one irrigation at tuberization, G_0S_0 = No gypsum + no silicon, G_0S_1 = No gypsum + 150 kg ha^{-1} silicon, G_1S_0 = 150 kg ha^{-1} gypsum + no silicon, G_1S_1 = 150 kg ha^{-1} gypsum + 150 kg ha^{-1} silicon.

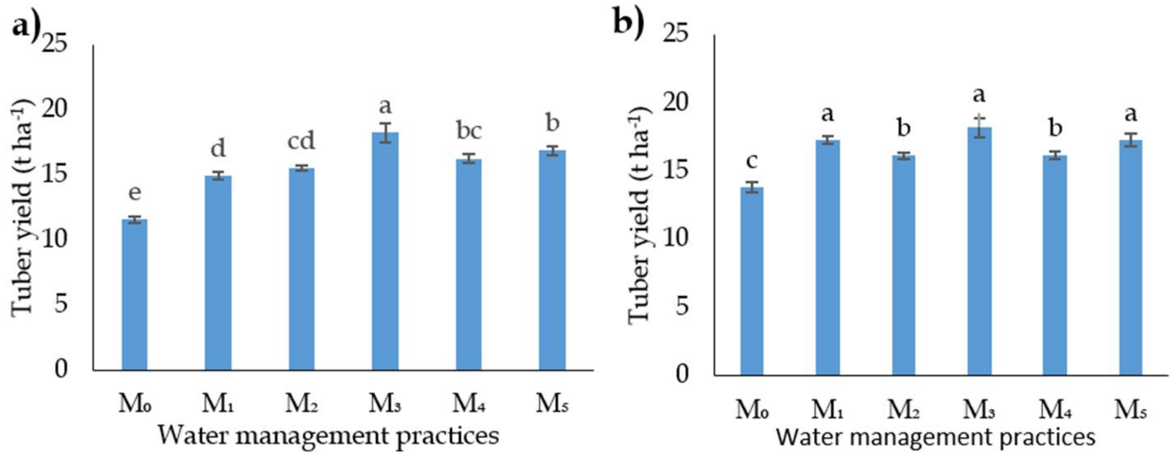

Fig. 2. Effect of water management practices on tuber yield of potato at a) Sadar upazila and b) Kaliganj upazila.

M_0 = No mulching, M_1 = Mulching, M_2 = No mulching + one irrigation at stolon formation, M_3 = Mulching + recommended irrigation, M_4 = No mulching + recommended irrigation, M_5 = Mulching + one irrigation at tuberization.

Effect of gypsum with silicon

In Sadar upazila, All the treatments were significantly increased the tuber yield (t ha-1) over control. The highest tuber yield (16.93 t ha-1) was recorded from the treatment G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) and the lowest tuber yield (14.54 t ha-1) was recorded from the G0S0 (no gypsum + no silicon) treatment (Figure 3a and Table 6). In Kaliganj upazila, the highest tuber yield (17.50 t ha-1) and the lowest tuber yield (15.58 t ha-1) was recorded from the same treatment as Sadar upazila (Figure 3b and Table 7). In Sadar upazila 16.43% increased tuber yield was found with the application of 150 kg ha-1 gypsum with 150 kg ha-1 silicon (G1S1) treatment and in Kaliganj upazila 12.32% increased tuber yield found in the same treatment over control.

