Journal of Agriculture and Food Research 19 (2025) 101603

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Potato production under zero tillage with rice straw mulching as a promissory technology to diversify rice-based systems in Southwest Coastal Bangladesh

David A. Ramírez [a,*], M. Monower Hossain [b], E.H.M. Shofiur Rahaman [c], Carlos Mestanza [a,d], Javier Rinza [a], Johan Ninanya [a,d], Felipe de Mendiburu [d], Hildo Loayza [a], Marcel Gatto [e,f], Jan F. Kreuze [a]

[a] International Potato Center (CIP), Headquarters P.O. Box 1558, Lima, 15024, Peru
[b] Internatinal Potato Center (CIP), Prodipan, Moheshwarpasha, Khulna, 9100, Bangladesh
[c] Internatinal Potato Center (CIP), Banani, Dhaka, 1215, Bangladesh
[d] Universidad Nacional Agraria La Molina, Lima, Peru
[e] International Potato Center (CIP), South Africa
[f] University of Witwatersrand, School of Economics and Finance, South Africa

ARTICLE INFO

Keywords:
Solanum tuberosum
C footprint
Soil C stocks
Crop modeling
Soil salinity

ABSTRACT

Extreme precipitations that promote flooding, salinity, and soils with low drainage and aeration are challenges that affect food production in the Southwest of Bangladesh. After rice cultivation, most lands are kept fallow, emphasizing the urgency of research on techniques that allow crop diversification to guarantee food security. In this study, 2 years-trials on farmers' plots were established in 3 locations of Khulna district-Bangladesh to test potato cultivation under zero tillage with rice straw mulching (ZT) in comparison to conventional cultivation (CT) after rice. A soil quality index (SQI) using the partial least squares method was run considering key soil indicators related to crop production. ZT allowed a higher tuber yield and a lower C footprint than CT. Although neither method significantly affected soil organic carbon stock, there was a significant increment from season 1 to 2 (29.0 ± 11.3 and 45.8 ± 9.4 Mg ha^{-1}, respectively). ZT allowed potato cultivation 15–25 days earlier than CT. Although crop modeling did not show a significant increase in potential tuber yield when simulating the earlier planting of ZT, this advantage will be crucial in the future, considering that high-intensity rainfall events are increasing, flooding the fields and preventing crop cultivation. Alkalinity, carbonates, and anaerobic soil conditions drove the SQI, influencing the elements kept in the past rice cultivation with a concomitant effect in tuber yield. ZT is a promising technology that allows crop diversification based on soil sustainability and labor reduction in challenging agroecologies like Southwest Bangladesh. Socioeconomic studies into adoption and scaling approaches are necessary for a proper technological transfer.

1. Introduction

Approximately 30 % of Bangladesh's arable land is located in the coastal zones [1]. About 1.7 million hectares of coastal land are affected by varying soil salinity [2]. The intrusion of salinity due to climate change has had a severe impact on these areas, leading to an annual loss of about 14 million tons of food grains. This significant reduction, amounting to an overall yield decline of 20–40 %, raises significant concerns about food security [3]. In the coastal regions, particularly during the "Rabi" season (mid-November to mid-March), cropping intensity decreases due to environmental hazards associated with salinity [2]. Furthermore, other factors such as the late harvest of "Aman" rice (rice cultivated from July to December), a shorter winter period, difficulties in tillage, and a lack of fresh irrigation water, limit crop cultivation during this season [4]. As a result, agricultural land use in coastal areas remains significantly lower than the national average cropping intensity [2].

Bangladesh's rapidly growing population and shrinking farmland

* Corresponding author.
E-mail address: d.ramirez@cgiar.org (D.A. Ramírez).

https://doi.org/10.1016/j.jafr.2024.101603
Received 20 September 2024; Received in revised form 6 December 2024; Accepted 18 December 2024
Available online 19 December 2024

require an urgent increase in cropping intensity to sustain food production and farm income. Among the country's critical food crops, potatoes rank second in production and third in cultivated land area [5]. Over recent years, Bangladesh has consistently produced an average of 8.9 million metric tons of potatoes, cultivated primarily during the winter season (mid-November to mid-February) [6]. However, in this country the winter duration is becoming very short [7], and especially in the Southwest Coastal, the planting in this season is delayed due to the late harvesting of "Aman" rice, and because most of the agricultural land is flooded during the monsoon season [8]. As a result, late-planted potatoes receive very short winters, which are unsuitable for tuberization, resulting in non-profitable yields.

On the other hand, rice-based systems dominate cropping patterns in the coastal zones of tropical deltas in Asia [9]. In Southwest Bangladesh, the most prevalent practice is the fallow-fallow-"Aman" rice pattern [10], which generates a significant quantity of rice straw due to the cultivation of tall and long-duration rice varieties. Most of this rice straw is either left in the fields or burned openly, presenting an opportunity for its use as mulch in subsequent cropping seasons [11,12]. Farmers adopt various practices to manage adverse cultivation conditions during the "Rabi" season, including mulching with water hyacinth and ash, use of compost to reduce salinity, and rotation with "Rabi" crops such as sesame, mungbean, and grass pea [10,13]. Zero tillage combined with rice-straw mulching stands out as an innovative approach for promoting sustainable intensification and diversification, particularly for potato cultivation [11,14]. Although potato cultivation is uncommon in the Southwest region due to the poor performance of traditional varieties in saline conditions, researchers are making significant efforts to develop high-yielding potato varieties capable of thriving in these challenging environments [15,16]. Consequently, the combination of zero tillage, rice-straw mulching, and improved varieties offers a promising solution for potato cultivation in the challenging saline coastal regions [17]. This method allows to grow potatoes immediately after rice harvest, reducing labor costs and other farming expenses, while minimizing environmental degradation risks, benefiting farmers, and increasing agricultural productivity [11,18]. Although this technology has shown improved productivity and profitability compared to conventional cultivation in India's saline areas of West Bengal [14,19], the underlying causes for these higher yields, such as soil factors including moisture retention, organic matter content, and nutrient availability, remain unclear and require further investigation. Additionally, comparisons of carbon emissions between systems have been limited [11].

In this study, 2-years trials on farmers' fields were assessed in three locations in Southwest Bangladesh to: i) compare tuber yield, C footprint, and soil carbon stocks in fields cultivated with potatoes under conventional tillage (CT) and zero tillage with rice-straw mulch (ZT); ii) analyze the timing and crop duration effect of both technologies through simulation using a potato crop model; and iii) create a zone-specific soil quality index that allows an understanding of the leading soil indicators related to potato production. Because it is possible to establish potatoes immediately after rice harvest using the ZT approach, we hypothesized that higher tuber yield under ZT, with a concomitant C footprint reduction, is caused mainly by the early cultivation that allows the growth of potatoes under optimum conditions, taking advantage of winter temperatures. Moreover, the high inputs of fertilizers used for rice cultivation (before "Rabi" potatoes) in interaction with calcareous grey floodplain soil, characteristics of dominant soils of Southwest Bangladesh [20], will determine soil indicators associated with calcium carbonate, anaerobic condition, salinity, and over-fertilization that could promote tuber yield under both tillage practices.

2. Materials and methods

2.1. Study area and plant material

The experiments on farmers' fields were conducted for two potato growing seasons (2021-22 and 2022-23) and established in Fultola (22.7088° N, 89.5262° E, 1 m asl) and Hogalbunia (22.7558° N, 89.5021° E, 1 m asl) locations in Batiagatha "upazila" and Moshamari (22.5978° N, 89.4722° E, 1 m asl) location in Dacope "upazila" belonging to the Khulna district in Southwest Bangladesh (Fig. 1). The climate of this region is sub-tropical, belonging to the Ganges Tidal Floodplain Agro-ecological zone [21]. Soils are categorized as non-calcareous grey floodplain soil [22]. The texture of soils is silty loam to clay, most of the topsoils are slightly acidic to moderate alkaline (pH 6.61–8.30), soils contain low to medium organic matter (0.76–3.37 %) with slightly to strong salinity values (1.46–5.86 dS m^{-1}) (Tables S1 and S2). The first potato growing season (December 2021–March 2022, hereafter named "season 1") was wet (83 mm of precipitation in total), characterized by an average temperature of 22.1 ± 0.39 °C, and daily maximum and minimum temperatures ranged between 20.6-36.5 and 12.0–26.8 °C, respectively (Fig. 2). In contrast, the second potato growing season (December 2022–March 2023, hereafter named "season 2") was dry, with 97.6 % less (2 mm) precipitation than the former, and it was characterized by an average temperature of 21.4 ± 0.47 °C, and daily maximum and minimum temperatures ranged between 17.4–34.4 and 8.2–25.2 °C, respectively (Fig. 2). Two BARI (Bangladesh Agricultural Research Institute) released varieties viz. BARI Alu 72 and BARI Alu 78 were used in this study. Both varieties come out of the International Potato Center's breeding program and mature early, around 85–90 days, with BARI Alu 78 yielding more than BARI Alu 72 [23]. BARI Alu 72 was released from CIP 396311.1 in 2016, and it is heat and salt-tolerant and suitable for table purposes [23]. BARI Alu 78 was released from CIP 380606.6 in 2017, and it is an early bulker that can grow in saline areas [23].

2.2. Treatments and management

Two factors were tested in all the trials: tillage methods and varieties. Potato under CT and ZT were the two treatments for the first factor. BARI Alu 72 and BARI Alu 78 varieties were the treatments for the second factor. Four management treatment combinations were used: BARI Alu 72 + CT, BARI Alu 72 + ZT, BARI Alu 78 + CT, and BARI Alu 78 + ZT. The two-factor experiment was laid out in the strip plot design with four replications (Fig. S2). The experimental field was divided into 16-unit plots (4 treatments × 4 replications) in each location, with a plot area of 4.8 × 10 m^2 (Fig. S2). ZT implementation and management were based on Kakraliya et al.'s [24] procedure. Thus, the plant density used was 12.5 individuals m^{-2}, and the spacing between lines and plants was 0.4 and 0.2 m, respectively. In season 1, ZT treatments were established between 17–22 December 2021, whereas CT treatments were installed between 10–15 January 2022. In all trial locations, after harvesting potatoes in season 1, the land remained fallow up to July due to high soil salinity and scarcity of quality irrigation water. In the wet season (June-early December 2022), transplanted "Aman" rice was grown under rainfed conditions. Plowing, transplanting of rice seedlings, fertilization, and weeding were done according to local customs during the rice cropping season. In season 2, ZT treatments were established between 10–17 December 2022, and CT treatments were set between December 28, 2022 and January 3, 2023. Potato planting under ZT was performed just after harvesting "Aman" rice. However, in seasons 1 and 2, due to the excess soil moisture after monsoon during the "Aman" rice season, additional time was required to drain/dry the excess water before plowing the land to cultivate potatoes under CT. Therefore, this treatment's planting time was 15–25 days after ZT potato planting.

