PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.3167

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RESEARCH ARTICLE

Integrated nutrient management improves yield, quality and nutrient uptake of baby corn under sub-tropical condition

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OPEN ACCESS

ARTICLE HISTORY

Received: 05 December 2023
Accepted: 02 December 2024

Available online
Version 1.0 : 04 February 2025

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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Sarker MH, Kheya SA, Zaman F, Islam SS, Kader MA, Ahsan AFMS, Hasan AK. Integrated nutrient management improves yield, quality and nutrient uptake of baby corn under sub-tropical condition. Plant Science Today (Early Access). https://doi.org/10.14719/pst.3167

Abstract

A consistent supply of nutrients is critical for reaching optimum quality and output in baby corn. To address this issue, we looked at how integrated nitrogen management affected baby corn growth, productivity, quality, and nutrient absorption. Seven different fertilizer combinations of organic and inorganic fertilizers were administered on three varieties viz., Baby Star, Dream Sweet-3, and MSC No. 001. The study was replicated three times using a split-plot design. Integration of Baby Star variety and 75% recommended dose of chemical fertilizer (RD) + cow dung (CD) @ 10 t ha^{-1} outperformed all the combinations in terms of plant height, leaf area index, total dry matter, and crop growth rate. This combination took a minimum of days to tasseling and silking. Compared to the solo application of inorganic fertilizer, Baby Star showed a 34% increase in cob yield with husk and a 32% rise in cob yield without husk at 75% RD + CD @ 10 t ha^{-1}. The greatest levels of protein and starch were detected in Baby Star with 75% RD + cow dung at 10 t ha^{-1}, however, the highest levels of total soluble solid (TSS) were found in Dream Sweet-3 with 75% RD + CD @ 10 t ha^{-1}. Baby Star variety also had more N, P, K, and S content at 75% RD + CD @ 10 t ha^{-1} fertilizer level. Finally, it can be inferred that the Baby Star with 50% RD + CD @ 10 t ha^{-1} performed better and seemed to be the potential method for sustainable baby corn production.

Keywords

baby corn; mineral fertilizer; nutrient uptake; organic amendments; quality

Introduction

Baby corn refers to the immature, dehusked ears of maize (*Zea mays* L.) that are harvested as a vegetable shortly after silking, usually within 1 to 2 days when the silk measures approximately 2 to 3 cm in length (1). Baby corn belongs to the Poaceae family. As a monoecious plant, it possesses two inflorescences: a terminal male inflorescence (tassel) and a lateral female inflorescence (ear). The fruit of baby corn is a form of caryopsis, often known as a grain, that is husked. Baby corn are only immature ears from regular-sized corn plants. Because of its rapid growth and development, a farmer in some climate-friendly places may plant four or more crop cycles of young cob corn every year. This potential is dependent on local agro-climatic circumstances, including temperature ranges, rainfall patterns, and growing season duration (2). It is highly adaptable and does not require intense cultivation. In light of these facts, baby corn has a promising future. Baby corn farming is a relatively new trend that has proven to be a hugely profitable endeavor in nations like Thailand and Taiwan (3). In Bangladesh, it has the ability to generate foreign cash while also providing farmers with improved economic returns. The global output of baby corn is estimated to be over 1.8 million metric tons per year, with large contributions from countries such as Thailand, India, and the Philippines, which are recognized for considerable cultivation of this crop. In Bangladesh, baby corn output is roughly 20,000 metric tons per year, demonstrating increased local demand and interest in this healthy food (4). In Bangladesh, no variety has been cultivated specifically for baby corn. In earlier times, any variety of maize was utilized but in-depth research was not done to find out varieties that would be best for this purpose (5). For commercial production, the variety of baby corn should have early maturity, short duration, more corns per plant, synchronized maturity, and yellow-colored corns.

The productivity of baby corn is influenced by a number of variables, the most significant of which is mineral nutrition. The production and quality of maize plants were significantly impacted by various nutritional levels (6). When all necessary fertilizers are applied chemically, soil fertility is negatively impacted, resulting in unsustainable yields. A single supplier cannot provide enough nutrients at balanced levels. Combining the use of organic and inorganic fertilizers has long been known to generate positive and desired effects in terms of yield, quality of agricultural products, and soil fertility according to a very wide body of research (7, 8). The qualities of soil can be improved by organic manure on a physical, chemical, and biological level (9). The main positive impacts of applying cow dung include reversing the negative effects of soil acidity, salinity, and alkalinity and adding nutrients to the soil. With the presence of cow dung, N fertilizer use efficiency is increased. Encompassing diverse organic and inorganic sources of nitrogen, it was discovered that productivity could be maintained by replacing 50% of mineral fertilizer-N with cow dung in different agro-ecological zones (10). Utilizing organic manure in addition to chemical fertilizer has proven to be extremely important for maintaining soil fertility and crop output sustainability.

The supply of nutrients is essential for guaranteeing greater baby corn output. The three main nutrients nitrogen (N), phosphorus (P), and potassium (K) must be applied in sufficient amounts. N, P, and K are engaged in physico-chemical reactions of the baby corn plant body and help to increase the values of quality parameters. Baby corn responds more strongly to applied nitrogen (11). Phosphorus availability to organisms is influenced by its tendency to bind with soil particles, making it difficult for plants to access (12). This approach not only enhances phosphorus availability but also promotes sustainable nutrient management in agriculture. According to (13), the use of 150:75:40 kg NPK ha^{-1} + 10 t farm yard manure (FYM) resulted in the highest baby corn and fodder outputs with the best quality. To be sustainable, nutrient management strategies must first be lucrative to attract investment and long-term adoption. Investors prioritize profitability, concentrating on ways that increase production while lowering costs, therefore balancing financial returns and environmental aims. According to (14), private investors appreciate stability and development potential, particularly in areas influenced by regulatory and environmental changes. To appeal to investors, nutrient management must combine economic incentives with environmental advantages, paving the stage for long-term agricultural breakthroughs.

Therefore, it's essential to employ a comprehensive plan to optimize suitable nutrient management for baby corn. Regarding this, we have provided an experimental inquiry to evaluate the impact of integrated nutrient management on the growth, yield, quality, and nutrient absorption of baby corn.