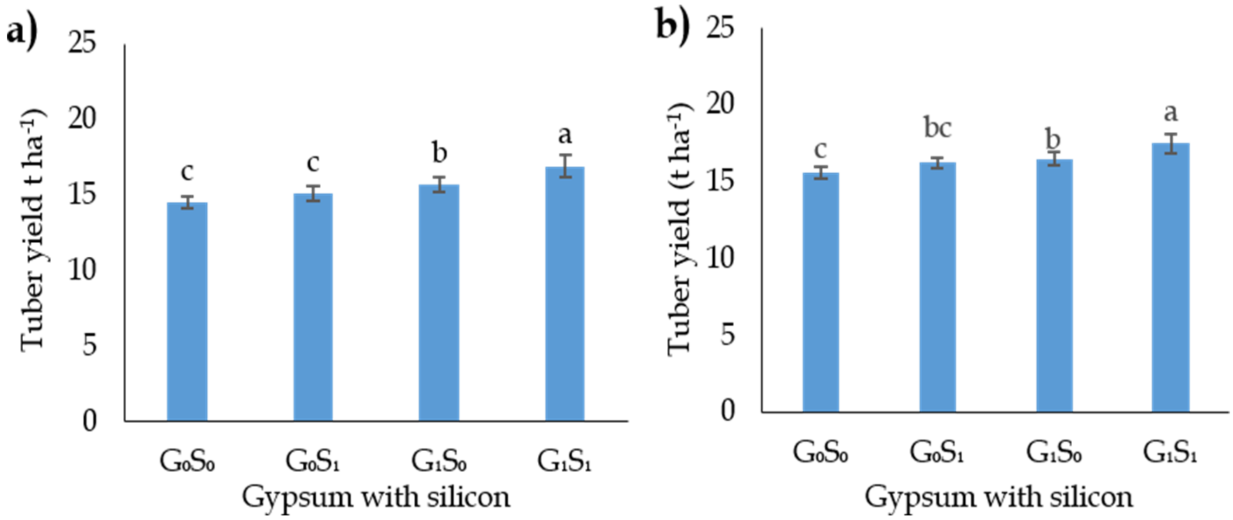

Fig. 3. Effect of gypsum with silicon on tuber yield of potato at a) Sadar upazila and b) Kaliganj upazila.
G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, from M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment, maximum tuber yield (22.36 t ha-1) was recorded. On the other hand, M0G0S0 (no mulching + no gypsum + no silicon) treatment resulted the minimum tuber yield (10.99 t ha-1) (Figure 4a and Table 6). In Kaliganj upazila, from the observation the same treatment as Sadar upazila showed the highest tuber yield (21.70 t ha-1) and the lowest tuber yield (13.33 t ha-1) was observed from M0G1S0 (150 kg ha-1 gypsum + no silicon) treatment which was statistically identical with M0G0S0 (no mulching + no gypsum + no silicon) treatment (Figure 4b and Table 7). From the observed data, in Sadar upazila 103.45% and in Kaliganj upazila 62.79% increased tuber yield was found with the application of mulching with recommended irrigation and 150 kg ha-1 gypsum with 150 kg ha-1 silicon (M3G1S1) treatment over control (M0G0S0).

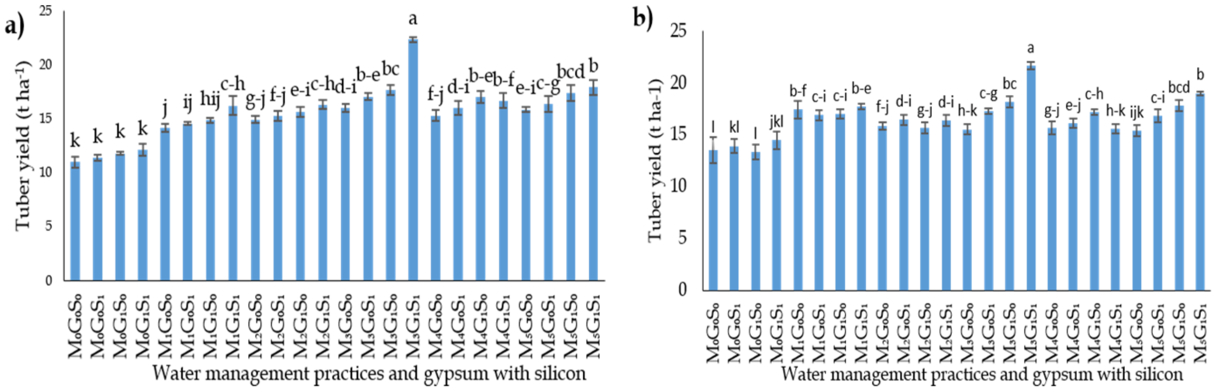

Fig. 4. Interaction effect of water management practices and gypsum with silicon on tuber yield of potato at a) Sadar upazila and b) Kaliganj upazila
M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization, G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Na+: K+ (ratio)

Effect of water management practices

In Sadar upazila, the minimum Na+: K+ (0.64) was recorded from the M3 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. Besides, the maximum Na+: K+ (1.13) was recorded from M2 (no mulching + one irrigation at stolon formation) treatment (Figure 5a and Table 6). In Kaliganj upazila, the lowest Na+: K+ (0.64) was recorded from the same treatment and the highest Na+: K+ (1.08) was recorded from the M0 (no mulching) treatment (Figure 5b and Table 7).

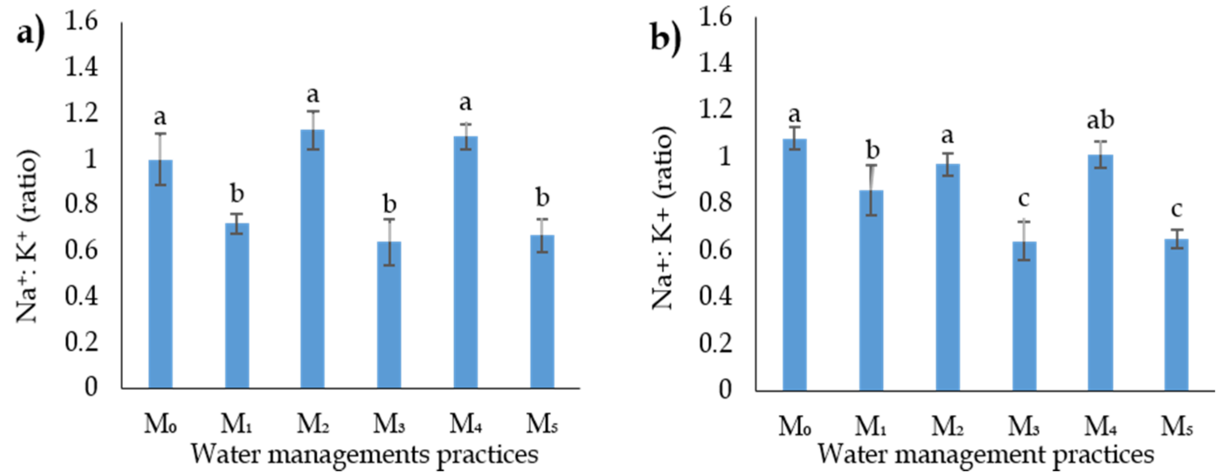

Fig. 5. Effect of water management practices on Na+: K+ of potato at a) Sadar upazila and b) Kaliganj upazila.