Basal fertilizers were applied during the planting of potatoes for both tillage methods. This included 10 t ha^{-1} of farmyard manure and N-P-K-S-Zn-Mg-B, equivalent to 100-28.8-86.7-6-4-2-1.6 kg ha^{-1} [24]. This mixture contained specific nutrients: urea (46.6 % N), triple superphosphate (20 % P), muriate of potash (50 % K), gypsum (18.6 % S), zinc sulphate (34.7 % Zn), magnesium sulphate (75 % Mg), and borax (11 % B). For CT, the land was prepared through plowing and cross-plowing,

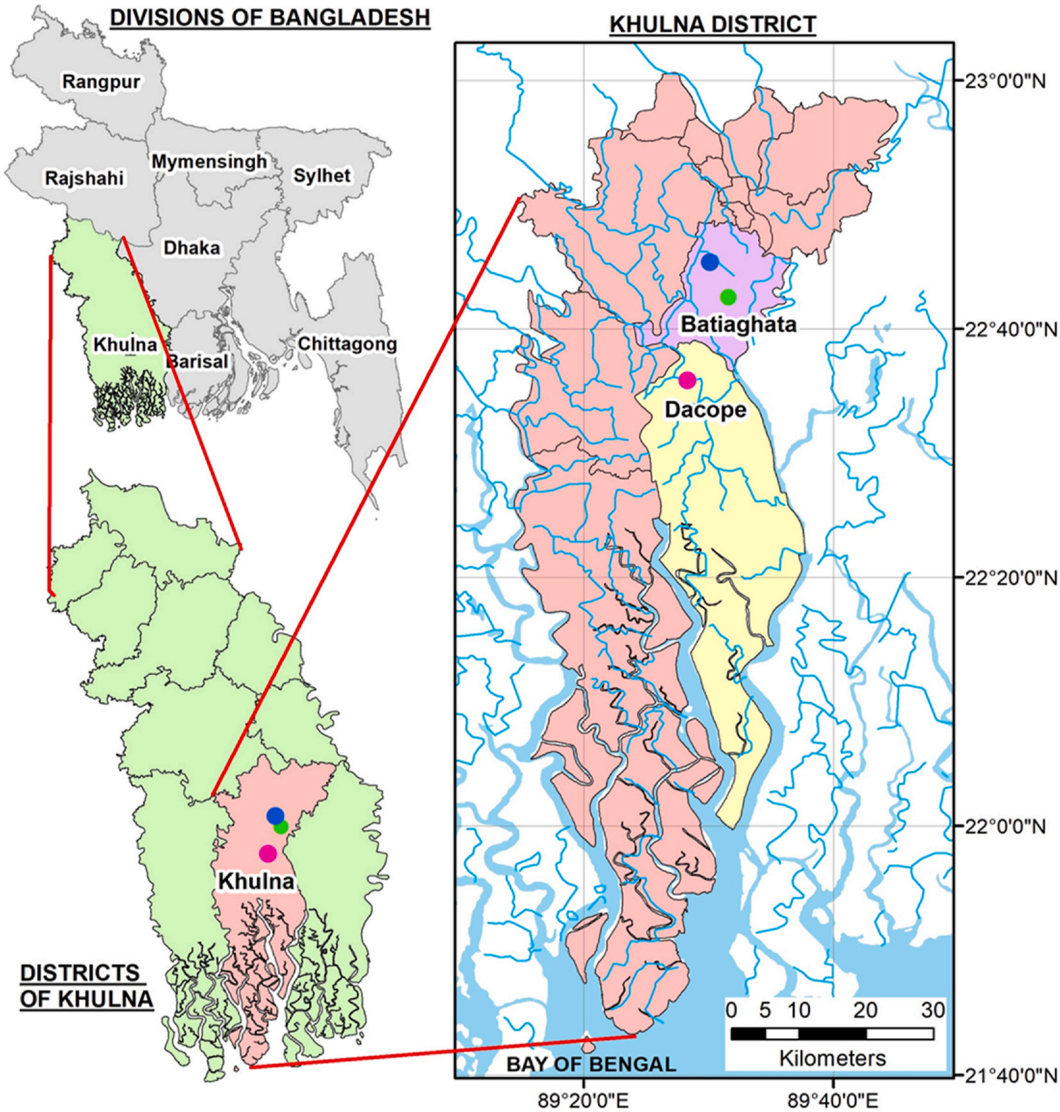

Fig. 1. Location of the three agronomic trials in Bathiagata and Dacope "upazilas" belonging to Khulna district in Bangladesh.

furrows were created, and seeds were sown into these furrows. Afterward, the basal fertilizers were applied, seeds were covered with soil, and ridges were formed (first earthing up). A second earthing up took place 40 days after planting (DAP), where 32 kg ha^{-1} N was top-dressed using urea. For ZT, potato tubers were planted (laid down on top of the soil) just after rice harvesting. Farmyard manure and the basal dose of fertilizers was placed on both sides of the potato planting line. After that, a layer of rice straw of 15 cm thickness (9 t ha^{-1}) was used to cover the entire area [24]. ZT did not require any earthing or intercultural operations; however, similar to CT, 32 kg ha^{-1} N was top-dressed applied using urea at 40 DAP. At 50 DAP, a foliar fertilizer (Vitamix, ACI Fertilizer, Bangladesh) was sprayed for both tillage methods, delivering 1.25-1.67-2.29–0.68 kg ha^{-1} of N-P-K-S [24].

Between 4-6 and 6–7 agrochemical applications to prevent pests and diseases were done during seasons 1 and 2, respectively (see details in Table S3). Irrigations were done every 7–20 days using a water pump for both tillage treatments. The amount of water irrigated was calculated gravimetrically based on soil moisture at a depth of 0.30 m. For CT, irrigation was performed by pumping water from water reservoirs (lake and pond) to the furrows with 0.30 m^3 min^{-1} flow and 20.1–30.2 mm per irrigation. Early in the season, irrigation water was fresh to slightly saline (0–1 dS m^{-1}), but salinity increased to 2–3.5 dS m^{-1} towards the end of the season in March. For ZT, splash irrigation was applied with 0.23 m^3 min^{-1} of flow and 10.1–15 mm per irrigation. The distances from the water sources to the experimental plots of Hogalbunia, Fultola, and Moshamari were 90, 180, and 230 m, respectively. A diesel engine 1 hp water pump (RFL Motors Ltd., Bangladesh) was used to supply water at the Hogalbunia and Fultola locations. For the Moshamari location, another diesel engine water 2 hp pump (ACI Motors Ltd., Bangladesh) was used. For CT, 38.3–75.0 and 105–165 mm of irrigation was applied in seasons 1 and 2, respectively, at the 3 locations. For ZT, 35.5–63.7 and 75–110 mm irrigation was applied in seasons 1 and 2, respectively. In both tillage methods, the amount of irrigation was calculated by the following formula:

$$Amount\ of\ irrigation\ (mm) = \frac{Flow\ rate\ \left(m^3\ min^{-1}\right) * Irrigation\ time\ (min) * 1000\ L}{48\ m^3} \tag{1}$$

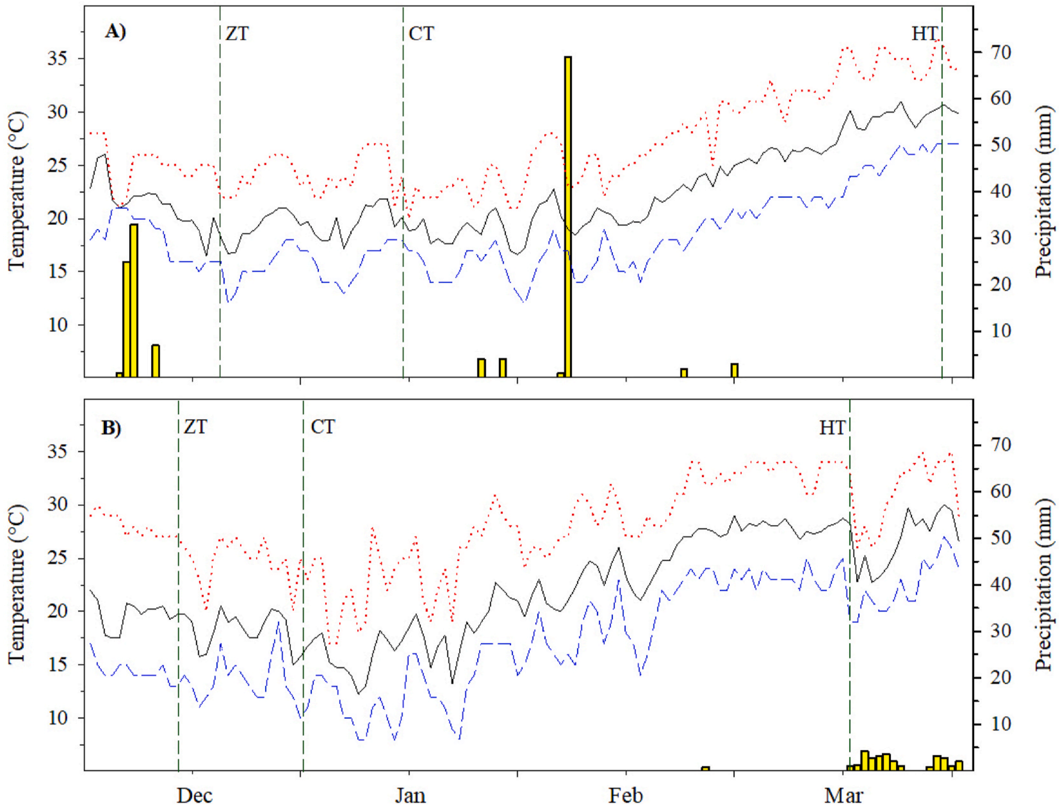

Fig. 2. Daily average (black solid line), maximum (red dotted line), minimum (blue dashed line) air temperature, and precipitation (yellow bars) recorded by Khulna Regional Inspection Center Meteorological Station during 2021–22 (A) and 2022-23 (B) cropping seasons. Vertical green dashed lines tagged with ZT, CT, and HT correspond to the median date (for the 3 locations) of planting time for zero tillage, planting time for conventional tillage, and harvest time, respectively, in the three experimental sites (Hogalbunia, Moshamari, and Fultola, see Fig. 1). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2.3. Yield assessment, C footprint calculation, economic analysis and crop modeling simulation

Potato harvest took place when 80 % of the plants achieved senescence, as defined by the phenological stage 650 of Jefferies and Lawson's [25] categories, i.e., "half leaves yellow." Harvest was carried out on the same dates for both treatments: March 27, 2022 for season 1 and March 16, 2023 for season 2. Each plot's total fresh tuber yield (FTY) was determined by weighting tubers from four randomly selected spots (1 m × 0.8 m), and the mean value was converted to t ha^{-1}. Healthy tubers (without damages) with a weight >20 g each were used for marketable tuber yield (MTY) calculation [26]. Carbon footprint (CF, kg CO_2-eq t^{-1} of tuber fresh) was estimated using the "Cool Farm Tool–Potato" platform (CFT-Potato; version 2.11; [27]). CFT-Potato is based on crop management information (yield, number of seeds, planting and harvest date, fertilizer and irrigation water applied, and chemical pesticides), soil characteristics, and energy used [28]. The economic analysis was done by local prices in Taka and converted to US dollars (1 USD = 104 Taka), were set at 55 Taka per kg for tuber seed, 2 Taka per kg for straw, 500 Taka for labor operations and 40 Taka per kg for marketable potato. Gross return was calculated by multiplying the FTY with market price of tubers (USD t^{-1}). The benefit-cost rate (BCR) was calculated by dividing the gross return by the cost of cultivation, and the net return was determined by the difference between the cost of cultivation and the gross return [14]. The cost of cultivation was calculated using the costs of tuber seeds, fertilizers, pesticides, straw, machinery, irrigation, and labor operations.

To assess the effect of different planting dates used in both management treatments (see section 2.2) on potential potato yield, a simulation exercise was run using the SOLANUM model [29], for the planting dates of ZT and CT in seasons 1 and 2 (four cases) for both potato varieties. This model assumes that potential potato yield is determined solely by crop traits and climate, while other constraints (water availability, soil nutrients, pests, etc.) are controlled [30]. The SOLANUM's Parameter Estimator, a routine that translates expert knowledge of crop phenology into the model parameters [31], was used to calibrate the model for both varieties. For this purpose, a consultation with experts in the study area and literature revision [16,32] was carried out to collect the data required by the Parameter Estimator routine (planting and harvest dates, day of emergence, day of the maximum canopy cover, maximum canopy cover index, and day of physiological maturity and tuber initiation onset) for BARI Alu 72 and BARI Alu 78. Daily data of minimum and maximum temperatures and solar radiation for ZT and CT growing season (November–April) for 20 years (2000–2020) were obtained from NASA Prediction Of Worldwide Energy Resources (NASA POWER) project using the R package "nasapower" [33]. Since the three locations have similar climatic conditions as they belong to the same Koppen's climatic classification [34] and are in the same NASA POWER data grid, data were retrieved only for the Fultola location. Finally, the simulation exercise was run in R software v 4.2.3 [35]. Differences between potential yield simulated were analyzed using the Kruskal-Wallis rank sum test [35].