Materials and Methods

Site description

An experiment was executed in the Rabi (winter) season (November 2016 to February 2017) in Bangladesh. The soil in the test region is a silty clay loam. For the purpose of evaluating the chemical characteristics of the soil, soil samples from the experimental field were taken both before and after the crop was harvested (Table 1). The experimental site's subtropical environment is characterized by somewhat low temperatures and little rainfall throughout the winter months (Fig. 1).

Table 1. Chemical characteristics of the experimental soil before and after harvesting

Soil Status	pH	OC (%)	Exchangeable K (meq/100 g)	Total N (%)	Available P (µg g^{-1})
			Before planting		
	5.8	0.585	0.13	0.054	12.5
			After harvesting		
F_1	-	0.615	0.15	0.063	13.1
F_2	-	0.753	0.20	0.081	15.1
F_3	-	0.897	0.28	0.095	16.4
F_4	-	0.678	0.18	0.075	14.2
F_5	-	0.849	0.26	0.093	16.3
F_6	-	0.594	0.14	0.055	12.5
F_7	-	0.603	0.15	0.058	12.9

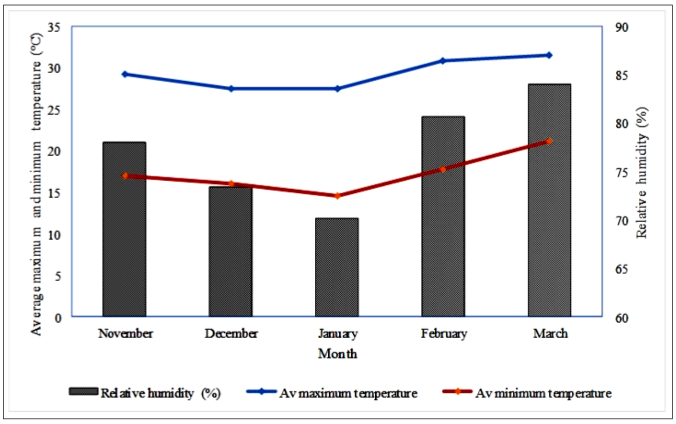

Fig. 1. Distribution of monthly temperature and relative humidity of the experimental site during the crop growth period.

Experimental setup

To fulfill the proposed objectives, three hybrid corn varieties viz., Baby Star (Hybrid Baby Corn), Dream Sweet-3 (Hybrid Sweet Corn), and MSC No. 001 (Hybrid Baby Corn) selected from screening experiments based on higher yield and quality (protein %, Starch %, and TSS), and seven different organic and inorganic fertilizer combinations viz., recommended dose of chemical fertilizer (RD), RD + cow dung (CD) @ 5 t ha^{-1}, RD + CD @ 10 t ha^{-1}, 75% RD + CD @ 5 t ha^{-1}, 75% RD + CD @ 10 t ha^{-1}, 50% RD + CD @ 5 t ha^{-1} and 50% RD + CD @ 10 t ha^{-1} were used in the experiment in a split-plot design (main plot-varieties, sub plot-nutrient management) with three replications. Each plot measured 13.5 m^2 (4.5 × 3 m). In unit plots, treatments were assigned at random.

Crop husbandry

To achieve the desired tilth for growing baby corn, the field was prepared by three cultivator ploughings and two power tilling ploughings, followed by laddering. The furrow was cut with a tine, and two seeds were placed at each point at a distance of 50 × 25 cm and a depth of 3–4 cm. Next, the seeds were adequately covered with light soil to enable germination. Before planting, well-decomposed cow dung was put into the plots in accordance with the treatment plan and properly mixed. Chemical fertilizers such as urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate, and boric acid were administered to each plot in accordance with the treatment. Prior to planting, one-third of the urea was treated as a basal dosage. The remaining two-thirds of the urea was then applied in two equal splits, at 15 days after sowing (DAS) and 35 DAS. Recommended doses of TSP, MoP, gypsum, zinc sulphate, and boric acid were administered as per the layout plan. The nutrient requirements [(N = 199.33 kg ha^{-1}), P = 35.74 kg ha^{-1}, K = 94.97 kg ha^{-1}, S = 21.44 kg ha^{-1}, Zn= 2.32 kg ha^{-1} and B = 1.26 kg ha^{-1}); HYG (8± 0.80)] were calculated based on soil test values using the following formula (15).

$$F_r = U_f - \frac{C_i}{C_s} \times (S_t - L_s)$$

Where, F_r= Fertilizer nutrient required for given soil test value, U_f = Upper limit of the recommended fertilizer nutrient for the respective soil test value interpretation (STVI) class, Ci = Units of class intervals used for fertilizer nutrient recommendation, C_s =Units of class intervals used for STVI class, S_t = Soil test value, L_s = Lower limit of the soil value within the STVI class,

Nitrogen (N) was determined using the Kjeldahl method, Phosphorus (P) was analyzed using the Olsen method, Potassium (K) was measured through flame photometry, Sulphur (S) was quantified by the turbidimetric method, Zinc (Zn) and boron (B) were analyzed using atomic absorption spectrophotometry (AAS) and the hot water extraction method, respectively (16 - 18).

Sampling and Measurements

Cow dung

The elements potassium (K), total nitrogen (N), phosphorus (P), and organic carbon (C) were all measured in decomposed cow dung samples. About 0.83% N, 0.27 % P, 0.42 % K, 23% organic matter (OM), and 30 % moisture were recorded in the decomposed cow dung sample. The Walkley-Black technique was used to calculate organic C (16). Total N was determined using the micro-Kjeldahl method (17). Samples were assayed in a 450°C furnace before being colorimetrically tested for total P (18). After ashing, potassium was identified using a flame photometer.

Plant

Ten plants at random from each plot were chosen to collect data on yield and factors that influence yield. Prior to harvesting the crop, the chosen plants were collected, and the appropriate data was recorded in accordance. For a chemical examination, samples of the immature cob without husk and stover were also preserved. Cob and plant samples were dried in an oven at 65°C for 48 hours and then ground by a grinding machine to pass through a sieve and stored in small paper bags in desiccators. The samples were then examined for the presence of N, P, K, and S.