M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization.

In Sadar upazila, the lowest Na+: K+ (0.66) found from the G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment and the highest Na+: K+ (1.11) was recorded from the G0S0 (no gypsum + no silicon) treatment (Figure 6a and Table 6). whereas, in Kaliganj upazila, the lowest Na+: K+ (0.73) and the highest Na+: K+ (1.08) was recorded from the same treatments (Figure 6b and Table 7).

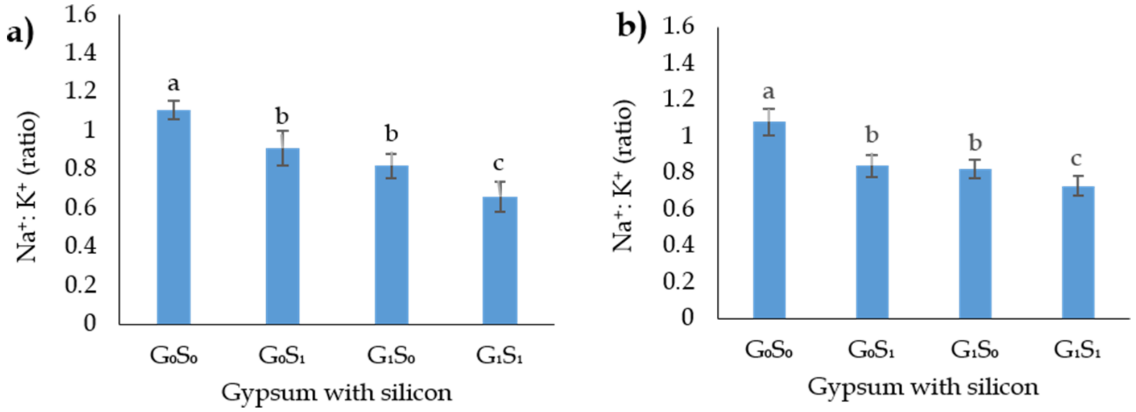

Fig. 6. Effect of gypsum with silicon on Na+: K+ of potato at a) Sadar upazila and b) Kaliganj upazila

G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, the minimum Na+: K+ (0.28) was recorded from the M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. The maximum Na+: K+ (1.34) was recorded from M4G0S1 (no mulching + no gypsum + 150 kg ha-1 silicon) treatment (Figure 7a and Table 6) Similarly, in Kaliganj upazila, same treatment as Sadar upazila resulted the lowest Na+: K+ (0.49) and the highest Na+: K+ (1.42) was observed from M0G0S0 (no mulching + no gypsum + no silicon treatment) (Figure 7b and Table 7).

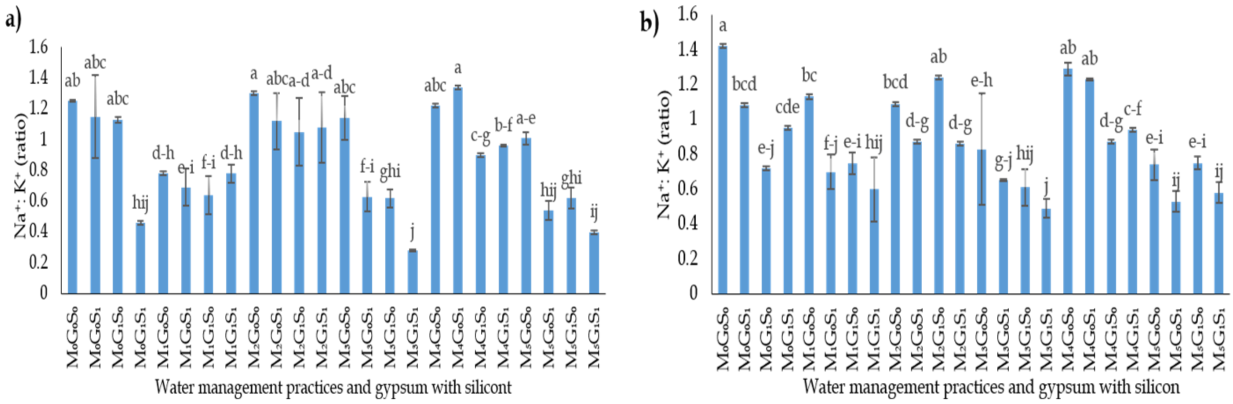

Fig. 7. Interaction effect of water management practices and gypsum with silicon on Na+: K+ of potato at a) Sadar upazila and b) Kaliganj upazila.

M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization, G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Proline Content (mg g-1 fresh weight)
Effect of water management practices

In Sadar upazila, the lower proline content (2.83 mg g-1 fresh weight) was recorded from the application of M5 (mulching + irrigation at tuberization) treatment. The higher proline content (3.77 mg g-1 fresh weight) was recorder from M4 (mulching + recommended irrigation) treatment (Figure 8a and Table 6). Similarly, in Kaliganj, the application of water management M3 (mulching + recommended irrigation) treatment showed the lower proline content (3.70 mg g-1 fresh weight) and the higher proline content (4.92 mg g-1 fresh weight) was recorded from M2 (no mulching + one irrigation at stolon formation) treatment (Figure 8b and Table 7).