2.4. Soil quality index and C stocks calculation

Ninety-six composite soil samples were collected from the three locations per each season. The samples were collected from 3 spots of each plot in a zigzag pattern using a regular auger in two fixed depths soil profiles: 0–0.15 m and 0.15–0.30 m. Then, the soil samples were mixed into one composite sample to represent each plot. At the same time, undisturbed soil samples were extracted with a soil core, which was dried in an oven and weighed to determine dry bulk density (Bd) by core method [36]. Soil organic carbon concentration (SOC), soil pH, electrical conductivity (ECe), total nitrogen content, total equivalent carbonates, available phosphorus, and soluble nitrate were determined at the Laboratory of Soil Resource and Development Institute (see protocol details followed by the lab in Table S1).

A soil quality index (SQI) was calculated using the weighted additive approach [37] to determine the most important soil indicators related to potato production. All the eight measured target soil variables (TSV; Bd, SOC, pH, Ece, N, $CaCO_3$, P, and NO_2) were considered for SQI formulation. Outlier values were handled by a random forest-based multivariate method using the "outForest" package [38]. To estimate the weights of each TSV (wTSV) related to FTY, the Partial Least Squares (PLS) regression [39] using both seasons' values was used to predict FTY eliminating the effect of both tillage methods (CT and ZT). The number of components used for the PLS regression was determined by leaving one out cross-validation and the lowest root mean square error. Then, wTSV for a specific TSV was calculated by dividing the absolute value of its PLS regression coefficient by the total sum of all PLS regression coefficients. This analysis was implemented using the "pls" package [40] and then run in R language 4.3.1 [35]. Later, each TSV was scaled from 0 to 1 to homogenize the different magnitudes using the "min-max" scaling method with the "caret" package [41]. For each TSV whose PLS regression coefficient had a negative sign, its scaled value was replaced by its complement (1 - scaled value) because its interpretation must be considered inversely. Finally, the SQI was calculated as the total sum of each wTSV multiplied by its corresponding scaled value of TSV (sTSV) as follows:

$$SQI = \sum wTSV * sTSV \tag{2}$$

SOC stock (SOC_{stock}, Mg ha^{-1}) was calculated to quantify carbon storage between the cropping seasons 1 and 2. SOC_{stock} for season 1 ($SOC_{stock\ season\_1}$) and season 2 ($SOC_{stock\ season\_2}$) was calculated as the SOC concentration (%) multiplied by Bd and by soil volume (1 m^2 at a fixed depth of 0.15 and 0.30 m). Changes in Bd over time require SOC_{stock} correction using the concept of equivalent soil mass [42] instead of soil mass by fixed depth. This correction was made for $SOC_{stock\ season\_2}$ ($\widehat{SOC}_{stock\ season\_2}$) using the simplified method proposed by Fowler et al. [43]. Thus, $\widehat{SOC}_{stock\ season\_2}$ was calculated by multiplying $SOC_{stock\ season\_2}$ by a factor depending on both seasons' values of Bd and SOC and a constant k (k = 1.724), which assumes that organic matter is 58 % carbon, as follows [44]:

$$\widehat{SOC}_{stock\_season\_2} = SOC_{stock\_season\_2} * \frac{Bd_{season_1}}{Bd_{season_2}} * \frac{1 - k*SOC_{season_1}}{1 - k*SOC_{season_2}} \tag{3}$$

2.5. Statistical analysis

All field data for both seasons collected and processed are available in the Dataverse repository [45,46]. The data were analyzed using R language 4.3.1 [35]. To assess changes in SOC_{stock} between seasons 2 and 1 ($\widehat{SOC}_{stock\ season\_2}$ – $SOC_{stock\ season\_1}$), a paired *t*-test was applied between experimental units. The effect of treatments on SOC_{stock} changes ($\widehat{SOC}_{stock\ season\_2}$ – $SOC_{stock\ season\_1}$) was compared by a mixed effect analysis of variances using the "lmerTest" package [47]. To evaluate the response of FTY, MTY, and CF to location, varieties, management factors, and their interactions, a General Analysis of Deviance was conducted using a generalized linear mixed model with the "GAD" package [48]. This model accounted for location, variety, and management as fixed factors and replications (blocks) as random factors along with their interactions. Then, a post hoc multicomparison for FTY and CF was performed using the Least Significant Difference test with the "Agricolae" package [49].

3. Results

3.1. Tuber yield, C footprint, economic benefit and potential yield simulation

In season 1, MTY and FTY ranged between 6.7-24.4 and 10.3–34.3, and 0–10.5 and 0–14.5 t ha^{-1} under ZT and CT treatments, respectively (Fig. 3-A, C, E). MTY and FTY were significantly affected by locations, management, and potato varieties. MTY showed significant differences for all factor interactions, whereas FTY was significantly affected by location × management and management × variety interactions (Table 1). FTY and MTY were 342.5 and 481.7 %, 267.6 and 213.2 %, 653.4 and 2110.5 % higher under ZT than CT for Hogalbunia, Moshamari and Fultola, respectively, for BARI Alu 72 (Fig. 3-A, C, E). For BARI Alu 78, FTY and MTY were 266.8 and 340.3 %, 381.4 and 239.8 %, 873.8 and 3750.0 % higher under ZT than CT for Hogalbunia, Moshamari, and Fultola, respectively (Fig. 3-A, C, E). In season 2, MTY and FTY ranged between 3.1-22.8 and 6.4–29.5, and 2.5–19.2 and 5.0–21.5 t ha^{-1} under ZT and CT treatments, respectively (Fig. 3-B, D, F). Management and variety significantly affected MTY and FTY, as the interactions between management × variety and location × management were significant for MTY and FTY, respectively (Table 1). FTY and MTY were 184.5 and 221.0 %, 344.3 and 498.6 %, 300.6 and 491.5 % higher under ZT than CT for Hogalbunia, Moshamari and Fultola, respectively, for Alu BARI 72 (Fig. 3-B, D, F). For Alu BARI 78, FTY and MTY were 239.7 and 281.8 %, 274.0 and 448.4 %, 304.9 and 353.9 % higher under ZT than CT for Hogalbunia, Moshamari and Fultola, respectively (Fig. 3-B, D, F).

In season 1, CF ranged between 109.0–426.0 and 357.1–6197.7 kg CO_2-eq t^{-1} of FTY under ZT and CT, respectively (Fig. 4-A, C, E). CF was significantly affected by location, management, and location × management interaction (Table 1). For both varieties, ZT reduced CF by 79.7 ± 1.79, 79.2 ± 2.42, and 92.2 ± 1.88 % compared to CT for Hogalbunia, Moshamari, and Fultola, respectively (Fig. 4-A, C, E). In season 2, CF ranged between 141.4-353.4 and 575.9–1962.3 kg CO_2-eq t^{-1} of FTY under ZT and CT, respectively (Fig. 4-B, D, F). CF was significantly affected by location, variety, management, and all the interactions (Table 1). For both varieties, ZT reduced CF by 70.6 ± 2.22, 84.2 ± 1.54, and 82.6 ± 0.57 % compared to CT for Hogalbunia, Moshamari, and Fultola, respectively (Fig. 4-B, D, F). Regarding CF sources, emission, seed production (37.2 ± 7.37 %), followed by soil/fertilizer (25.4 ± 4.04 %) and energy use (field operations, 20.9 ± 0.71 %), were the most important during season 1. Whereas during season 2, seed production (33.9 ± 5.76 %), followed by energy use (field operations, 29.8 ± 0.72 %) and soil/fertilizer (22.3 ± 3.23 %) were the most important CF source emissions (Fig. 4, Table S4). In a combined analysis of both seasons, seed production (48.4 ± 3.46 %) and soil/fertilizer (31.04 ± 0.94 %) were the most important sources of CF for CT and ZT, respectively. On the other hand, due to the high cost of cultivation in all treatments (3240 ± 37.8 USD ha^{-1}) and the fluctuating gross return, BCR and net return ranges of 0.36–2.79 and -2073–5454 USD ha^{-1}, 0.33–2.48 and -2351–4703 USD ha^{-1}, and 0.08–2.25 and -2980–4085 USD ha^{-1} were achieved for Hogalbunia, Moshamari and Fultola, respectively for both seasons. Furthermore, for both varieties, ZT increased BCR by 243.51 ± 21.85 %, 313.53 ± 23.45 % and 1038.75 ± 229.01 % in comparison to CT for Hogalbunia, Moshamari and Fultola respectively (see Table S5).

In yield simulations, the relative errors resulting from the SOLANUM model calibration were 3.7 and 3.2 % for BARI Alu 72 and 78, respectively. The potential yield simulated using ZT planting dates ranged between 33.7 and 46.6 t ha^{-1} and 29.3–41.0 t ha^{-1} for BARI Alu 72 and 78, respectively, for both seasons (Fig. 5). The potential yield simulated with CT planting dates ranged between 33.4–43.2 and 29.9–38.7 for

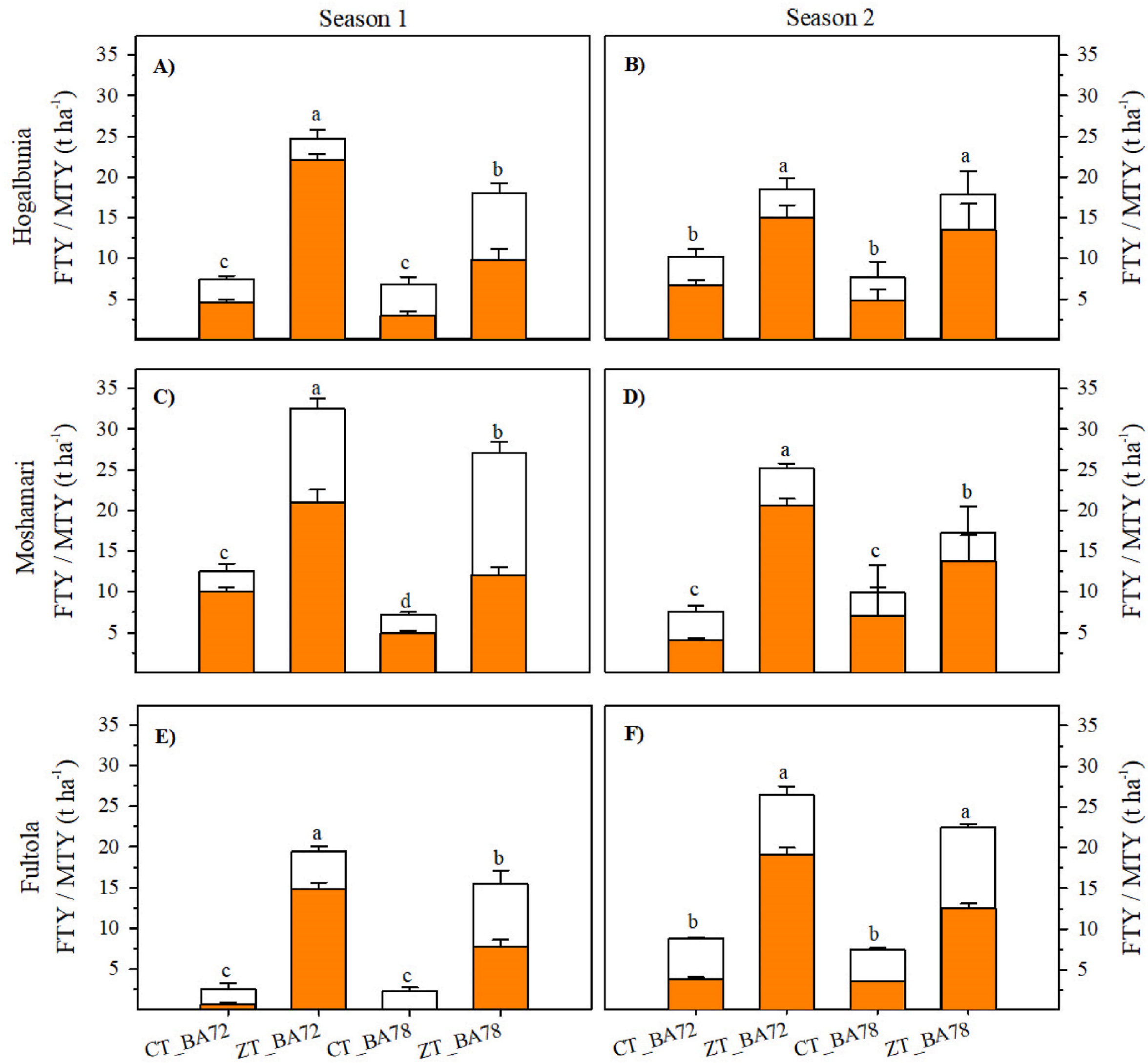

Fig. 3. Average (± standard error) values of marketable (MTY; inner orange bars) and total fresh tuber yield (FTY; white bars) produced under conventional tillage (CT) and zero tillage with rice-straw mulching (ZT) using BARI Alu 72 (BA72) and BARI Alu 78 (BA78) varieties during 2021–22 (season 1; A, C, and E) and 2022-23 (season 2; B, D, and F) seasons for three locations: Hogalbunia (A and B), Moshamari (C and D) and Fultola (E and F) in Khulna district - Bangladesh. The different letters show significant differences assessed by the Least Significant Difference test ($p < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
F-values of Analysis of Variance using the linear mixed-effect model to test the effect of locations (LO), management (MAG), varieties (VAR) and their interactions on marketable tuber yield (MTY), total fresh tuber yield (FTY), and C footprint (CF) during 2021–22 (season 1) and 2022-23 (season 2) seasons. ***p < 0.001, **p < 0.01, *p < 0.05.