Assessment of N, P, K, and S content

To measure N, 100 mg (0.1 g) of oven-dried powdered sample was placed in a 100 ml Kjeldahl flask together with 1.1 g of a catalyst mixture consisting of K_2SO_4: $CuSO_4.5H_2O$: selenium in a ratio of 10: 1: 0.1, 2 mL of 30% H_2O_2, and 3 mL of conc. H_2SO_4. The flask was swirled and allowed to stand for about 10 minutes. The flask was then heated, and this process was maintained until the digest lost its color. The flask was swirled and left to stand for around 10 minutes. The digest was put into a 100 mL volumetric flask after chilling, and the volume was then raised to the appropriate level using distilled water. Similar steps were taken to create a blank reagent. The estimate of the total N was done using this digest. The microkjeldahl technique was used to determine the nitrogen content of the plant's grain and straw (19). In the presence of a K_2SO_4 catalyst combination (K_2SO_4: $CuSO_4$: Se = 10: 1: 1), an extracted 0.1 g sample was digested with 10 ml concentrated H_2SO_4 in a fume hood. A 5 ml solution of 40% NaOH was then added to the digest in the distillation flask. By adding 0.02 N H_2SO_4 to the distillate trapped in the H_3BO_3 indicator solution, nitrogen concentration was calculated.

For the detection of P, K, and S, 0.5 g of plant samples were put into a dry, clean 100 ml Kjeldahl flask for the digestion of the plant materials. In the ratio of 2: 1, 10 ml of di-acid (HNO_3: $HClO_4$) was added. The flask was steadily heated to a temperature of 200°C after being left for some time. When the thick white $HClO_4$ vapors appeared, the heating was briefly halted, and after cooling, 6 mL of 6 N HCl was added. The contents of the flask were boiled until they became sufficiently clean and colorless. After cooling the digest was transferred into a 100 ml volumetric flask and volume was made to 30 mL with distilled water and then filtered. From this stock solution, the flask's P, K, and S contents were ascertained.

Utilizing the vanadomolybdate technique, the total phosphorus content of various plant sections was ascertained (20). To determine the total P content, dried plant materials were digested using a concentrated HNO_3 and $HClO_4$ (Nitric perchloric acid) combination (21) using a twin beam spectrophotometer operating at a wavelength of 440 nm to determine the total P content of the extract. The total P content in the extract was determined by (21) using a double-beam spectrophotometer at 440 nm wavelength.

The vanadomolybdate technique (20) was also used to quantify total potassium. To determine the total K content, dried plant materials were digested using a concentrated HNO_3 and $HClO_4$ (Nitric perchloric acid) combination. Using an atomic absorption spectrophotometer with a 760 nm wavelength, the concentration of K was measured.

For the nitric perchloric acid digestion method, dried plant materials were digested with concentrated HNO_3 and $HClO_4$ (nitric perchloric acid) combination to determine the total S content. S was calculated using the turbidimetric technique with $BaCl_2.2H_2O$ by a twin beam spectrophotometer at 420 nm wavelength.

Nutrient uptake

Following the method below, the amount of nutrients that plants absorb from the soil was calculated:

$$\text{Nutrient uptake} = \frac{\%\,A \times Y}{100}\,\text{kg ha}^{-1}$$

Where,% A = Nutrient (N, P, K, and S) concentration of cob plant^{-1}, Y = Dry matter production of cob plant^{-1} (kg ha^{-1})

Growth parameters

At intervals of 15 days beginning at 20 DAS, plant height was measured in cm using a meter scale. Five plants were randomly selected from each plot and marked with tags before being measured till maturity.

Five plants were chosen at random from the sampling row in order to calculate the leaf area index (LAI). Leaf blades were separated and the leaf was measured by using an Area Meter at the Physiology Division, Bangladesh Agricultural Research Institute, Gazipur. Finally, LAI was determined using the formula described below (22):

$$LAI = \frac{LA}{P}$$

Where, LA = Leaf Area and P = Ground Area.

The same plant used to measure leaf area was used to collect data on total dry matter accumulation (g m^{-2}) at intervals of 15 days beginning with day 20 (DAS). Plant pieces were dried in an electric oven for at least 72 hours to get uniform weight, and then the dry weight was weighed while keeping a constant temperature of 70°C. Each sample's weight was measured upon drying.

Crop growth rate (CGR) was estimated using the following equation (23):

$$CGR = \frac{1}{A} \times \frac{W_2 - W_1}{T_2 - T_1}\; gm^{-2}\; day^{-1}$$

Where, W_1= dry matter production at T_1 time, W_2 = dry matter production at T_2 time, T_1 = time corresponding to the first harvest, T_2 = time corresponding to the second harvest, A = Ground area (m^2)

Yield and traits that contribute to yield

Characters that contribute to yield were noted in the data. The yield of fodder was also measured. Ten green plants were chosen at random, and they were all removed from the ground after the corn was harvested. For the purpose of estimating yield, the individual green plants were weighed, and mean values were noted. Then, this was reported after being transformed to t ha^{-1}.

Quality characters

The sample's protein content was calculated by multiplying the sample's nitrogen content by a factor of 6.25 (24).

$$Nitrogen\ (\%) = \frac{14 \times \text{Normality of } H_2SO_4 \times (\text{TV} - \text{TB}) \times \text{Vol. of } H_2SO_4 \times 100}{\text{Weight of sample} \times 100}$$

$$\text{Protein }(\%) = \text{Nitrogen }(\%) \times 6.25$$

The anthrone reagent technique was used to measure starch. After treating the sample with 80% alcohol to get rid of the sugars, perchloric acid is used to extract the starch. In a warm, acidic solution, starch is hydrolyzed to glucose and then dehydrated to hydroxymethyl furfural. Together with anthrone, this substance produces a green-colored substance. Using a spectrophotometer (Model-JASCO V-750) set to 630 nm (25), the sample's glucose content was measured using the standard graph. Starch content was calculated by multiplying the glucose content value by a factor of 0.9.

Total Soluble Solid (Brix%) was measured by a Digital Refractometer (Model-NR 151).

Other plant characters

During the crop cycle, the days to first tasseling (when at least one plant of each plot produced a male flower) and days to first silking (when at least one plant of each plot produced a female flower) were recorded.

Statistical analysis

The gathered data was properly organized and statistically analyzed. The computer software Statistics-10 was used to evaluate the data using the analysis of variance (ANOVA) approach, and the Duncan Multiple Range Test (DMRT) was used to determine the significance of the difference between the treatment means at the 5% level of probability (26).