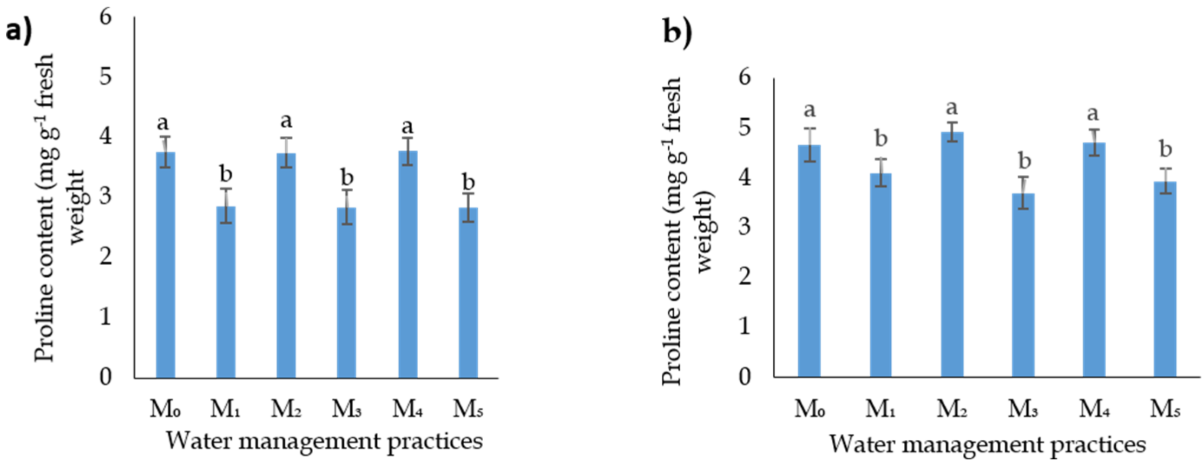

Fig. 8. Effect of water management practices on proline content of potato at Sadar upazila and b) Kaliganj upazila.

M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization.

Effect of gypsum with silicon

In Sadar upazila, the lower proline content (2.34 mg g-1 fresh weight) was recorded from G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. Whereas, higher proline content (4.28 mg g-1 fresh weight) was found from G0S0 (no gypsum + no silicon) treatment (Figure 9a and Table 6). Similarly, in Kaliganj upazila, the lower proline content (3.03 mg g-1 fresh weight) was founded from the application of G1S1 (150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment. The higher proline content (5.20 mg g-1 fresh weight) was found from control plot, G0S0 (no gypsum + no silicon) (Figure 9b and Table 7).

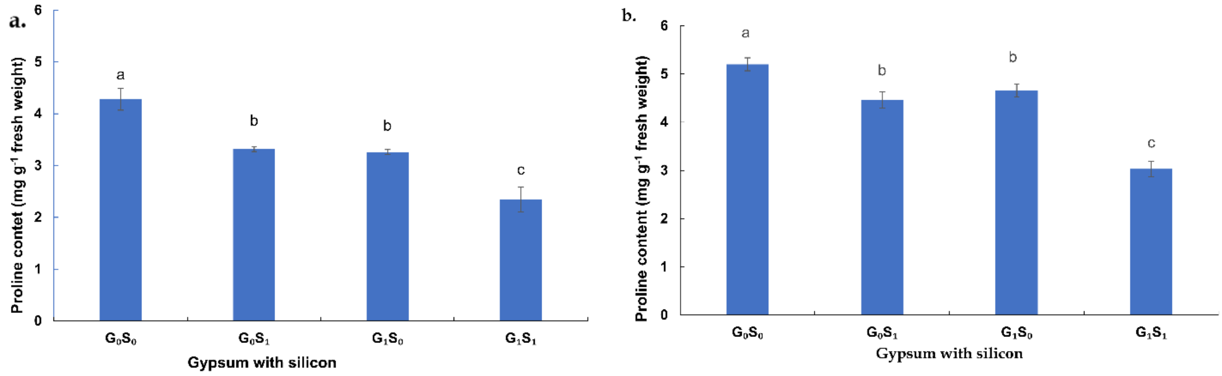

Fig. 9. Effect of gypsum with silicon on proline content of potato at a) Sadar upazila and b) Kaliganj upazila.

G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Interaction effect of water management practices and gypsum with silicon

In Sadar upazila, M3G1S1 (mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted the lowest proline content (1.27 mg g-1 fresh weight). On the other hand, M0G0S0 (no mulching + no gypsum + no silicon) treatment resulted the highest proline content (5.22 mg g-1 fresh weight) (Figure 10a and Table 6). In Kaliganj upazila, M3G1S1 mulching + recommended irrigation + 150 kg ha-1 gypsum + 150 kg ha-1 silicon) treatment resulted the lower proline content (1.99 mg g-1 fresh weight). The higher proline content (5.75 mg g-1 fresh weight) was observed from M0G0S0 (no mulching + no gypsum + no silicon) treatment (Figure 10b and Table 6).