Factor	Season 1			Season 2		
	MTY	FTY	CF	MTY	FTY	CF
LO	34.32***	93.36***	18.84***	11.73**	21.5***	4.32**
MAG	328.13***	453.4***	43.25***	85.15***	109.26***	354.1***
VAR	307.78***	33.57***	1.81	7.48*	6.46*	58.77***
LO × MAG	3.64	5.41*	14.9**	0.96	2.84	6.1*
LO × VAR	9.02**	2.21	0.2	0.39	0.17	7.1*
MAG × VAR	121.57***	10.7**	0.74	3.04	1.69	31.8***
LO × MAG × VAR	10.34**	3.1	0.31	0.96	1.63	4.32**

BARI Alu 72 and 78, respectively, for both seasons (Fig. 5). No significant differences (p-value >0.05) were detected between potential yield under ZT and CT planting dates for BARI Alu 72 in season 1 and BARI Alu 78 in both seasons (Fig. 5).

3.2. *Soil organic carbon stocks and soil quality index*

SOC_{stock} was not significantly affected by management, variety, and interaction for any of the locations, but it showed significant differences in the time factor (seasons) (Table 2). The global average SOC_{stock} in

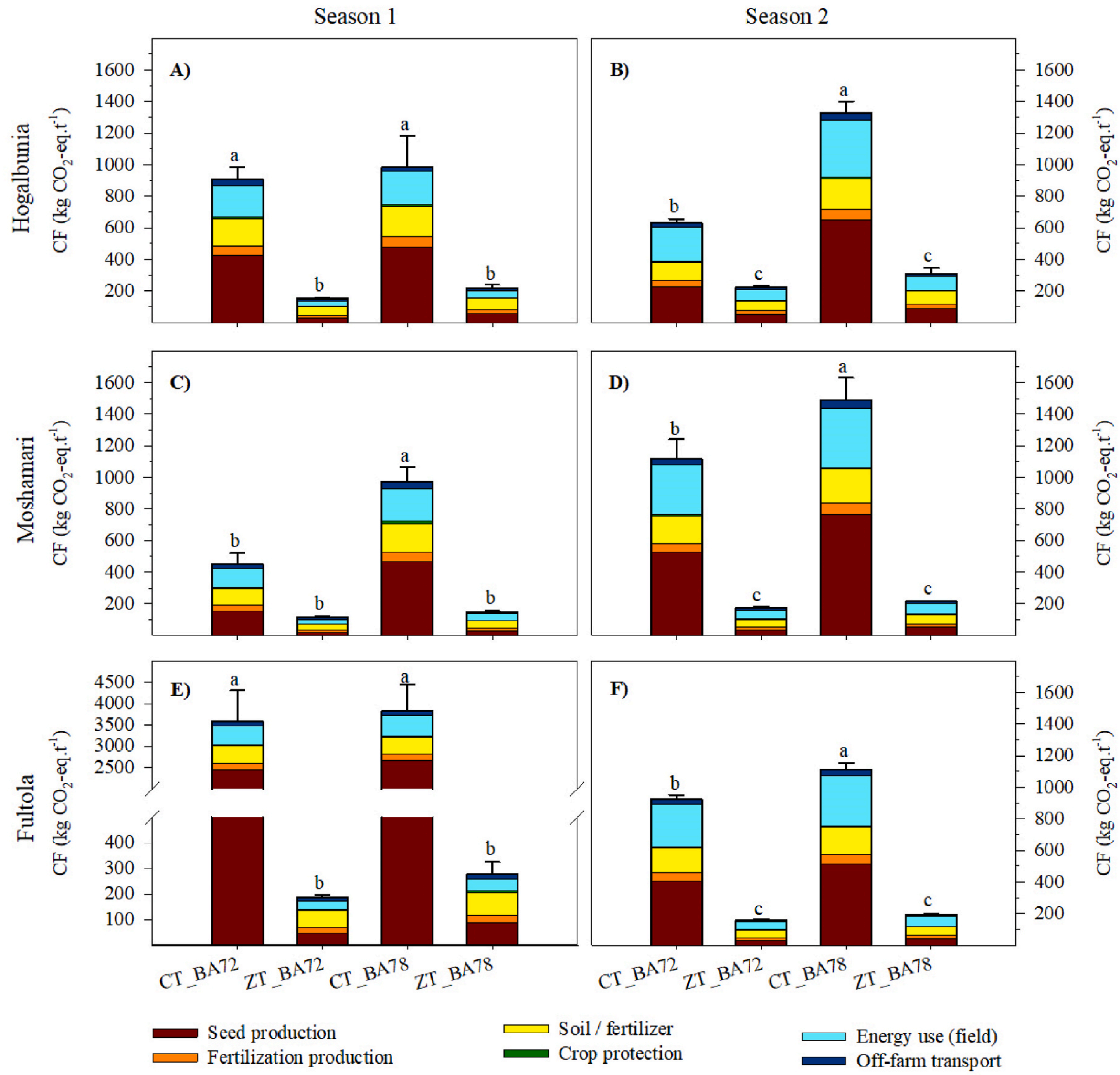

Fig. 4. Average (± standard error) values and different sources of C footprint (CF; in kg CO_2-eq t^{-1} of total fresh tuber) produced under conventional tillage (CT) and zero tillage with rice-straw mulching (ZT) using BARI Alu 72 (BA72) and BARI Alu 78 (BA78) varieties during 2021–22 (season 1; A, C, and E) and 2022-23 (season 2; B, D, and F) seasons for three locations: Hogalbunia (A and B), Moshamari (C and D) and Fultola (E and F) in Khulna district - Bangladesh. The different letters show significant differences assessed by the Least Significant Difference test ($p < 0.05$).

seasons 1 and 2 were 29.0 ± 11.3 and 45.8 ± 9.4 Mg ha^{-1}, respectively. The differences between years for each experimental unit vary from −29.96 to 36.41 Mg ha^{-1} (Fig. 6A). The global average of SOC_{stock} for ZT and CT was 38.7 ± 14.3 and 36.1 ± 12.3 Mg ha^{-1}, respectively (Fig. 6B). No significant differences in SQI could be observed as affected by any factor or interaction except for time (season) (Table 2). The global average of SQI was 0.61 ± 0.010 and 0.64 ± 0.009 in seasons 1 and 2, respectively (Fig. 6C), whereas in ZT and CT, the global average of SQI was 0.62 ± 0.010 and 0.63 ± 0.010, respectively (Fig. 6D). P, $CaCO_3$, Bd, and pH were the soil variables with higher influence in SQI, representing 77.4 % of the total weights (Table S4). During season 1, $CaCO_3$ was higher, and ECe was lower in ZT than in CT (Figs. S1–A). During season 2, SOC and N were higher under ZT, whereas $CaCO_3$ and P were higher under CT (Figs. S1–B). Compared to season 1, SOC and Bd increased, whereas $CaCO_3$ decreased for season 2 (Fig. S1).

4. Discussion

4.1. Zero tillage and mulching enabled productive potato cultivation in southwest Bangladesh

Crop cultivation in the coastal saline area of Bangladesh during the “Rabi” season is limited due to the late harvest of “Aman” rice, a short winter period, heavy soil structure, difficulty in tillage, high soil salinity, lack of fresh irrigation water and water stagnation in the early “Rabi” season [4]. These factors combined make profitable potato cultivation in Southwest Bangladesh nearly impossible [4]. To overcome these issues, this study utilized salt-tolerant varieties well-adapted to the region, such as BARI Alu 72 and BARI Alu 78, to evaluate the potential of ZT technique. Consistent with the results of previous studies [15,16], BARI Alu 72 demonstrates higher yields under saline soil conditions compared to other saline-tolerant BARI Alu varieties, indicating that it is the most suitable variety for potato production in Southwest of Bangladesh. Despite the challenging saline conditions, the potato yield obtained under ZT (19.8–25.5 t ha^{-1}) presented in this study was similar to the average national yield (21.9 t ha^{-1}; [50]), and was in the range of the

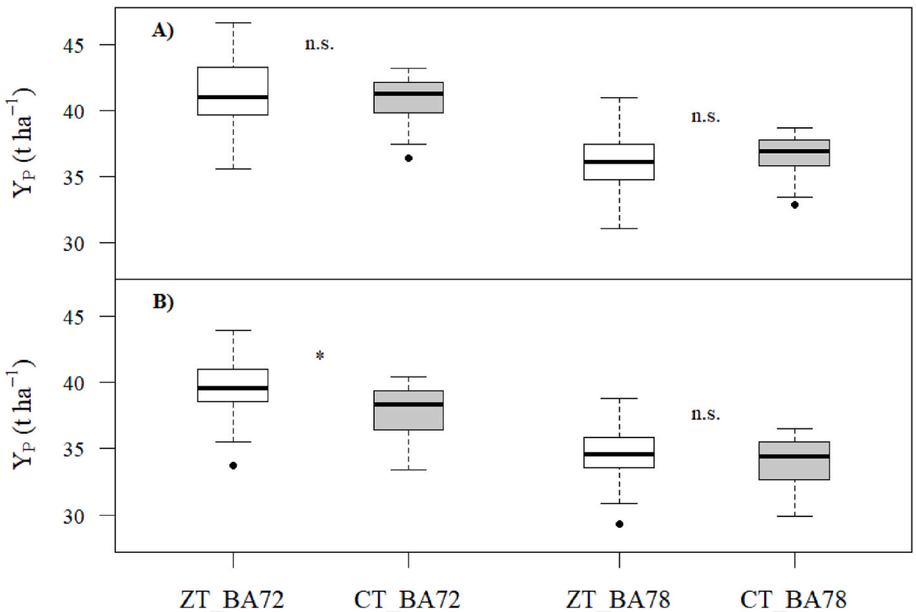

Fig. 5. Potential potato yield (Y_p) simulated by the SOLANUM model for BARI Alu 72 (BA72) and BARI Alu 78 (BA78) using the planting dates of zero tillage with rice-straw mulch (ZT) and conventional tillage (CT) management treatments for 2021–22 (A) and 2022–2023 (B) seasons. Planting dates were December 20 (ZT) and January 12 (CT) for the 2021–22 season; and December 14 (ZT) and December 31 (CT) for the 2022–23 season. Harvest dates were March 27 (2021–22 season) and March 16 (2022–23 season) for both management treatments. Simulations were performed for 20 years (2000–2020) using weather data from NASA's Prediction of Worldwide Energy Resources. * and n. s. Means difference significative (p-value <0.05) and not significative (p-value >0.05) detected by the Kruskal-Wallis rank sum test.