Results

Growth parameters

A wide range of significant difference in plant height was noticed in response to variety and fertilizer levels at all growth periods. From 20 DAS to 80 DAS, a gradual increase in plant height was documented in all combinations. When the Baby Star variety was treated with 75% RD + CD @ 10 t ha^{-1}, this combination produced the tallest plants and about 69%, 70%, 77%, 84%, and 85% increase in plant height at 20, 35, 50, 65 and 80 DAS, respectively, were recorded at this combination over MSC No. 001 with 50% RD + CD @ 5 t ha^{-1} which produced shortest plants (Table 2).

The baby corn's LAI was considerably greater in the plots where integrated nutrient management treatments had been used at all of the periodic intervals. According to data in Table 2, the rate of rise in the leaf area index for the baby corn crop was generally modest up to 20 DAS and then rose until crop harvest. The maximum LAI (0.25, 0.93, 2.11, 3.49, and 4.58, respectively) was recorded at 20, 35, 50, 65, and 80 DAS in the interaction of Baby Star and 75% RD + CD @ 10 t ha^{-1}. The lowest LAI (0.11, 0.47, 1.03, 1.69, and 2.73, respectively) was observed in MSC No. 001 with 50% RD + CD @ 5 t ha^{-1}.

At all development stages, considerable variability in dry matter accumulation was seen as a result of the interaction between a variety and various fertilizer dosages. It was observed that three baby corn varieties accumulated more dry matter when they interacted with 75% RD + CD @ 10 t ha^{-1} compared to other fertilizer treatments at all observations. But among the varieties, Baby Star showed maximum dry matter accumulation (30.73 g m^{-2}, 139.2 g m^{-2}, 403.48 g m^{-2}, 749.53 g m^{-2}, and 1217 g m^{-2}, respectively) at 20, 35, 50, 65 and 80 DAS with this fertilizer combination. All the varieties performed poorly in terms of total dry matter production when they were treated with 50% RD + CD @ 5 t ha^{-1} but MSC No. 001 variety with this fertilizer treatment exerted the lowest total dry matter amongst all (Table 3).

Crop growth rate measured in g m^{-2}day^{-1} showed similar trends to other growth parameters in response to the variety and fertilizer levels explored in this study. All the varieties attained highest CGR when they were treated with 75% RD + CD @ 10 t ha^{-1} and similar to other parameters in that case also Baby Star variety had the maximum CGR values (7.23 g m^{-2}day^{-1}, 17.62 g m^{-2}day^{-1}, 23.07 g m^{-2} day^{-1}, and 31.23 g m^{-2}day^{-1}, respectively) at 20-35, 35-50, 50 -65, and 65-80 DAS. The lowest CGR values (4.06 g m^{-2}day^{-1}, 10.29 g m^{-2}day^{-1}, 13.25 g m^{-2}day^{-1}, and 14.51 g m^{-2}day^{-1}, respectively) were found in MSC No. 001 with 50% RD + Cow dung @ 5 t ha^{-1} (Table 3).

Days to first tasseling and silking

There was a significant interaction between variety and fertilizer quantity on tasseling days. All the varieties at different fertilizer levels produced their first tassel within 60.24 to 71.88 days. Where variety MSC No. 001 took the highest number of days for tasseling at 50% RD + CD @ 5 t ha^{-1} but early tasseling was recorded in Baby Star at 75% RD + CD @ 10 t ha^{-1} treatment. Similarly, on days to initial silking, it was discovered that there was a strong

Table 2. Interaction effect of variety and fertilizer levels on plant height and leaf area index (LAI) of baby corn at different days after sowing.

Interaction		Plant height (cm)					Leaf area index (LAI)				
		20DAS	35DAS	50DAS	65DAS	80DAS	20DAS	35DAS	50DAS	65DAS	80 DAS
Baby Star	RD of chemical fertilizer	18.01h	44.35gh	67.72h	98.28gh	128.47g	0.16h	0.65gh	1.51g	2.46ef	3.52i
	RD + CD @ 5 t ha^{-1}	20.42d	50.23cd	76.68d	111.26d	148.57c	0.21d	0.80c	1.79e	2.88cd	4.07d
	RD + CD @ 10 t ha^{-1}	22.01b	52.96b	80.95b	118.75b	158.63b	0.23b	0.88b	2.03b	3.11bc	4.41b
	75% RD + CD @ 5 t ha^{-1}	19.18ef	47.20ef	72.06f	104.57f	138.16e	0.19f	0.73de	1.65f	2.67de	3.79f
	75%RD + CD @ 10 t ha^{-1}	22.93a	55.76a	86.13a	126.35a	168.77a	0.25a	0.93a	2.11a	3.49a	4.85a
	50% RD + CD @ 5 t ha^{-1}	15.88j	38.32lm	58.53n	86.81kl	111.08m	0.10n	0.48mn	1.24i	2.05gh	3.03n
	50% RD + CD @ 10 t ha^{-1}	16.91i	41.67ij	63.64k	92.37ij	119.46j	0.13k	0.57k	1.36h	2.26fg	3.25l
Dream Sweet-3	RD of chemical fertilizer	16.80i	40.77jk	62.32i	87.75k	117.79k	0.14j	0.57k	1.39h	2.30fg	3.42j
	RD + CD @ 5 t ha^{-1}	19.05f	46.18fg	70.56g	99.39g	132.68f	0.18g	0.71ef	1.67f	2.69de	3.90e
	RD + CD @ 10 t ha^{-1}	20.04d	48.73de	72.87e	105.75e	141.19d	0.20e	0.76d	1.89d	2.88cd	4.17c
	75% RD + CD @ 5 t ha^{-1},	17.89h	43.39hi	66.31il	93.40l	124.70h	0.16h	0.64hi	1.53g	2.49ef	3.65g
	75%RD + CD @ 10 t ha^{-1}	21.11c	51.33bc	77.54c	112.51c	150.24c	0.22c	0.82c	1.95c	3.16b	4.45b
	50% RD + CD @ 5 t ha^{-1}	14.82k	35.23n	54.46p	77.430	103.49o	0.15h	0.39o	1.11j	1.93hi	2.86p
	50% RD + CD @ 10 t ha^{-1}	15.78j	38.31lm	58.57n	82.42m	110.13m	0.13k	0.48mn	1.25i	2.11gh	3.05n
MSC No. 001	RD of chemical fertilizer	16.02j	38.77kl	57.39o	80.79n	107.91n	0.12l	0.53l	1.27i	2.12gh	3.14m
	RD + CD @ 5 t ha^{-1}	18.16gh	43.91h	64.98j	91.49j	122.19l	0.15l	0.61ij	1.53g	2.48ef	3.58h
	RD + CD @ 10 t ha^{-1}	18.47g	44.33gh	67.03hi	97.35h	130.01g	0.16h	0.68fg	1.69f	2.79d	3.82f
	75% RD + CD @ 5 t ha^{-1},	17.06i	41.26ij	61.07m	85.97l	114.83l	0.14j	0.58jk	1.40h	2.30fg	3.36j
	75%RD + CD @ 10 t ha^{-1}	19.47e	47.19ef	71.33f	103.57f	138.33e	0.19f	0.72e	1.77e	2.92bd	4.07d
	50% RD + CD @ 5 t ha^{-1}	13.51l	32.71o	48.51q	68.37a	91.29q	0.11n	0.47n	1.03k	1.69i	2.73o
	50% RD + CD @ 10 t ha^{-1}	15.04k	36.43mn	53.93p	74.33p	101.42p	0.12l	0.51lm	1.14j	1.94hi	2.95o
Level of sig.		*	*	*	*	*	*	*	*	*	*
CV (%)		6.78	5.37	6.05	5.34	5.66	10.87	3.73	5.33	5.17	5.54