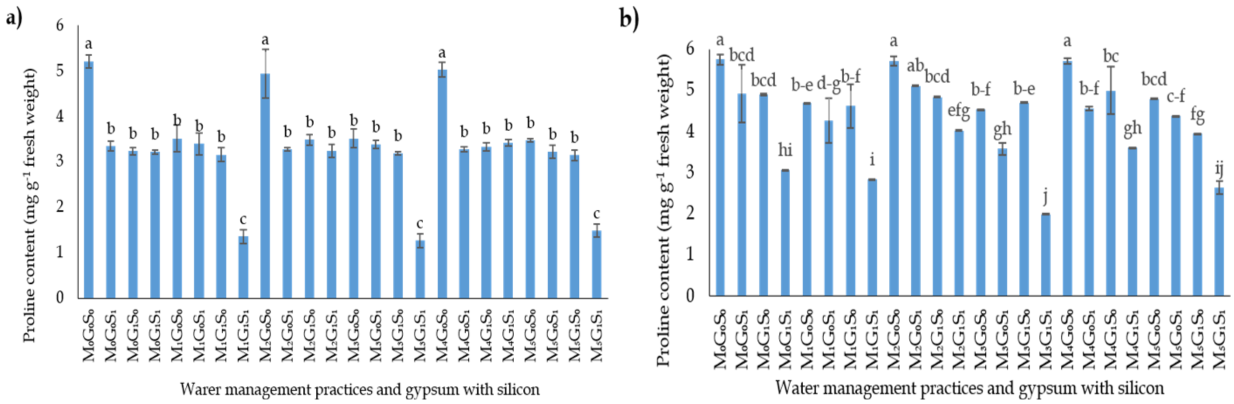

Fig. 10. Interaction effect of water management practices and gypsum with silicon on proline content of potato at a) Sadar upazila and b) Kaliganj upazila

M0 = No mulching, M1 = Mulching, M2 = No mulching + one irrigation at stolon formation, M3 = Mulching + recommended irrigation, M4 = No mulching + recommended irrigation, M5 = Mulching + one irrigation at tuberization. G0S0 = No gypsum + no silicon, G0S1 = No gypsum + 150 kg ha-1 silicon, G1S0 = 150 kg ha-1 gypsum + no silicon, G1S1 = 150 kg ha-1 gypsum + 150 kg ha-1 silicon.

Table 6. ANOVA table with Mean square and F value of Satkhira Sadar.

Source of variation	Replication	Main plot (water management)	Error (water management)	Sub plot (Gypsum with silicon)	Main plot: Sub plot (Water management: Gypsum with silicon)	Error (Gypsum with silicon)
df	2	5	10	3	15	36
Plant height (Mean square)	7.635	136.236*	3.07	49.037**	16.170*	8.221
Plant height (F value)	2.4869	44.3738		5.9645	1.9668	
Tuber five^{-1} plant (Mean square)	0.181	12.320**	0.031	3.667**	0.168**	0.031
Tuber five^{-1} plant (F value)	1.4992	30.0908		7.4399	1.9387	
Tuber length (Mean square)	2.074	13.910**	0.975	5.277**	1.601**	0.606
Tuber length (F value)	2.1263	14.2637		8.7108	2.6431	
Tuber periphery (Mean square)	1.659	36.138**	0.545	5.628**	1.731*	0.788
Tuber periphery (F value)	3.0461	66.3544		7.1394	2.1965	
Tuber weight plant^{-1} (Mean square)	527	46599.000**	84	3136.000**	207.000*	106
Tuber weight plant^{-1}(F value)	2.5991	12.0583		27.5156	2.6523	
Tuber yield (kg m^{-2})(Mean square)	0.003	0.621*	0.006	0.190*	0.027*	0.008
Tuber yield (kg m^{-2}) (F value)	0.4016	97.9469		23.4755	3.2958	
Tuber yield (t ha^{-1}) (Mean square)	0.254	62.0**	0.634	19.0**	2.67**	0.81
Tuber yield (t ha^{-1}) (F value)	0.4016	97.9469		23.4755	3.2958	
Na/k (Mean square)	0.017	0.612**	0.024	0.647**	0.104**	0.04
Na/k (F value)	0.7102	25.133		16.2159	2.6083	
Proline content (Mean square)	0.379	2.992**	0.063	11.361**	0.884**	0.082
Proline content (F value)	6.0536	47.7991		138.007	10.7316	
Haulm yield (Mean square)	0.48376	1.58177**	0.01471	0.48838**	0.06909**	0.02071
Haulm yield (F value)	32.898	107.566		23.583	3.336	

Table 7. ANOVA table with Mean square and F value of Kaliganj Upazila, Satkhira.