Table 2
Analysis of Variance with Satterthwaite's method assessing the effect of management (MAG), varieties (VAR), and seasons for soil organic carbon stocks and soil quality index in each location. Mean of Squares (MS), Denominator of the degree of freedom (DDF), Calculated F (F). ***p < 0.001, **p < 0.01, *p < 0.05.

Location	Factor	Soil Organic C Stocks			Soil Quality Index		
		MS	DDF	F	MS	DDF	F
Hogalbunia	MAG	176.6	27	3.03	9.65×10^{-3}	6	0.899
	VAR	8.75	27	0.15	0.0158	53	1.470
	MAG × VAR	79.8	27	41.7	4.67×10^{-4}	53	0.044
	season	79.8	27	1.37**	0.073	53	6.802*
Fultola	MAG	46.0	21	0.63	2.05×10^{-4}	6	0.029
	VAR	142.4	21	1.98	3.94×10^{-4}	53	0.057
	MAG × VAR	3.1	21	0.04	5.65×10^{-3}	53	0.816
	season	3469.9	21	48.19**	0.0917	53	13.24***
Moshamari	MAG	12.4	27	0.12	0.0142	59	2.88
	VAR	35.4	27	0.34	7.0×10^{-6}	59	0.001
	MAG × VAR	119.1	27	1.14	0.0004	59	0.087
	season	1151.9	27	10.9**	0.049	59	9.86**

values (17.08–29.6 t ha^{-1}) obtained by Sarangi et al. [14,19,51] under the same management condition (15 cm of rice straw thickness) in the coastal region of the Ganges Delta. This method even allowed to endure floodings caused by heavy rainfall events as occurred in season 1 (Fig. 2), which compromised tuber yield under CT, especially in the Fultola site (Fig. 3), it also allows to reduce soil salinity as reported by Sarangi et al. [14,19,51] in the same study region. These findings highlight the potential of ZT for sustainable agricultural intensification and climate adaptation in Bangladesh, where potatoes are generally not a crop, provided that the availability of freshly harvested rice straw, quality tuber seed and labor for planting is ensured. Conversely, the overall values of cost of cultivation of this study exceed the values reported by other studies such as Sarangi et al. [14,51] under ZT. Similarly, the increased profitability of ZT compared to CT expressed in BCR (1.89 ± 0.20) and net return (2800.08 ± 621.26 USD ha^{-1}) in both seasons due to savings in the labor (human and machinery) and irrigation cost, coincides with previous reports in a similar agroecology [14,19,51].

In this study, the two tillage methods were planted at different times. ZT was planted immediately after the "Aman" rice harvest, while CT was delayed 15–25 days. The delay in CT is due to monsoon flooding, which recedes from October to late December [8], delaying drainage and "Rabi" crop cultivation. Additionally, the heavy silty clay soils in the region retain moisture [13], preventing optimal field preparation and planting times and thus delaying potato crop establishment under CT. Furthermore, these soil characteristics are extremely hard when dry, creating unfavorable conditions for field preparation and crop growth. It has been reported that delayed planting dates can cause potato yield reduction [52,53], especially in Bangladesh, where the winter (end of November to end of January) is very short [7] and compromising the tuberization process. In this context, potatoes planted under ZT achieved better conditions for crop growth because they allowed planting immediately after the rice harvest and maintained good soil moisture levels, avoiding the formation of hard soil layers. In addition, it can enable a more appropriate growing season if high-intensity rainfall increases in the future owing to climate change [54]. The simulation

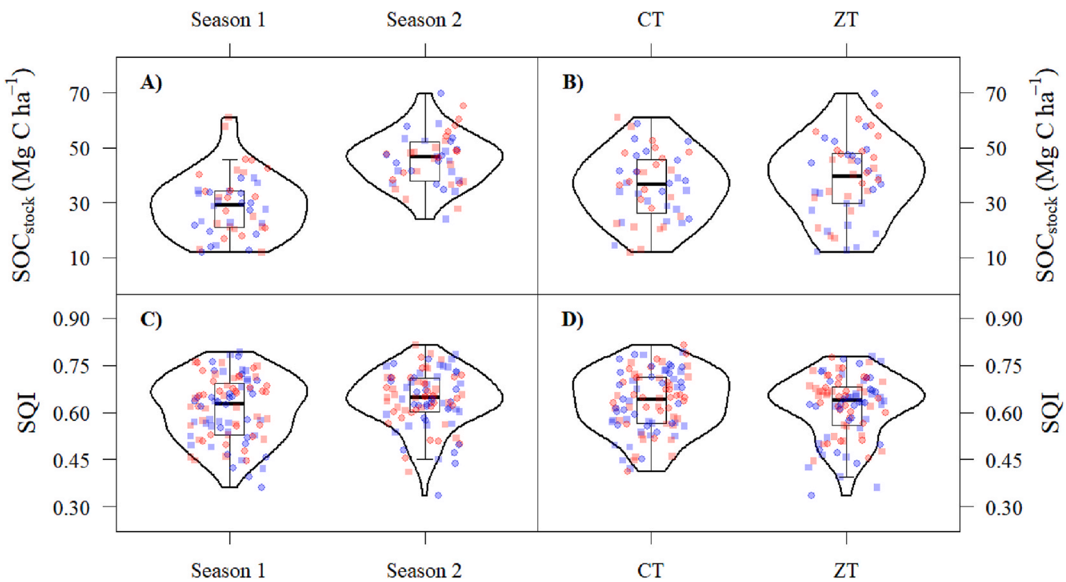

Fig. 6. Soil organic carbon stock (SOC_{stock}) and soil quality index (SQI) showing temporal changes from the 2021–22 (season 1) and 2022–23 (season 2) potato growing seasons (A and C), and comparison between conventional (CT) and zero tillage with rice-straw (ZT) managements (B and D). Symbols in red and blue color represent BARI Alu 72 and BARI Alu 78 varieties, respectively. Square and circle symbols represent CT and ZT management, respectively, in subfigures A and C, whereas those symbols represent season 1 and season 2, respectively, in subfigures B and D. Each value integrates soil samples assessed in 0–0.15 and 0.15–0.30 m depth profiles. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

exercise using the SOLANUM crop model in this study showed that the different timings of potato cultivation used by both methods in this study did not primarily affect the potential yield (Fig. 5), suggesting that this factor could not have contributed significantly to the differences in the yield performance observed and thus did not support the initial hypothesis. A potential factor that could influence the reduced yield of CT compared to ZT is seed deterioration. Cold storage facilities are closed in early November, and because of the delayed planting of CT, seeds were stored at room temperature for a longer time, which could have affected their quality.

The harvest in this study was established when plants were in the senescence stage (see section 2.3), which co-occurred under CT and ZT during both seasons. Because plants were sown 15–25 days later under CT, potatoes under CT reached the senescence stage earlier (74 and 76 days in seasons 1 and 2) than plants under ZT (97 and 92 days in seasons 1 and 2). The time to senescence for the varieties used in this study is normally around 90 days. Thus, senescence was significantly accelerated under CT at these locations, whereas it could be considered normal to slightly delayed under ZT. Senescence is intricately regulated by both internal (aging and phytohormones) and external (environmental stress) factors [55,56]. Gayler et al. [57] found that high temperatures and N shortage can accelerate leaf senescence in potatoes. In contrast, ZT has been reported to effectively reduce N leaching and regulate soil temperature [14,58,59], which can promote delayed senescence. Evidence of this interaction (delayed senescence under ZT) has been observed in crops such as wheat [60], tomatoes [61], and potatoes [62]; however, the underlying mechanisms are still not fully understood. In ecophysiological studies, it has been reported that delayed senescence (measured as the slope of chlorophyll reduction) in potatoes is related to a higher yield [63–65], because there is a more extended period for photosynthesizing with a concomitant C translocation to tubers [66,67]. A higher parameter duration related to a higher permanence of canopy cover in modeling exercises also supports the hypothesis of higher yield under delayed senescence in potatoes [28]. Delayed senescence promoted by ZT could explain the higher yield, but this hypothesis must be addressed in future studies.

Potato cultivation under ZT resulted in a significant 62.6–96.9 % decrease of CF compared to CT. The lower yield of potatoes in CT was found to be mainly due to C emissions from "seed production" (Fig. 4), which is directly related to the amount of tuber biomass generated compared to the initial biomass of seed tubers planted [26]. Assuming that tuber seeds have the same carbon emission charges as the potato crop, the lower yield is attributed to an inefficient process, leading to a higher energy consumption to achieve similar production levels [26]. Adverse conditions can also increase carbon release through root respiration [68,69]. This suggests that potatoes under CT may have experienced these adverse conditions, resulting in carbon losses that are not compensated by carbon assimilation through photosynthesis. On the other hand, the primary source of C emissions for ZT is the interaction between soil and fertilizer (Fig. 4). This is mainly due to poor soil drainage, clay soil, high compaction, and a high-water table, which can create anaerobic conditions that reduce soil nitrification [70,71]. These conditions may indirectly lead to carbon emissions [72].

4.2. Alkalinity, calcium carbonates, and clay conditions promoted soil quality index behavior in the study area

Based on the PLS method, this study proposes a SQI adapted to local conditions (calcareous, clay, and alkaline soil). This method ranks the soil indicators based on their relationship with tuber yield, eliminating the effect of tillage methods (see section 2.4). P and $CaCO_3$ were the soil variables with higher weights and negatively influenced this index (Table S4). The apparent paradox of why increased P has a negative effect on the index, and thus an inverse relationship with yield, can be explained by specific soil conditions. In anaerobic soils (promoted by clay quantity) under reducing conditions, P becomes more soluble and therefore more available to plants [73]. This increase in availability should improve crop yields. However, in alkaline soils (such as the study area, average pH = 7.7) and the high presence of $CaCO_3$, P combines with Ca, reducing its availability and crop yield [74]. On the other hand, in flooded soil conditions, Fe^{3+} is reduced to Fe^{2+}, whose mobility is reduced in the high presence of P [75]. A high deficiency of Fe promoted by P competition could also explain the reduced yield under a high quantity of P. The increase in carbonates decrease the potato yield [76], which is consistent with the negative influence of $CaCO_3$ on SQI. On the other hand, the high presence of uncharged $CaCO_3$ in the clay structure decreases the soil's capacity to retain and supply essential nutrients [77]. This could explain the low cation exchange capacity in clay soils of the study area (12.5–25.7 cmolc kg^{-1}, data not shown). The reductions in P (especially under ZT) and $CaCO_3$ in season 2 (Fig. S1) were the main reasons for the significant temporal increase in the SQI (Fig. 6C). Zero-tillage causes soil compaction, which affects the Bd rise in the first years [78]. Its coefficient in SQI was 0.92 (Table S4), which means that the maximum detected increment (Bd maximum – Bd minimum = 0.41 Mg ha^{-1}, Table S2) could cause an increment of 0.37 t ha^{-1} of tuber yield. Although Bd positively influenced the SQI and explained 19 % of this, this variable had a low impact on yield prediction. The increase in salinity (using ECe as an indicator) reduced the SQI; however, similar to Bd, its effect on yield prediction was low (ECe explained only 12 % of the SQI, Table S4). Contrary to the report by Sarangi et al. [14,19], ZT did not cause salinity reduction compared to CT in some zones of the Ganges Delta (Fig. S1). Clay soils with poor aeration have a low nitrification rate [69], causing ammonium to remain in the soil and be absorbed by plants. The alkaline and reducing conditions of the evaluated locations (calcareous grey floodplain soil) caused urea to be hydrolyzed as ammonium and not transformed into NO_2. The positive SQI coefficient for N (+0.04) and negative SQI coefficient for NO_2 (−0.27) suggested that ammonium was the predominant N form in the studied soils. Anaerobic conditions also drive slow decomposition of organic matter [79]. This phenomenon could be exacerbated under ZT in the clay study soil because this management trend increases anaerobic micro-sites in the soil [80] and reduces soil respiration. The increment in SOC in season 2 (especially under ZT; see Fig. S1) can explain the temporal rise in N because the main source of ammonium comes from organic matter and is associated with SOC.