Figures in the column followed by the same or no letter do not differ significantly at the 5% level. *Significant at 5% level

Table 3. Interaction effect of variety and fertilizer levels on total dry matter and crop growth rate of baby corn on different days after sowing

Interaction		Total dry matter					CGR (Crop growth rate)				Days to first tasseling	Days to first silking
		20DAS	35DAS	50DAS	65DAS	80DAS	20-35DAS	35-50DAS	50-65DAS	65-80DAS		
Baby Star	RD of chemical fertilizer	23.12f	106.1f	313.22h	586.67g	917.57f	0.16h	0.65gh	1.51g	2.46ef	65.18h	70.30gh
	RD + CD @ 5 t ha^{-1}	26.25d	121.5d	357.3d	668.1c	1043.85c	0.21d	0.80c	1.79e	2.88cd	63.28jk	68.55ij
	RD + CD @ 10 t ha^{-1}	28.88b	133.4b	381.83b	697.58b	1121.18b	0.23b	0.88b	2.03b	3.11bc	62.04l	67.44jk
	75% RD + CD @ 5 t ha^{-1},	24.64e	113.6	334.69f	626.29e	979.09d	0.19f	0.73de	1.65f	2.67de	64.54hi	69.52hi
	75%RD + CD @ 10 t ha^{-1}	30.73a	139.2	403.48a	749.53a	1217.98a	0.25a	0.93a	2.11a	3.49a	60.24m	64.53l
	50% RD + CD @ 5 t ha^{-1}	20.31h	91.86h	273.21l	513.06k	788.61jk	0.10n	0.48mn	1.24i	2.05gh	67.80de	72.82de
	50% RD + CD @ 10 t ha^{-1}	21.68g	98.78g	292.73j	548.93i	859.13h	0.13k	0.57k	1.36h	2.26fg	66.48g	71.25fg
Dream Sweet-3	RD of chemical fertilizer	22.19g	99.14g	291.59jk	545.54i	852.89h	0.14j	0.57k	1.39h	2.30fg	67.48ef	72.66de
	RD + CD @ 5 t ha^{-1}	25.2e	113.7e	332.85f	621.6e	970.8h	0.18g	0.71ef	1.67f	2.69de	65.03h	70.22gh
	RD + CD @ 10 t ha^{-1}	27.13c	121.5d	353.53d	653.23d	1044.43c	0.20e	0.76d	1.89d	2.88cd	63.86ij	69.08hi
	75% RD + CD @ 5 t ha^{-1},	23.65f	106.3f	311.8h	582.7g	910.45f	0.16h	0.64hi	1.53g	2.49ef	64.98h	70.96fg
	75%RD + CD @ 10 t ha^{-1}	28.57b	129.4	376.42c	702.07b	1132.57b	0.22c	0.82c	1.95c	3.16b	62.76kl	66.38k
	50% RD + CD @ 5 t ha^{-1}	19.49i	85.79i	254.09m	476.69m	740.39l	0.15h	0.39o	1.11j	1.93hi	69.55b	75.66b
	50% RD + CD @ 10 t ha^{-1}	20.8h	92.35h	272.5l	510.4k	798.55j	0.13k	0.48mn	1.25i	2.11gh	67.88de	73.82cd
MSC No.001	RD of chemical fertilizer	20.56h	91.66h	268.36l	501.76l	784.96jk	0.12l	0.53l	1.27i	2.12gh	68.53cd	73.98cd
	RD + CD @ 5 t ha^{-1}	23.36f	105.1f	306.41l	571.91h	893.06g	0.15l	0.61ij	1.53g	2.48ef	66.95fg	72.72de
	RD + CD @ 10 t ha^{-1}	24.89e	114.6	326.54g	597.74f	952.64e	0.16h	0.68fg	1.69f	2.79d	65.18h	70.36gh
	75% RD + CD @ 5 t ha^{-1},	21.92g	98.27g	286.97k	535.97j	837.62i	0.14j	0.58jk	1.40h	2.30fg	66.44g	71.87ef
	75%RD + CD @ 10 t ha^{-1}	26.48d	119.6d	345.68e	646.88d	1045.58c	0.19f	0.72e	1.77e	2.92bd	64.88h	68.66ij
	50% RD + CD @ 5 t ha^{-1}	17.35j	78.25j	232.60n	431.35n	649.00m	0.11n	0.47n	1.03k	1.69i	71.88a	78.48a
	50% RD + CD @ 10 t ha^{-1}	19.27i	85.27i	250.57m	469.12m	734.77l	0.12l	0.51lm	1.14j	1.94hi	69.11bc	74.54bc
Level of sig.			*	*	*	*	*	*	*	*	*	*
CV (%)			6.39	4.40	5.98	3.46	4.84	4.73	4.17	3.89	10.810.87	3.73

Figures in the column followed by the same or no letter do not differ significantly at the 5% level. *Significant at 5% level

interaction impact caused by variety and fertilizer amount. First silking required the longest period of time (78.48 days) for MSC No. 001 with fertilizer level 50% RD + CD @ 5 t ha^{-1}, while the shortest period of time (64.53) was required for Baby Star with treatment 75% RD + CD @ 10 t ha^{-1} (Table 3).