Source of variation	Replication	Main plot (water management)	Error (water management)	Sub plot (Gypsum with silicon)	Main plot: Sub plot (Water management: Gypsum with silicon)	Error (Gypsum with silicon)
df	2	5	10	3	15	36
Plant height (Mean square)	63.822	49.959**	8.726	210.465**	17.741*	7.104
Plant height (F value)	7.3142	5.7255		29.6269	2.4974	
Tuber five^{-1} plant (Mean square)	0.998	2.685*	0.51	3.281**	0.845**	0.214
Tuber five^{-1} plant (F value)	1.9578	5.2672		15.3252	3.9465	
Tuber length (Mean square)	2.925	2.653*	0.539	2.381**	2.226*	0.922
Tuber length (F value)	5.4261	4.9207		2.5816	2.4139	
Tuber periphery (Mean square)	11.792	23.547**	1.469	11.467**	2.694*	1.24
Tuber periphery (F value)	8.0253	16.0256		9.2454	2.1723	
Tuber weight plant^{-1} (Mean square)	74	46599.000**	84	3136.000**	207.000*	106
Tuber weight plant^{-1}(F value)	3.0755	14.2368		14.6467	2.0131	
Tuber yield (kg m^{-2}) (Mean square)	0.006	0.275**	0.01	0.174**	0.026*	0.01
Tuber yield (kg m^{-2}) (F value)	1.0954	23.2262		11.514	4.6117	
Tuber yield (t ha^{-1}) (Mean square)	0.573	27.475**	0.994	11.300**	3.855**	1.032
Tuber yield (t ha^{-1}) (F value)	0.5763	27.651		10.9475	3.7348	
Na/k (Mean square)	0.017	0.415**	0.031	0.401**	0.090**	0.021
Na/k (F value)	0.5443	13.4132		19.4266	4.3535	
Proline content (Mean square)	0.265	2.934**	0.219	15.508**	0.327*	0.172
Proline content (F value)	1.2069	13.3686		90.2617	1.901	
Haulm yield (Mean square)	0.54139	0.46651**	0.01872	0.18839**	0.06508**	0.01709
Haulm yield (F value)	28.9223	24.9218		11.0227	3.8076	

Correlation Matrix among the Yield and Yield Contributing Parameters of Potato under Saline Conditions

In Sadar upazila, pearson correlation coefficients among yield and yield contributing parameters are shown in Figure 11a. In this study, out of 45 associations, all associations were found significantly correlated. Tuber yield showed strong positive significant correlation with haulm yield, plant height, tuber plant-1 (no), tuber length, tuber periphery, tuber weight plant-1, tuber weight per m2 at $p < 0.001$. Similarly, tuber weight per m2, tuber weight plant-1, tuber plant-1 (no.), tuber periphery, tuber length and plant height showed strong positive significant correlation with each other at $p < 0.001$. Conversely, all the parameters had a negative correlation with Na+: K+ and proline content at $p < 0.001$ but Na+: K+ and proline content showed strong significant positive correlation with each other at $p < 0.001$. In Kaliganj upazila, pearson correlation coefficients among yield and yield contributing parameters are shown in Figure 11b. In this study, out of 45 associations, 44 associations were found significantly correlated. Tuber yield showed strong positive significant correlation with plant height, tuber plant-1 (no.), tuber length, tuber periphery, tuber weight plant-1, tuber weight per m2, haulm yield at $p < 0.001$. Similarly, tuber weight per m2 showed a strong positive significant correlation with plant height, tuber plant-1 (no.), tuber periphery, tuber weight plant-1 at $p < 0.001$, except tuber length showed significant positive correlation at $p < 0.01$. Again, tuber weight plant-1 showed strong positive significant correlation with plant height, tuber plant-1 (no.), tuber periphery at $p < 0.001$, except tuber length showed significant positive correlation at $p < 0.01$. Tuber periphery showed strong positive significant correlation with plant height at $p < 0.001$, tuber plant-1 (no.) at $p < 0.05$, and tuber length at $p < 0.01$. Tuber length showed significant positive correlation with plant height at $p < 0.01$. Conversely, all the parameters had a negative correlation with Na+: K+ and proline content at $p < 0.001$ but Na+: K+ and proline content showed a highly significant positive correlation with each other at $p < 0.001$.