4.3. Agriculture diversification can promote the increase of soil C stocks in challenging soils

Soil salinity significantly hampers soil health, agricultural productivity, and local livelihoods in the coastal region of Southwest Bangladesh [81]. Farmers in these areas typically cultivate only a single "Aman" rice crop during the monsoon season [82]. The soil health and production of "Rabi" crops remain limited. Sarangi et al. [14,19,51] reported that potato cultivation under ZT can reduce soil salinity in these areas. ZT practices can also significantly enhance soil health by increasing SOC levels depending on crop type (perennials exhibit more notable increases, [83]), soil profile [84]), and duration after ZT implementation [85]. Dewil et al. [86] and Acir et al. [87] detected substantial SOC_{stock} increments over 8 and 11 years, respectively. Long-term zero tillage on marginal agricultural lands increases the organic carbon content by approximately 0.35 Mg ha^{-1} $year^{-1}$ [88]. In temperate climates, changes in SOC_{stock} due to zero-tillage can be observed after 6 years of adoption [89]. In tropical climates, zero tillage increases SOC_{stock} by altering the chemical composition of stored organic carbon and reducing the susceptibility to mineralization over 15–30 years [90]. Although some studies in the Ganges Delta have reported an SOC increase promoted by ZT [14,19], the lack of a significant increase in SOC_{stock} under different potato management regimes in this study is likely due to the short-term nature of our trials. This practice would require a long-term continuation to improve soil C sequestration.

Intensive agricultural practices, characterized by high input usage and exhaustive tillage, significantly contribute to global land degradation, resulting in reduced organic matter [91]. This issue is particularly acute in regions facing environmental constraints, such as the coastal areas of Bangladesh, where salinity stress is escalating [92]. In response, crop diversification incorporating sustainable practices such as regenerative and conservation agriculture has emerged as a sustainable solution [93]. These practices enhance farmers' incomes [94,95] and improve soil health [96]. Recent studies [51] have highlighted that diversifying rice systems with potatoes under ZT and green gram in the Ganges Delta region can lead to improved rice equivalent yield (>10 t ha^{-1}), nearly double the net return, and a reduction in soil salinity, C footprint, and water usage. While this study did not initially observe a notable increase in SOC_{stock} from practices such as ZT, the subsequent potato cropping season revealed a positive trend (Fig. 6-A). This underscores the significance of rice diversification using potatoes for potential soil carbon sequestration, suggesting that agricultural diversification in challenging environments (like Southwest Bangladesh) can contribute to climate change mitigation efforts.

4.4. Future directions for scaling and adoption of potato under zero tillage and mulching technology

Community Nutrition Scholars (CNS) are individuals from local communities trained to promote nutritional awareness and support health and hygiene practices in Southwest Bangladesh [97]. In the Khulna district, CNS has promoted potato cultivation under ZT in coordination with local partners. During the 2021–22 "Rabi" season, a group of trained young women from the CNS provided courtyard training to community women farmers on ZT, health, hygiene, and nutrition, reaching 428 households [98]. Subsequently, 56 % of the participants adopted ZT without any subsidies or funding support, and 1295 households newly tested this technology through peer learning, demonstrating the effectiveness of on-farm demonstrations for scaling. Potato seed accessibility, availability and price of straw mulch, lack of fresh irrigation water during the production period, and severity of rodent pest infestation were recognized as the main constraints for adopting ZT [98]. Overcoming the above-mentioned constraints through local and regional governmental efforts could allow the scale of this technology to approximately 0.37 Mha, which is the approximate area of rice fields [99] growing very slightly (<2 dS m^{-1}) and slightly (3–7 dS m^{-1}) saline zones in Bangladesh (0.79 Mha) defined by Rahman and Uddin [100].

5. Conclusion

The cultivation of potatoes under ZT in the Southwest of Bangladesh mitigated the limitations of potato production under CT, allowing a stable and good yield (22.1 ± 0.89 t ha^{-1}), C footprint reduction (−1246 ± 295 kg CO_2-eq t fresh $tuber^{-1}$), and more resilience to extreme rainfall events, which will be crucial for climate change adaptation. Saline-tolerant improved potato varieties are essential in this region, with BARI Alu 72 proving to be a particularly suitable option. In addition, reducing labor and dependence on external inputs allows farmers to save production costs owing to less use of labor by avoiding tillage and earthing up and less use of irrigation application. Although our crop modeling exercise did not provide evidence that early cultivation of potatoes provided an advantage of ZT over CT, this factor will be crucial in the future, considering that monsoons become stronger and less predictable in the area. A potentially delayed senescence promoted by ZT is a phenomenon that requires more attention in future research. This could allow more time for C assimilation with a concomitant increase in yield. SOC_{stock} did not significantly increase under ZT. However, this variable increased in the second season, highlighting the potential for the diversification of rice systems with potatoes. Long-term studies (5–10 years) are recommended to visualize SOC_{stock} increments promoted by potatoes under ZT.

Alkalinity, calcium carbonates, and anaerobic conditions (driven by high clay content and flooding) were the main factors that promoted the behavior of the proposed site-specific SQI. P and $CaCO_3$ were the principal soil indicators that negatively influenced SQI, likely affecting Fe uptake and retention of other nutrients, respectively. The findings of this study suggest that iron-containing fertilizers may be necessary to correct this deficiency and improve crop yields. In addition, it is crucial to consider the interactions between nutrients and soil physical properties in agronomic management plans. Understanding soil mineralogical composition is crucial for improving nutrient management strategies and suggests the need for amendments that increase cation exchange capacity and improve soil fertility.

Research activities may be conducted in other low-lying regions where only a single crop ("Aman" rice) is grown to broaden the dissemination of ZT for potato production in rice systems. Promoting these sustainable practices requires the government to promote policies and extension services for ZT adoption and scaling through more field demonstrations, CNS reinforcement, and close coordination with local partners/agencies. However, there is a need to address potential limitations related to potato seed access, straw mulch availability, lack of fresh irrigation water, and rodent pest infestation to guarantee future adoption and scaling of this promising technology.

CRediT authorship contribution statement

David A. Ramírez: Writing – original draft, Supervision, Methodology, Conceptualization. **M. Monower Hossain:** Writing – original draft, Software, Investigation, Formal analysis, Data curation. **E.H.M. Shofiur Rahaman:** Writing – review & editing, Supervision, Investigation, Data curation, Conceptualization. **Carlos Mestanza:** Writing – original draft, Software, Methodology, Formal analysis. **Javier Rinza:** Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Johan Ninanya:** Writing – original draft, Visualization, Software, Formal analysis. **Felipe de Mendiburu:** Writing – review & editing, Software, Formal analysis. **Hildo Loayza:** Writing – review & editing, Software, Formal analysis, Conceptualization. **Marcel Gatto:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Jan F. Kreuze:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was funded by The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) through the fund for the promotion of innovation in agriculture (i4Ag): "Potato production through zero-tillage with straw mulch: an innovative technology for sustainable intensification and diversification of rice-based systems to improve livelihoods of small-scale farmers in Asia" (Agreement N°: 81275993). Special acknowledgment goes to Swapan Roy from OFRD-BARI for his support in the selection study area, experimental setup, and technical support.

Abbreviations:

BARI – Bangladesh Agricultural Research Institute, Bd – dry bulk density, CF – C footprint, CNS – Community Nutrition Scholars, CT – conventional cultivation, DAP – days after planting, ECe – electrical conductivity, FTY – Fresh tuber yield, MTY – Marketable tuber yield, PLS – partial least square, SOC – soil organic carbon concentration, SOC_{stock} – soil organic carbon stock, SQI – soil quality index, TSV – target soil variables, ZT – zero tillage with rice-straw mulch.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2024.101603.

Data availability

The data that support the findings of this study are openly available in the CGIAR Dataverse repository at https://doi.org/10.21223/CAQQ9N and https://doi.org/10.21223/TJFYYD

References

[1] M.T. Sultan, U. Mahmud, M.Z. Khan, Addressing soil salinity for sustainable agriculture and food security: innovations and challenges in coastal regions of Bangladesh, Future Foods (2023) 100260, https://doi.org/10.1016/j.fufo.2023.100260.

[2] M.Y. Miah, M.Z.U. Kamal, M.A. Salam, M.S. Islam, Impact of salinity intrusion on agriculture of Southwest Bangladesh-A review, Int. J. Agric. Pol. Res. 8 (2) (2020) 40–47, https://doi.org/10.15739/IJAPR.20.005.

[3] Bangladesh Center for Advanced Studies (BCAS), Bangladesh Center for Advanced Studies (BCAS), Assessing long-term impacts and vulnerabilities on crop production due to climate change in coastal areas of Bangladesh, Final report (2010) 10 (8) (2010).

[4] M.A. Ali, M.K. Shahadat, M. Rashid, Performance of zero tillage potato cultivation with different mulch materials in the south-western saline area of Bangladesh, Proceedings 36 (1) (2019) 29, https://doi.org/10.3390/proceedings2019036029.

[5] M.A. Rahim, N. Sultana, A.T.M. Mannan, N.U. Ahmed, Potato production in Bangladesh, in: Book: Potato Production Worldwide, Academic Press., Cambridge, 2023, pp. 397–407.

[6] FAOSTAT, Food and agriculture data, Food and Agriculture Organization of the United Nations (2024). https://www.fao.org/faostat/en/#home. (Accessed 17 June 2024).

[7] M.A.A. Mamun, A.A. Mahmud, M. Zakaria, M.M. Hossain, M.T. Hossain, Effects of planting times and plant densities of top-shoot cuttings on multiplication of breeder seed potato, Agri. and Natural Resources 50 (1) (2016) 26–31, https://doi.org/10.1016/j.anres.2014.08.001.

[8] S.A. Haque, Salinity problems and crop production in coastal regions of Bangladesh, Pakistan J. Bot. 38 (5) (2006) 1359–1365. https://www.researchgate.net/publication/228724784_Salinity_problems_and_crop_production_in_coastal_regions_of_Bangladesh.

[9] D.E. Johnson, E. Humphreys, Enhancing the productivity and sustainability of cropping systems in the coastal zones of tropical deltas of Asia, Field Crops Res. 263 (2021) 108059, https://doi.org/10.1016/j.fcr.2021.108059.

[10] M.Y. Miah, M.Z.U. Kamal, M.A. Salam, M.S. Islam, Impact of salinity intrusion on agriculture of Southwest Bangladesh-A review, Int. J. Agric. Pol. Res. 8 (2) (2020) 40–47, https://doi.org/10.15739/IJAPR.20.005.

[11] D.A. Ramírez, C. Silva-Díaz, J. Ninanya, M. Carbajal, J. Rinza, S.K. Kakraliya, M. Gatto, J. Kreuze, Potato zero-tillage and mulching is promising in achieving agronomic gain in Asia, Agronomy 12 (2022) 1494, https://doi.org/10.3390/agronomy12071494.

[12] S.K. Sarangi, B. Maji, S. Digar, K.K. Mahanta, P.C. Sharma, M. Mainuddin, Zero tillage potato cultivation, Indian Farming 68 (4) (2018) 23–26. https://epubs.icar.org.in/index.php/IndFarm/article/view/81722.

[13] M.N. Rahman, M.G.M. Amin, M.K. Mondal, S.E. Humphrey, Rabi crop establishment methods for increasing land productivity in the coastal zone of Bangladesh. Conference Proceedings of Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices, Colombo, Sri Lanka, 2015, pp. 504–515.

[14] S.K. Sarangi, B. Maji, P.C. Sharma, S. Digar, K.K. Mahanta, D. Burman, U. K. Mandal, S. Mandal, M. Mainuddin, Potato (*Solanum tuberosum* L.) cultivation by zero tillage and paddy straw mulching in the saline soils of the Ganges Delta, Potato Res. 64 (2021) 277–305, https://doi.org/10.1007/s11540-020-09478-6.

[15] M. Rahman, H. Rashid, M.K. Shahadat, A.A. Topu, A. Hossain, S.A.I. Nihad, Field performance of some potato varieties under different saline conditions of Bangladesh, Afr. J. Agric. Res. 17 (11) (2021) 1480–1487.