Yield and traits that contribute to yield

Every attribute that affects yield responded to variety and fertilizer amount. Also, a significant interaction was detected between variety and fertilizer levels. According to Table 2, the treatment using Baby Star and 75% RD + CD at 10 t ha^{-1} produced the most cobs plant^{-1} (3.00), whereas the treatment using MSC No. 001 and 50% RD + CD at 5 t ha^{-1} produced the fewest cobs plant^{-1} (1.62). A range of 8.17 cm to 11.38 cm cob length and 0.82 cm to 1.01 cm cob diameter were reported in this study, where the cob of Baby Star variety attained maximum length and diameter at 75% RD

+ CD @ 10 t ha^{-1} fertilizer level. Similarly, the cob reached the highest weight with husk (63.44 g) and without husk (14.88 g) when the Baby Star variety was treated with 75% RD + CD @ 10 t ha^{-1}. It is noted that all other varieties also performed well at this fertilizer level than others. MSC No. 001 reached lower grain weight with husk (48.89 g) and without husk (10.24 g) at 50% RD + CD @ 5 t ha^{-1}. The combined application of 75% of RD of chemical fertilizer and cow dung @ 10 t ha^{-1} enhanced the cob production of three baby corn types compared to the chemical fertilizer applied alone. However, the further decrease in chemical fertilizer in combination with chemical fertilizer resulted in lower cob yield than solo application of chemical fertilizer. About 34%, 31%, and 27% increase in cob yield with husk and 32%, 33%, and 31% increase in cob yield without husk at 75% RD + CD @ 10 t ha^{-1} over solo application of chemical fertilizer was documented in Baby star, Dream Sweet-3 and MSC No. 001, respectively. But among all these, the Baby Star variety yielded more cob with husk (13.86 t ha^{-1}) and without husk (3.52 t ha^{-1}) at 75% RD + CD @ 10 t ha^{-1} and MSC No. 001 variety yielded less cob with husk (7.13 t ha^{-1}) and without husk (1.71 t ha^{-1}) at 50% RD + CD @ 5 t ha^{-1}. A similar pattern was seen in the fodder yield, where Baby Star had the highest yield (35.85 t ha^{-1}) when treated with 75% RD + CD at 10 t ha^{-1} and MSC No. 001 had the lowest yield (18.43 t ha^{-1}) when treated with 50% RD + CD at 5 t ha^{-1} (Table 4).

Quality Characters

Due to the interaction impact of variety and fertilizer levels, the protein, starch, and TSS content of baby corn greatly varied. The protein and starch content ranged from 7.05% - 13.59% and 41.41% - 63.48%, respectively. The highest protein and starch content was observed in Baby Star fertilized with 75% RD + CD @ 10 t ha^{-1} whereas the minimum protein content was obtained in MSC No. 001 with 50% RD + CD @ 5 t ha^{-1} treatment. The maximum TSS (10.52%) was obtained in Dream Sweet-3 when fertilized with 75% RD + CD @ 10 t ha^{-1} while the lowest (4.71%) was documented in Baby Star with 50% RD + CD @ 5 t ha^{-1} treatment (Table 4).

Nutrient uptake by baby corn

The varieties of baby corn and the amount of fertilizer used both had a significant influence on nutritional absorption.

Table 4. Interaction effect of variety and fertilizer levels on yield contributing features, yield, and quality of baby corn

	Interaction	No. of cob plant^{-1}	Cob length (cm)	Cob diameter (cm)	Cob wt. with husk (g)	Cob wt. without husk (g)	Yield with husk(t ha^{-1})	Yield without husk (t ha^{-1})	Fodder yield (t ha^{-1})	Protein content (%)	Starch content (%)	TSS (%)
Baby Star	RD of chemical fertilizer	2.31e	9.45i	0.88g	55.94ef	12.45g	10.3f	2.66e	27.28ef	10.3ef	48.83j	5.37no
	RD + CD @ 5 t ha^{-1}	2.64c	10.28 d	0.92de	57.55e	13.73c	11.94d	3.05c	31.57c	11.94c	55.29d	6.11kl
	RD + CD @ 10 t ha^{-1}	2.77b	10.81b	0.97b	59.63b	14.2b	12.98b	3.21b	33.49b	12.43b	59.67b	6.33jk
	75% RD + CD @ 5 t ha^{-1},	2.47d	9.98f	0.91ef	56.83c	13.23ef	11.09e	2.85d	29.35d	11.09d	51.96g	5.73mn
	75%RD + CD @ 10 t ha^{-1}	3.00a	11.38a	1.01a	63.44a	14.88a	13.86a	3.52a	35.85a	13.59a	63.48a	6.95hi
	50% RD + CD @ 5 t ha^{-1}	2.02hi	8.41l	0.85i	52.58kl	11.39l	8.88ij	2.28gh	23.57ij	8.88ij	43.12o	4.71p
	50% RD + CD @ 10 t ha^{-1}	2.16fg	8.97j	0.87gh	54.34hi	11.88ik	9.56g	2.49f	25.36gh	9.56gh	45.89l	5.03op
Dream Sweet-3	RD of chemical fertilizer	2.11gh	9.03j	0.86hi	53.93ij	11.57kl	9.46gh	2.31g	24.26hi	9.23hi	46.89k	7.92e
	RD + CD @ 5 t ha^{-1}	2.44d	9.82g	0.9f	55.92ef	12.82fg	10.97e	2.69e	28.08de	10.7d	53.1f	9.19c
	RD + CD @ 10 t ha^{-1}	2.61c	10.15e	0.95c	56.37de	13.41de	11.81d	2.91d	29.52d	11.03d	54.15e	9.88b
	75% RD + CD @ 5 t ha^{-1},	2.27ef	9.39i	0.88g	54.77gh	12.14hj	10.19f	2.51f	26.1fg	9.94fg	49.9i	8.53d
	75%RD + CD @ 10 t ha^{-1}	2.79b	10.75b	0.98b	59.98b	13.98bc	12.46c	3.08c	31.89bc	11.96c	56.55c	10.52a
	50% RD + CD @ 5 t ha^{-1}	1.82j	8.02n	0.83j	52.46lm	10.59op	8.15k	1.97k	20.96k	7.96l	42.29p	6.82hi
	50% RD + CD @ 10 t ha^{-1}	1.96i	8.55k	0.85i	53.11kl	11.03mn	8.78ij	2.13ij	22.55jk	8.57jk	45.11m	7.35fg
MSC No.001	RD of chemical fertilizer	1.94i	9.00j	0.85i	50.05o	11.33lm	9.07hi	2.18hi	23.56ij	8.86ij	44.07n	6.62ij
	RD + CD @ 5 t ha^{-1}	2.27ef	9.52h	0.87gh	52.08m	12.21hl	10.3f	2.49f	27.27ef	10.27ef	49.91i	7.53f
	RD + CD @ 10 t ha^{-1}	2.44d	9.95f	0.92de	53.35jk	12.79fg	10.96e	2.68e	28.34de	10.77d	50.92h	8.03e
	75% RD + CD @ 5 t ha^{-1},	2.1gh	9.41i	0.86hi	50.98n	11.72jl	9.67g	2.33g	25.35gh	9.54gh	46.9k	7.06gh
	75%RD + CD @ 10 t ha^{-1}	2.61c	10.43c	0.93d	55.43fg	13.13ef	11.57d	2.85d	29.64d	11.11d	53.14f	8.55d
	50% RD + CD @ 5 t ha^{-1}	1.62k	8.17m	0.82j	48.89p	10.24p	7.13l	1.71l	18.43l	7.05m	41.41o	5.82lm
	50% RD + CD @ 10 t ha^{-1}	1.79j	8.61k	0.83j	49.38p	10.91no	8.51jk	2.03jk	21.9k	8.13kl	42.73op	6.21k
Level of sig.		*	*	*	*	*	*	*	*	*	**	**
CV (%)		3.55	4.75	7.53	4.89	3.5	3.82	4.33	4.45	5.97	4.93	5.27