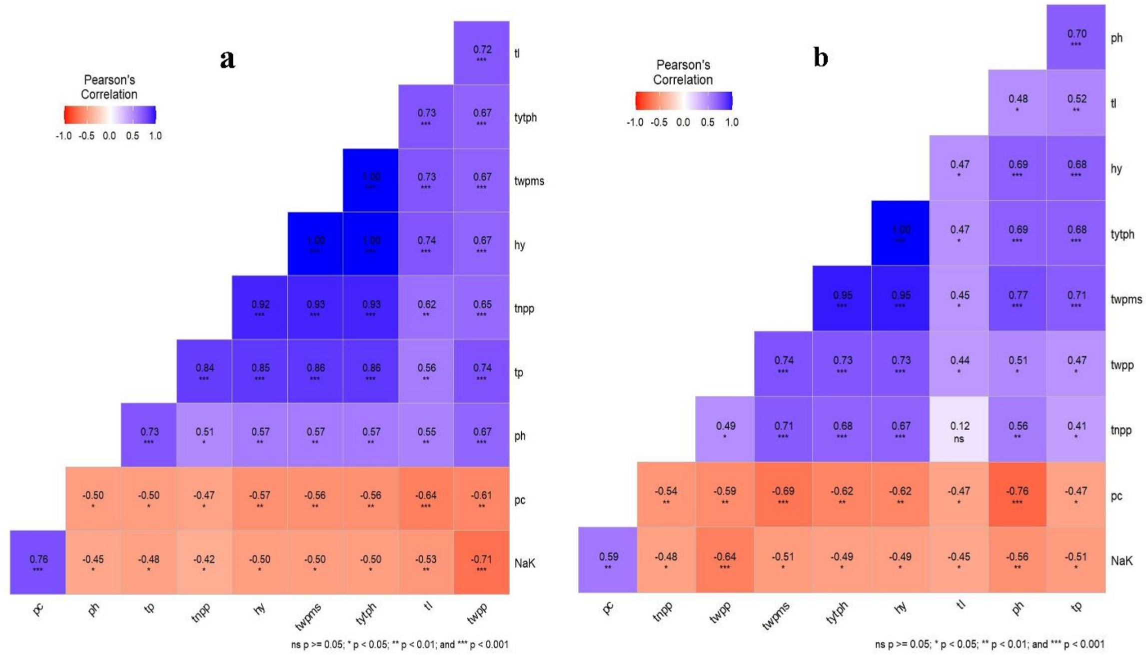

Fig. 11. Correlation analysis among the studied parameters at a) Sadar upazila and b) Kaliganj upazila. Here, ph = plant height (cm), tnpp = tuber plant-1 (no.), tl = tuber length (cm), tp = tuber periphery (cm), twpp = tuber weight plant-1 (g), twpms = tuber weight (kg m-1), tytph = tuber yield (t ha-1), NaK = Na+: K+ (ratio), pc = proline content (mg g-1 fresh weight), hy = haulm yield (t ha-1)

Principal Component Analysis of ten yield and yield Contributing Parameters of Potato under Saline Conditions

Principal component analysis (PCA) was conducted at both locations to identify the key factors contributing to salinity stress in potato plants. The analysis incorporated ten variables, including tuber weight per plant, tuber weight per m^2, tuber yield, haulm yield, plant height, tuber number per plant, tuber length, tuber periphery, Na^+: K^+ ratio, and proline content. In Sadar upazila, the first two principal components (PCs) accounted for 78.5% of the total variance, with PC1 explaining 66.2% and PC2 contributing 12.3%. Haulm yield, tuber periphery, and tuber weight per plant were positive contributors, while tuber yield, tuber weight per m^2, and tuber number per plant were the most influential. In contrast, plant height and tuber length had the lowest contributions, whereas Na^+: K^+ ratio and proline content were negative contributors (Figure 12a). In Kaliganj upazila, the first two PCs explained 74.1 % of the total variance, with PC1 accounting for 64.2% and PC2 for 9.9%. Tuber weight per plant, plant height, and tuber periphery were positive contributors, with tuber weight per m^2, haulm yield, and tuber yield being the most significant. Tuber length and tuber number per plant had the lowest contributions, while Na^+: K^+ ratio and proline content were negative contributors (Figure 12b).

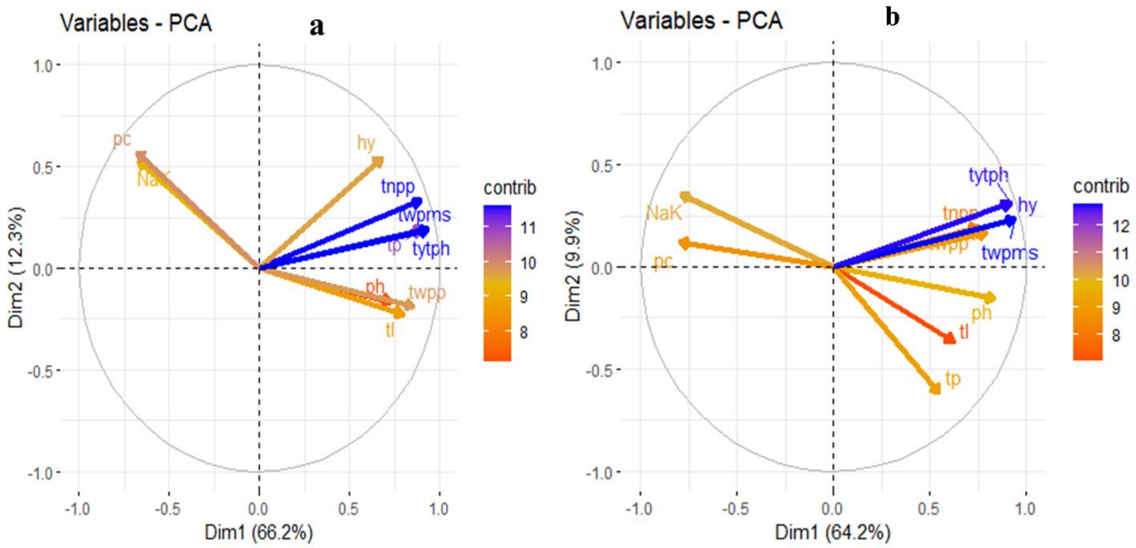

Fig. 12. Correlation co-efficient among nine parameters of potato yield and yield contributing character under saline conditions at a) Sadar upazila and b) Kaliganj upazila.

Here, ph = plant height (cm), tnpp = tuber plant-1 (no.), tl = tuber length (cm), tp = tuber periphery (cm), twpp = tuber weight plant-1 (g), twpms = tuber weight (kg m-1), tytph = tuber yield (t ha-1), NaK = Na+: K+ (ratio), pc = proline content (mg g-1 fresh weight), hy = haulm yield (t ha-1)

Discussion

Crop production in coastal saline regions is constrained during the Rabi season due to high soil salinity and limited freshwater availability (Kundu et al., 2024). This study found that mulching and recommended irrigation significantly improved plant growth, reduced salt intrusion, and enhanced tuber yield. Irrigation management boosts salt tolerance, lowers soil pH, and increases nutrient availability (Machado and Serralheiro, 2017). Mulching promotes early germination, increases tuber numbers, and improves yields (Ray et al, 2016 amd Wang et al., 2009). Mulching and irrigation effectively lowered the Na+: K+ ratio by reducing Na+ uptake and enhancing K+ retention, while untreated conditions exhibited higher salinity stress (Asaduzzaman et al., 2023 and Meena et al., 2022). These practices also reduced proline accumulation, indicating decreased osmotic stress, as proline plays a role in ROS scavenging and osmotic adjustment (Haque et al., 2021). Thus, integrating mulching and irrigation mitigates salinity stress and enhances potato productivity in saline environments (Sabbour and Hussein2024).