[16] M.M. Islam, M.N. Uddin, S. Naznin, M.N. Amin, M.R.H. Mondol, A. Naznin, M. Z. Ferdous, M. Salim, R.M. Karim, B.C. Kundu, Screening for export potential potato varieties in Bangladesh, Int. J.Plant Soil Sci. 34 (20) (2022) 623–634, https://doi.org/10.9734/ijpss/2022/v34i2031197.

[17] E.H.M.S. Rahaman, N. Kawarazuka, Potato zero tillage using rice straw mulch. Technology Brief. Hanoi, Vietnam: CGIAR Initiative on Asian Mega-Deltas. https://hdl.handle.net/10568/134581, 2023.

[18] A. Ojah, D. Bhattacharjee, Zero tillage (ZT) potato cultivation, Bhartiya Krishi Anusandhan Patrika 36 (4) (2022) 347–349, https://doi.org/10.18805/BKAP35.

[19] S.K. Sarangi, M. Mainuddin, S. Raut, U.K. Mandal, K.K. Mahanta, Coastal salinity management and cropping system intensification through conservation agriculture in the Ganges delta, Soil Systems 8 (2024) 80, https://doi.org/10.3390/soilsystems8030080.

[20] S.M. Imamul Huq, J.U. Md Shoaib, Major soil types, The Soils of Bangladesh. World Soils Book Series 1 (2013) 41–49. Springer, Dordrecht.

[21] M.M.H. Raziuddin Khan, M.K. Shahadat, S.S.A. Kamar, T.T.A. Bhuiyan, M. S. Rahman, M.Z. Rahman, H.M. Khairul Bashar, Phenology, thermal time requirement, growth and yield of winter mungbean (*Vigna radiata*) as influenced by sowing dates in Ganges tidal floodplain (AEZ-13) in Bangladesh, Op. Acc. J. Bio. Sci. & Res. (2020), https://doi.org/10.46718/JBGSR.2020.04.000092.

[22] S. Ahmmed, M. Jahiruddin, S. Razia, R.A. Begum, J.C. Biswas, A.S.M.M. Rahman, M.M. Ali, K.M.S. Islam, M.M. Hossain, M.N. Gani, G.M.A. Hossain, M.A. Satter, Fertilizer Recommendation Guide-2018, Bangladesh Agricultural, vol. 1215, Research Council (BARC), Farmgate, Dhaka, 2018, p. 223p.

[23] BARC, Crop Production Technology, Potato, AGRI-ADVISORY PORTAL. Bangladesh Agricultural Research Council (BARC), Ministry of Agriculture, 2023. http://cropzoning.gov.bd:82/CropInfo/ProductionTechs?c=36.
[24] S.K. Kakraliya, M. Gatto, D.A. Ramírez, J. Kreuze, B. Kumar, Manual on potato production through zero tillage and straw mulch, International Potato Center (2024) 46. Lima, Peru.
[25] R.A. Jefferies, H.M. Lawson, A key for the stages of development of potato (*Solanum tuberosum*), Ann. Appl. Biol. 119 (1991) 387–399, https://doi.org/10.1111/j.1744-7348.1991.tb04879.x.
[26] M.H. Rahman, M.M. Alam Patwary, H. Barua, M. Hossain, M.M. Hasan, Screening of salt tolerant CIP potato germplasm for saline areas, The Agriculturists 11 (1) (2013) 95–102, https://doi.org/10.3329/agric.v11i1.15249.
[27] Cool farm alliance, Version 2.11.0. Available online: https://app.coolfarmtool.org/account/login/. (Accessed 16 February 2024).
[28] A.J. Haverkort, J.G. Hillier, Cool farm Tool – potato: model description and performance of four production systems, Potato Res. 54 (2011) 355–369, https://doi.org/10.1007/s11540-011-9194-1.
[29] CIP-PSE Division, Solanum, URL: http://cipotato.org/site/inrm/home/downmod.htm. (Accessed 16 January 2023).
[30] R. Quiroz, H. Loayza, C. Barreda, C. Gavilán, A. Posadas, D.A. Ramírez, Linking process-based potato models with light reflectance data: does model complexity enhance yield prediction accuracy? Eur. J. Agron. 82 (2017) 104–112, https://doi.org/10.1016/j.eja.2016.10.008.
[31] D. Harahagazwe, B. Condori, C. Barreda, A. Bararyenya, A.A. Byarugaba, D. A. Kude, C. Lung'aho, C. Martinho, D. Mbiri, B. Nasona, B. Ochieng, J. Onditi, J. M. Randrianaivoarivony, C.M. Tankou, A. Worku, E. Schulte-Geldermann, V. Mares, F. de Mendiburu, R. Quiroz, How big is the potato (*Solanum tuberosum* L.) yield gap in Sub-Saharan Africa and why? A participatory approach, Open Agric 3 (1) (2018) 180–189, https://doi.org/10.1515/opag-2018-0019.
[32] A. Al Mahmud, M.J. Alam, B.C. Kundu, M. Skalicky, M.M. Rahman, E. S. Rahaman, M. Sultana, M.S.H. Molla, A. Hossain, A.M. El-Shehawi, M. Brestic, A.E. Sabagh, Selection of suitable potato genotypes for late-sown heat stress conditions based on field performance and stress tolerance indices, Sustainability 13 (5) (2021) 2770, https://doi.org/10.3390/su13052770.
[33] A.H. Sparks, nasapower: a NASA POWER global meteorology, surface solar energy and climatology data client for R, J. Open Source Softw. 3 (30) (2018) 1035, https://doi.org/10.21105/joss.01035.
[34] K.H. Mahmud, S.B. Abid, R. Ahmed, Development of a climate classification map for Bangladesh based on Koppen's climatic classification, Soc. Sci. 39 (2018) 23–36. https://www.researchgate.net/publication/354381452_Development_of_Climate_Classification_Map_for_Bangladesh_Based_on_Koppen's_Climate_Classification.
[35] R Core Team, R:, A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, 2023. https://www.R-project.org/.
[36] ISO, ISO 11272:2017(en) Soil quality — Determination of dry bulk density, 2017.
[37] O. Rinot, G.J. Levy, Y. Steinberger, T. Svoray, G. Eshel, Soil health assessment: a critical review of current methodologies and a proposed new approach, Sci. Total Environ. 648 (2019) 1484–1491, https://doi.org/10.1016/j.scitotenv.2018.08.259.
[38] M. Mayer, Package "outForest": multivariate outlier detection and replacement. https://github.com/mayer79/outForest, 2023.
[39] V. de Paul Obade, R. Lal, Towards a standard technique for soil quality assessment, Geoderma 265 (2016) 96–102, https://doi.org/10.1016/j.geoderma.2015.11.023.
[40] B.H. Mevik, R. Wehrens, The pls package: principal component and partial least squares regression in R. J. Stat, Software 18 (2) (2007), https://doi.org/10.18637/jss.v018.i02.
[41] M. Kuhn, J. Wing, S. Weston, A. Williams, C. Keefer, A. Engelhardt, T. Cooper, Z. Mayer, B. Kenkel, R. Core Team, M. Benesty, R. Lescarbeau, A. Ziem, L. Scrucca, Y. Tang, C. Candan, T. Hunt, Package 'caret': classification and regression training, The R Journal 223 (7) (2020). https://github.com/topepo/caret/.
[42] J.W. Wendt, S. Hauser, An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers, Eur. J. Soil Sci. 64 (1) (2013) 58–65, https://doi.org/10.1111/ejss.12002.
[43] A.F. Fowler, B. Basso, N. Millar, W.F. Brinton, A simple soil mass correction for a more accurate determination of soil carbon stock changes, Sci. Rep. 13 (1) (2023), https://doi.org/10.1038/s41598-023-29289-2.
[44] D.W. Pribyl, A critical review of the conventional SOC to SOM conversion factor, Geoderma 156 (3–4) (2010) 75–83, https://doi.org/10.1016/j.geoderma.2010.02.003.
[45] M. Hossain, E. Rahaman, M. Gatto, J. Kreuze, J. Rinza, M. Carbajal, D. Ramirez, Potato production through zero-tillage with straw mulch during 2021-2022 season in agronomic trials in the Khulna district, Bangladesh (Soil analysis and yield data), International Potato Center V1 (2022), https://doi.org/10.21223/CAQQ9N.
[46] M. Hossain, E. Rahaman, M. Gatto, J. Kreuze, J. Rinza, M. Carbajal, D. Ramirez, Potato production through zero-tillage with straw mulch during 2022-2023 season in agronomic trials in the Khulna district, Bangladesh (Soil analysis and yield data), International Potato Center V1 (2023), https://doi.org/10.21223/TJFYYD.
[47] A. Kuznetsova, P.B. Brockhoff, R.H.B. Christensen, lmerTest package: tests in linear mixed effects models, J. Stat. Software 82 (13) (2017), https://doi.org/10.18637/jss.v082.i13.
[48] L. Sandrini-Neto, E. Gilbert, M. Camargo, Package "GAD": analysis of variance from general principles. https://cran.r-project.org/package=GAD, 2024.
[49] F. de Mendiburu, Agricolae: statistical procedures for agricultura research, R package version 1 (2023) 3–7. https://CRAN.R-project.org/package=agricolae.
[50] Bangladesh Bureau of Statistics (BBS), Yearbook of Agricultural Statistics 2022, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, 2023.
[51] S.K. Sarangi, M. Mainuddin, R.W. Bell, S. Digar, Rice-zero tillage potato-green gram and conservation agriculture enable sustainable intensification in the coastal region, JISCAR 42 (2024) 88–97, https://doi.org/10.54894/JISCAR.42.1.2024.147322.
[52] K.S. Krishnappa, Effect of planting time on the yield and yield attributes of potato in Eastern Karnataka, Current Research University of Agricultural Sciences Bangalore 20 (11) (1991) 239–240.
[53] J. Peter, W. Cerng, L. Hruska, Yield Formation in potatoes, in: J. Peter, W. Cerng, L. Hruska (Eds.), Yield Formation in the Main Field Crops, University of Agriculture, Prague-Suchdol, Czechoslovakia, 1988, pp. 268–296.
[54] S. Shahid, Trends in extreme rainfall events of Bangladesh, Theor. Appl. Climatol. 104 (2011) 489–499, https://doi.org/10.1007/s00704-010-0363-y.
[55] Y. Guo, G. Ren, K. Zhang, Z. Li, Y. Miao, H. Guo, Leaf senescence: progression, regulation, and application, Mol. hortic. 1 (2021) 1–25, https://doi.org/10.1186/s43897-021-00006-9.
[56] L. Shi, L. de Biolley, M.A. Shaikh, M.E. de Vries, S.U. Mittmann, R.G. Visser, S. Prat, C.W. Bachem, Aging later but faster: how StCDF1 regulates senescence in *Solanum tuberosum*, New Phytol. 242 (6) (2024) 19525, https://doi.org/10.1111/nph.19525.
[57] S. Gayler, E. Wang, E. Priesack, T. Schaaf, F.X. Maidl, Modeling biomass growth, N-uptake and phenological development of potato crop, Geoderma 105 (3–4) (2002) 367–383, https://doi.org/10.1016/S0016-7061(01)00113-6.
[58] J. Ding, W. Hu, J. Wu, Y. Yang, H. Feng, Simulating the effects of conventional versus conservation tillage on soil water, nitrogen dynamics, and yield of winter wheat with RZWQM2, Agric. Water Manag. 230 (2020) 105956, https://doi.org/10.1016/j.agwat.2019.105956.
[59] A. Yagioka, M. Komatsuzaki, N. Kaneko, H. Ueno, Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching, Agric. Ecosyst. Environ. 200 (2015) 42–53, https://doi.org/10.1016/j.agee.2014.09.011.
[60] O.M. Kitonyo, V.O. Sadras, Y. Zhou, M.D. Denton, Evaluation of historic Australian wheat varieties reveals increased grain yield and changes in senescence patterns but limited adaptation to tillage systems, Field Crops Res. 206 (2017) 65–73, https://doi.org/10.1016/j.fcr.2017.02.017.
[61] V. Kumar, A. Abdul-Baki, J.D. Anderson, A.K. Mattoo, Cover crop residues enhance growth, improve yield, and delay leaf senescence in greenhouse-grown tomatoes, Hortscience 40 (5) (2005) 1307–1311, https://doi.org/10.21273/HORTSCI.40.5.1307.
[62] L. Chang, F. Han, S. Chai, H. Cheng, D. Yang, Y. Chen, Straw strip mulching affects soil moisture and temperature for potato yield in semiarid regions, Agron. J. 112 (2) (2020) 1126–1139, https://doi.org/10.1002/agj2.20103.
[63] D.A. Ramírez, W. Yactayo, R. Gutiérrez, V. Mares, F. De Mendiburu, A. Posadas, R. Quiroz, Chlorophyll concentration in leaves is an indicator of potato tuber yield in water-shortage conditions, Sci. Hortic. 168 (2014) 202–209, https://doi.org/10.1016/j.scienta.2014.01.036.
[64] X. Li, D.A. Ramírez, J. Qin, R. Dormatey, Z. Bi, C. Sun, H. Wang, J. Bai, Water restriction scenarios and their effects on traits in potato with different degrees of drought tolerance, Sci. Hortic. 108525 (2019), https://doi.org/10.1016/j.scienta.2019.05.052.
[65] C. Silva-Díaz, D.A. Ramírez, J. Rinza, J. Ninanya, H. Loayza, R. Gómez, N. L. Anglin, R. Eyzaguirre, R. Quiroz, Radiation interception, conversion and partitioning efficiency in potato landraces: how far are we from the optimum? Plants 9 (2020) 787, https://doi.org/10.3390/plants9060787.
[66] J.L. Rolando, D.A. Ramírez, W. Yactayo, P. Monneveux, R. Quiroz, Leaf greenness as a drought tolerance related trait in potato (*Solanum tuberosum* L.), Environ. Exp. Bot. 110 (2015) 27–35, https://doi.org/10.1016/j.envexpbot.2014.09.006.
[67] D.A. Ramírez, J.L. Rolando, W. Yactayo, P. Monneveux, R. Quiroz, Is discrimination of 13C in potato leaflets and tubers an appropriate trait to describe genotype responses to restrictive and well-watered conditions? J. Agron. Crop Sci. 201 (2015) 410–418, https://doi.org/10.1111/jac.12119.
[68] T.J. Bouma, D.R. Bryla, On the assessment of root and soil respiration for soils of different textures: interactions with soil moisture contents and soil CO_2 concentrations, Plant Soil 227 (2000) 215–221, https://doi.org/10.1023/A:1026502414977.
[69] H. Lambers, O.K. Atkin, F.F. Millenaar, Respiratory patterns in roots in relation to their functioning, in: Y. Waisel, A. Eshel, U. Kafkaki (Eds.), Plant Roots: the Hidden Half, fourth ed., CRC Press, New York, 2002, pp. 521–552.
[70] L. Cui, D. Li, Z. Wu, Y. Xue, F. Xiao, L. Zhang, Y. Song, Y. Li, Y. Zheng, J. Zhang, Y. Cui, Effects of nitrification inhibitors on soil nitrification and ammonia volatilization in three soils with different pH, Agronomy 11 (8) (2021) 1674, https://doi.org/10.3390/agronomy11081674.
[71] R.M. Longo, W.J.D. Melo, Hidrólise da uréia em latossolos: efeito da concentração de uréia, temperatura, pH, armazenamento e tempo de incubação, Rev. Bras. Ciência do Solo 29 (4) (2005) 651–657, https://doi.org/10.1590/s0100-06832005000400018.
[72] U. Skiba, B. Ball, The effect of soil texture and soil drainage on emissions of nitric oxide and nitrous oxide, Soil Use Manag. 18 (1) (2002) 56–60, https://doi.org/10.1111/j.1475-2743.2002.tb00050.x.
[73] W.H. Patrick, R.A. Khalid, Phosphate release and sorption by soils and sediments: effect of aerobic and anaerobic conditions, Science 186 (4158) (1974) 53–55, https://doi.org/10.1126/science.186.4158.53.