Figures in the column followed by the same or no letter do not differ significantly at the 5% level. *Significant at 5% level.

According to Table 5, the Baby Star variety at 75% RD + CD @ 10 t ha^{-1} absorbed the highest amounts of N (141.59 kg ha^{-1}), P (20.16 kg ha^{-1}), K (117.83 kg ha^{-1}), and S (8.76 kg ha^{-1}). Whereas, the minimum N (81.48 kg ha^{-1}), P (11.09 kg ha^{-1}), K (65.23 kg ha^{-1}), and S (4.79 kg ha^{-1}) uptake were documented in MSC No. 001 at 50% RD + CD @ 5 t ha^{-1} treatment (Table 5).

Table 5. Interaction effect of variety and fertilizer levels on nutrient uptake of baby corn

Interaction		Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Sulphur (kg ha^{-1})
Baby Star	RD of chemical fertilizer	109.34g	15.49e	90.89i	6.71f
	RD + CD @ 5 t ha^{-1}	123.77d	17.56c	102.9d	7.62c
	RD + CD @ 10 t ha^{-1}	133.09b	18.95b	110.76b	8.23b
	75% RD + CD @ 5 t ha^{-1},	116.33f	16.49d	96.71f	7.15de
	75% RD + CD @ 10 t ha^{-1}	141.59a	20.16a	117.83a	8.76a
	50% RD + CD @ 5 t ha^{-1}	96.58k	13.66g	80.28n	5.90h
	50% RD + CD @ 10 t ha^{-1}	102.76i	14.55f	85.42l	6.29g
Dream Sweet-3	RD of chemical fertilizer	99.07k	13.80g	83.84m	6.17g
	RD + CD @ 5 t ha^{-1}	117.66e	15.66e	94.92h	7.02e
	RD + CD @ 10 t ha^{-1}	124.52cd	16.68d	97.81e	7.23b
	75% RD + CD @ 5 t ha^{-1},	105.41h	14.70f	89.21k	6.58f
	75% RD + CD @ 10 t ha^{-1}	125.18c	17.76c	104.07c	7.71c
	50% RD + CD @ 5 t ha^{-1}	87.51o	12.13i	74.05o	5.42i
	50% RD + CD @ 10 t ha^{-1}	93.11m	12.96h	78.79o	5.78h
MSC No. 001	RD of chemical fertilizer	96.13l	13.44g	74.87p	5.49i
	RD + CD @ 5 t ha^{-1}	102.29ij	14.45f	84.76l	6.25g
	RD + CD @ 10 t ha^{-1}	108.84g	15.39e	90.19j	6.67f
	75% RD + CD @ 5 t ha^{-1},	101.65j	13.57g	79.66n	5.87h
	75% RD + CD @ 10 t ha^{-1}	115.79f	16.38d	95.95f	7.10de
	50% RD + CD @ 5 t ha^{-1}	81.48p	11.09j	65.23s	4.79k
	50% RD + CD @ 10 t ha^{-1}	89.89n	12.73h	70.35r	5.16j
Level of sig.		*	*	*	*
CV (%)		5.97	4.93	3.87	5.27

Figures in the column followed by the same or no letter do not differ significantly at the 5% level. *Significant at 5% level.

Discussion

Combining inorganic and organic fertilizers is an ecologically sound approach for optimizing nutrient uptake, which raises the efficiency of fertilizers while reducing nutrient losses (27).

In this regard, the effectiveness of the combined use of synthetic fertilizer and cow dung was evaluated on the growth, production, quality, and nutrient absorption of three types of maize. In terms of plant height, LAI, total dry matter, and CGR, the Baby Star variety performed better with 75% RD + CD @ 10 t ha^{-1} than all other combinations. This is consistent with the findings of (28), who reported similar improvements in maize growth metrics with integrated nutrient management systems. The Synergistic action of organic and inorganic fertilizers enabled a continuous release of nitrogen (N), phosphorous (P), and potassium (K) (28). The timely and quick release of nutrients as well as the improved accessibility of N, P, and K were the main contributors to it (29). It was therefore connected to increased cell division and growth, which brought an increase in plant height, leaf number, and LAI (30). The Baby Star variety receiving enough nutrients from the soil met their physiological needs and showed vigorous growth by uninterrupted cell division and cell elongation. The maximum plant height was identified at this interaction because it causes the internodes to develop more and the stem to grow longer. Unrestricted cell growth, cell elongation, and leaf expansion increased the leaf surface area, which in turn raised the LAI. More leaf area surface which intercepted and utilized more solar radiation paved the way for more production of total dry matter. Applying the right quantity of mixed organic and inorganic fertilizer led to an increase in cell volume, meristematic activity, protoplasm production, and function. Consequently, the photosynthetic area expanded, which led to greater CGR (31, 32).