The application of gypsum and silicon significantly improved plant growth, tuber quality, and yield under saline conditions. In this study, 150 kg ha^{-1} gypsum with 150 kg ha^{-1} silicon produced the highest yield, indicating their combined role in mitigating salt stress and enhancing potato productivity. Gypsum improves soil structure, nutrient availability, and starch content, while silicon enhances plant height, tuber weight, and stress tolerance (Amer et al., 2023, Crusciol et al., 2009 and Gowayed et al., 2017). Gypsum supplies Ca^{2+}, replacing Na^{+} and reducing salinity stress (Suryawanshi et al., 2013), while silicon aids nitrogen fixation and enhances tolerance to extreme conditions (Wadas, 2022). The lowest Na+: K+ ratio in the G1S1 treatment indicates reduced Na+ accumulation and salinity stress. Additionally, gypsum and silicon lowered proline content, suggesting stress alleviation (Ferdous et al., 2018; Yamika et al., 2018). Silicon also mitigates ROS-induced stress, stabilizing cellular membranes (Singh et al., 2022). Thus, gypsum and silicon effectively improve soil properties, nutrient uptake, and tuber yield in saline environments. The combined application of mulching, irrigation, gypsum, and silicon significantly reduced salinity stress and improved potato growth and tuber quality in both locations (Wang et al., 2022). The highest yield was recorded with M3G1S1 treatment (22.36 t ha^{-1} in Sadar upazila and 21.70 t ha^{-1} in Kaliganj upazila), likely due to enhanced plant growth from optimized water and nutrient management. Mulching, gypsum, and silicon improved plant nutrition, increased K^{+}, P, Ca^{2+}, and Mg^{2+} uptake, enhanced saline stress tolerance, and improved soil water retention, thereby reducing Na^{+} and Cl^{-} accumulation and increasing productivity (Silva et al., 2023). According to Crusciol et al. (2014) and Thongsook and Kongbangkerd (2011), gypsum and silicon also improved the physical and chemical characteristics of the soil, reducing salt stress while promoting plant development. Therefore, adding these amendments improves the availability of water and nutrients for sustainable potato production while also efficiently counteracting soil salinity.

In this study correlation analysis showed tuber yield had highly positive significant correlation with other parameters at $p < 0.001$ in both locations. Conversely Na+: K+ and proline content showed highly negative correlation with tuber yield at both locations. Understanding these parameters associations will provide valuable insights for potato production in salinity affected area.

PCA, a multivariate technique, simplifies complex data into principal components, helping researchers understand parameters combinations (Hossen et al., 2025 and Abdi and Williams, 2010). In Sadar upazila, the first two PCs explained most of the variance (74%), PC1 contributed 63.4% of the variance, mainly driven by tuber yield, tuber weight per m2, and tuber plant-1 and PC2 explained 10.6% of the variance, primarily associated with Na+: K+ and proline content. In Kaliganj upazila the first two PCs explained most of the variance (65.5%), PC1 contributed 55.9% of the variance, mainly driven by tuber yield, tuber weight per m2 and tuber length and PC2 explained 9.6% of the variance, primarily associated with Na+: K+ and proline content. Higher coefficients in the analysis suggest parameters that strongly influence for crop productions (Sanni et al., 2012).

Incorporating mulching, irrigation, gypsum, and silicon application greatly increased potato output and decreased salt stress by improving nutrient uptake and lowering proline concentration and Na buildup. In order to produce potatoes sustainably in saline coastal regions, combine mulching, appropriate irrigation, and soil additions such as silicon and gypsum to enhance crop performance and soil health. Both locations showed the similar response to the application of mulching with irrigation and gypsum with silicon fertilization, which suggested that all the parameters significantly alleviated salinity stress and increased potato productivity. The tuber yield was higher in Sadar upazila than Kaliganj upazila, possibly due to the lower salinity level in Sadar upazila.

Conclusion:

Based on the experimental results, it is concluded that the combined application of water management practices (mulching and irrigation) and gypsum with silicon fertilizer showed better performance on the yield and yield-contributing parameters of potato in both locations. The result of the experiment also revealed that the application of mulching with irrigation and gypsum with silicon gave the highest tuber yield among the tested treatments in both locations but different salinity level in both locations influenced the yield of potato. Therefore, mulching with irrigation and gypsum with silicon fertilization could be applied at a large scale for mass production of potatoes and also for other crops in salinity affected area. Further field trials by more farmers are needed across the country to take their feedback before making recommendations.

Consent for publication:

All authors declare their consent for publication.

Author contribution:

The manuscript was edited and revised by all authors

Conflicts of Interest:

The author declares no conflict of interest.

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