[74] Y. Geng, S. Pan, L. Zhang, J. Qiu, K. He, H. Gao, Z. Li, D. Tian, Phosphorus biogeochemistry regulated by carbonates in soil, Environ. Res. 214 (2022) 113894, https://doi.org/10.1016/j.envres.2022.113894.
[75] L. Montás Ramírez, N. Claassen, A. Amílcar Ubiera, H. Werner, A.M. Moawad, Effect of phosphorus, potassium and zinc fertilizers on iron toxicity in wetland rice (*Oryza sativa* L.), Plant Soil 239 (2) (2002) 197–206, https://doi.org/10.1023/a:1015099422778.
[76] N.P. Rogovska, A.M. Blackmer, A.P. Mallarino, Relationships between soybean yield, soil pH, and soil carbonate concentration, SSSA (Soil Sci. Soc. Am.) J. 71 (4) (2007) 1251–1256, https://doi.org/10.2136/sssaj2006.0235.
[77] L.G. Shields, M.W. Meyer, Carbonate clay: measurement and relationship to clay distribution and cation-exchange capacity, SSSA (Soil Sci. Soc. Am.) J. 28 (3) (1964) 416–419, https://doi.org/10.2136/sssaj1964.03615995002800030034x.
[78] I. Bogunovic, P. Pereira, I. Kisic, K. Sajko, M. Sraka, Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia), Catena 160 (2018) 376–384, https://doi.org/10.1016/j.catena.2017.10.009.
[79] J. Chen, V. Mueller, V. Coastal climate change, soil salinity and human migration in Bangladesh, Nat. Clim. Change 8 (2018) 981–985, https://doi.org/10.1038/s41558-018-0313-8.
[80] S. Mangalassery, S. SjÖGersten, D.L. Sparkes, S.J. Mooney, Examining the potential for climate change mitigation from zero tillage, The J. Agril. Sci. 153 (7) (2015) 1151–1173, https://doi.org/10.1017/s0021859614001002.
[81] M. Salehin, M.M.A. Chowdhury, D. Clarke, S. Mondal, S. Nowreen, M. Jahiruddin, A. Haque, Mechanisms and drivers of soil salinity in coastal Bangladesh. Ecosystem services for well-being in deltas, in: R. Nicholls, C. Hutton, W. Adger, S. Hanson, M. Rahman, M. Salehin (Eds.), Ecosystem Services for Well-Being in Deltas, Palgrave Macmillan, Cham, 2018, pp. 333–347, https://doi.org/10.1007/978-3-319-71093-8_18.
[82] R.R. Saha, M.A. Rahman, M.H. Rahman, M. Mainuddin, R.W. Bell, D.S. Gaydon, Cropping system intensification under rice based system for increasing crop productivity in salt-affected coastal zones of Bangladesh, J. Indian Soc. Coastal Agril. Res. 37 (2) (2019) 172, https://doi.org/10.3390/proceedings2019036172.
[83] M.R. Nunes, D.L. Karlen, K.S. Veum, T.B. Moorman, C.A. Cambardella, Biological soil health indicators respond to tillage intensity: a US meta-analysis, Geoderma 369 (2020) 114335, https://doi.org/10.1016/j.geoderma.2020.114335.
[84] J.S. Lin, M.V.M. Sarto, T.L. Carter, D.E. Peterson, C. Gura, L. Mino, M. Rohrs, H. Lucas, J. Clark, C.W. Rice, Soil organic carbon, aggregation and fungi community after 44 years of no-till and cropping systems in the Central Great Plains, USA, Arch. Microbiol. 205 (3) (2023) 84, https://doi.org/10.1007/s00203-023-03421-2.
[85] R. Bhatt, S.S. Kukal, Soil physical environment as affected by double zero tillage in rice-wheat cropping system of north-west India, Asian J. Soil Sci. 10 (2015) 166–172, https://doi.org/10.15740/has/ajss/10.1/166-172.
[86] R.K. Dewil, M. Fukuda, N. Takashima, A. Yagioka, M. Komatsuzaki, Soil carbon sequestration and soil quality change between no-tillage and conventional tillage soil management after 3 and 11 years of organic farming, Soil Sci. Plant Nutr. 68 (2021) 133–148, https://doi.org/10.1080/00380768.2021.1997552.
[87] N. Acir, H. Günal, İ. Çelik, Z.B. Barut, M. Budak, Ş. Kılıç, Effects of long-term conventional and conservational tillage systems on biochemical soil health indicators in the Mediterranean region, Arch. Agron Soil Sci. 68 (2020) 795–808, https://doi.org/10.1080/03650340.2020.1855327.
[88] S. Hussain, S. Hussain, R. Guo, M. Sarwar, X. Ren, D. Krstic, Z. Aslam, U. Zulifqar, A. Rauf, C. Hano, M.A. El-Esawi, Carbon sequestration to avoid soil degradation: a review on the role of conservation tillage, Plants 10 (10) (2021) 2001, https://doi.org/10.3390/plants10102001.
[89] H.V. Cooper, S. Sjögersten, R.M. Lark, S.J. Mooney, To till or not to till in a temperate ecosystem? Implications for climate change mitigation, Environ. Res. Lett. 16 (5) (2021) 054022, https://doi.org/10.1088/1748-9326/abe74e.
[90] H.V. Cooper, S. Sjögersten, R.M. Lark, N.T. Girkin, C.H. Vane, J.C. Calonego, C. Rosolem, S.J. Mooney, Long-term zero-tillage enhances the protection of soil carbon in tropical agriculture, European J.Soil Sci. 72 (2021) 2477–2492, https://doi.org/10.1111/ejss.13111.
[91] P.M. Kopittke, N.W. Menzies, P. Wang, B.A. McKenna, E. Lombi, Soil and the intensification of agriculture for global food security, Environ. Int. 132 (2019) 105078, https://doi.org/10.1016/j.envint.2019.105078.
[92] U. Habiba, MdA. Abedin, R. Shaw, A.W.R. Hassan, Salinity-induced livelihood stress in coastal region of Bangladesh, in: MdA. Abedin, U. Habiba, A.W.R. Shaw (Eds.), Community, Environment and Disaster Risk Management, Emerald Group Publishing Limited, Leeds, 2013 0000013013, https://doi.org/10.1108/S2040-7262, 139–165.
[93] T. Yu, L. Mahe, Y. Li, X. Wei, X. Deng, D. Zhang, Benefits of crop rotation on climate resilience and its prospects in China, Agronomy 12 (2022) 436, https://doi.org/10.3390/agronomy12020436.
[94] B.B. Lin, Resilience in agriculture through crop diversification: adaptive management for environmental change, Bioscience 61 (2011) 183–193, https://doi.org/10.1525/bio.2011.61.3.4.
[95] Rukhsana, Crop diversification: an adaptative option for climate change resilience in West Bengal, in: A. Alam, Rukhsana (Eds.), Climate Change, Agriculture and Society. Approaches toward Sustainability, Springer Nature, Switzerland AG., 2023, pp. 175–193.
[96] R. Vernooy, Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice, Agroecology and Sustainable Food Systems 46 (2022) 877–901, https://doi.org/10.1080/21683565.2022.2076184.
[97] N. Kawarazuka, F. Ibrahim, E.H.M.S. Rahaman, G. Prain, The roles of community nutrition scholars in changing mothers' child feeding, food preparation, and hygiene practices in southern Bangladesh, Front. Public Health 11 (2023) 1135214, https://doi.org/10.3389/fpubh.2023.1135214.
[98] E.H.M.S. Rahaman, M. Hossain, N. Kawarazuka, Farmers' adoption on potato zero-tillage and straw mulching in the Ganges Delta of Bangladesh, International Potato Center (2024). https://hdl.handle.net/10568/141662.
[99] International Food Policy Research Institute (IFPRI), Global spatially-disaggregated crop production statistics data for 2020 version 1.0, Harvard Dataverse v3 (2024), https://doi.org/10.7910/DVN/SWPENT.
[100] A. Rahman, M.N. Uddin, Challenges and opportunities for saline agriculture in coastal Bangladesh, in: K. Negacz, P. Vellinga, E. Barrett-Lennard, R. Choukr-Allah, T. Elzenga (Eds.), Future of Sustainable Agriculture in Saline Environments, CRC Press, Boca Raton, 2021, pp. 125–145.