Baby corn is an extensive nutrition feeder, which benefits from nutrient-rich fertilizers and if a shortage arises at the tasseling and silking phases, it might almost cause crop failure (33). In this experiment, it was noticed that the variety MSC No. 001 took maximum days for first tasseling and silking at 50% RD + CD @ 5 t ha^{-1}. The faster tasseling and silking observed in Baby Star under higher nutrient regimes are consistent with the findings of (34), who discovered that adequate nutrient supply, particularly N and P, accelerates the reproductive phases in maize by increasing meristematic activity and supporting a higher rate of cell division. In contrast, the delayed tasseling and silking in MSC No. 001 with decreased nutrient intake reflects studies by (35), who discovered that nutrient-deficient maize experienced limited leaf growth and lower chlorophyll content, resulting in delayed reproductive development. Insignificant amounts of nutrients, particularly starvation of nitrogen, inhibited cell division of meristematic tissue, which decreased leaf expansion, leaf surface area, and number of leaves. This resulted in lower chlorophyll efficiency during photosynthesis, which produced lower assimilates and finally it took the greatest number of days to first tasseling and silking. This outcome was in line with the conclusions reached by (36, 37). Contrarily, the variety Baby Star with 75% RD + CD @ 10 t ha^{-1} took the shortest period of time for the first tasseling and silking. This might be because the right amount of combined organic and inorganic fertilizer was used, which boosted cell volume, meristematic events, and activity of protoplasm, which subsequently elevated photosynthetic area and generated more assimilates with the vigorous growth of the plant. This can be supported by the Baby Star variety's shorter time required for first tasseling and silking (38).

The Baby Star variety had the maximum yield and contributing factors when fertilized with 75% recommended dosage and cow dung at 10 t ha^{-1}. The MSC No. 001 variety, treated with 50% RD + CD at 5 t ha^{-1}, had the lowest results. In terms of yield components such as cob length, diameter, and weight, our findings are comparable with those published by (39) who found that combining cow dung with lower quantities of synthetic fertilizers resulted in higher yields than solo fertilizer treatments. Zhang et al. (39) highlighted that the combined fertilization approach stimulates root development and photosynthetic efficiency, which directly contributes to the cob yield attributes.

Baby Star's greater performance appears to be due to the increased availability of important macronutrients including nitrogen (N), phosphorus (P), and potassium (K), as well as helpful enzymes generated as a result of increased fertilizer application. Nitrogen, in particular, is necessary for chlorophyll formation and leaf growth, both of which are required for effective photosynthesis (40). Phosphorus promotes root development and energy transmission within plants, aiding growth processes at critical periods (41). Potassium increases stomatal function, leading to better CO_2 absorption and higher photosynthetic efficiency (42). These nutrients work together to boost photosynthetic activity, improving dry matter production, leaf area index (LAI), and crop growth rate (CGR), resulting in better cob yield parameters such as cob length, diameter, and weight without husk (43). Furthermore, (44) found that organic fertilizers, particularly cow dung, boost soil microbial activity and enzymatic function, which aids in nutrient mineralization and availability. This discovery lends credence to the significance of cow dung in improving the soil's nutritional profile, which, when paired with inorganic sources, assures a consistent supply of N, P, and K. This combination dramatically increases maize vegetative growth and biomass, as seen in Baby Star.

Baby corn variety and fertilization rates interacted in a statistically meaningful way in terms of N, P, K, and S absorption. Baby Star showed the maximum amounts of N, P, K, and S absorption at 75% RD + CD @ 10 t ha^{-1}. Garcia and Norton (45) revealed the relevance of balanced sulfur levels in increasing seed development and quality, specifically the function of S in protein synthesis and enzyme activity, which are crucial for kernel quality, as found in our work. The combination of organic and inorganic fertilizers helps to accumulate more nitrogen, phosphorous, and potassium in the soil than solo application of fertilizers (46). Several enzymes released by cow dung have been linked to an increase in the activity of heterotrophic bacteria and fungi in soil. By doing so, soil enzymes can help to convert unavailable forms of nutrients into accessible forms (47). The amount of nitrogen in cob and stover may also be enhanced because slowly mineralizable nitrogen from integrated sources assures appropriate availability for absorption and transportation to the plant parts during the growth season. Nitrogen is the primary component of protein and can greatly enhance the protein level of baby corn. According to research by (48), baby corn's better physiological and biochemical activity under a proper and balanced nutrition supply may have raised the protein content of the plant. Similar to this, the organic sources ensure P, K, and S availability in soil for a longer time and improve P, K, and S absorption with continuous nutrient supply.

Long-term studies on soil health, sustainability, and the use of smart technology for optimized fertilizer application are essential. Future research should focus on conducting cost-benefit analyses of nutrient management and expanding the study to different climates. Investigating the role of biofertilizers and environmental impacts, such as greenhouse gas emissions, is also critical. Lastly, effective farmer education through extension programs and mobile tools is necessary for the practical implementation of research findings.

Conclusion

The use of both chemical and organic fertilizers in the development of baby corn is a viable technique for increasing agricultural sustainability. These approaches, which optimize nutrient absorption, not only promote plant growth, yield, and quality, but also contribute to the sustainable intensification of agricultural production. The good results of mixing lowered dosages of inorganic fertilizer with organic additions such as cow dung (CD) indicate a balanced strategy that reduces reliance on synthetic fertilizers. Future research should broaden the scope of this work to include cost-benefit analysis, environmental impact assessments, and long-term sustainability evaluations. Furthermore, determining the scalability of these approaches across various agro-ecological zones and farming systems would be critical.

Acknowledgements

The authors would like to thank the Bangladesh Agricultural Research Institute authority, Joydebpur, Gazipur, for the fellowship and financial assistance to conduct the research offered to MHS.

Authors' contributions

MHS and AKH prepared the research plan and methodology. MHS, SAK and AKH performed the statistical analysis and drafted the manuscript. FZ, SSI, MAK and AFMSA participated in the reviewing and editing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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