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Effects of integrated nutrient management and fertilizers on the yield of baby corn in Punjab's climatic context

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Abstract

The combined impacts of climate change and increased chemical fertilizer use are diminishing soil fertility, thereby reducing agricultural productivity and farmland yield potential. This study investigates the effect of integrated nutrient management on baby corn. Results showed that the highest cob length (14.28 cm) and green fodder yield (45.56 t ha^{-1}) were achieved using elevated levels of nitrogen (160 kg ha^{-1}) and phosphorus (120 kg ha^{-1}), supplemented with zinc (6 kg ha^{-1}) and *Azotobacter*. Soil nutrient availability was assessed, indicating that treatment with 160 kg N + 100 kg P + 6 kg Zn + *Azotobacter* results in available nitrogen levels of 277.2 kg ha^{-1} and the highest organic carbon content (0.26%). Available phosphorus content (ranging from 24.1 to 24.3 kg P ha^{-1}) is observed with 120 kg P. Nutritional quality parameters were also influenced by nutrient levels, with the treatment of 160 kg N + 120 kg P + 6 kg Zn + *Azotobacter* showing the highest total soluble solids (11.2% brix) and protein content (17.9%). The treatment of 140 kg N + 100 kg P + 6 kg Zn exhibits the maximum fiber content (26.5%). In summary, the study underscores the positive impact of biofertilizers and zinc on fodder yield and soil properties. Integrating biofertilizers and micronutrients is recommended for sustaining agriculture and maintaining soil health over the long term.

Keywords

climate change; chemical fertilizers; soil fertility; agricultural land; integrated nutrient management; green fodder yield; baby corn

Introduction

The escalating global population and the pervasive impacts of climate change have emerged as critical concerns, compelling farmers to strive for enhanced food production. In this pursuit of meeting the escalating demands for food and livestock feed, agricultural practitioners have increasingly resorted to the application of chemical fertilizers, predominantly supplying essential nutrients like nitrogen, phosphorus, and potassium. However, this prevailing practice has inadvertently led to imbalances in micronutrient levels and a consequential decline in soil fertility (1). This, in turn, poses a significant and looming threat to overall agricultural productivity and sustainability.

Within this context, the cultivation of baby corn emerges as a multifaceted solution. Beyond its primary use as a consumable vegetable, baby corn plants, post-cob harvest, can be repurposed as valuable forage for livestock (2). With a remarkably short growth cycle of 60–70 days, the feasibility of harvesting up to four crops annually becomes a tangible

reality. Notably, the growth and development of maize crops, from which baby corn is derived, hinge upon specific moisture and temperature thresholds.

Baby corn, renowned for its attributes, stands as a pivotal vegetable crop. Its abbreviated cultivation duration, coupled with its commendable nutritional profile (approximately 15–18% proteins, 2% fat, 6% crude fiber, and a notable content of ascorbic acid, ranging between 75 to 80 mg/100 mg cob), underscores its significance. This composition accentuates its role as a valuable dietary component (3). Moreover, its economic yield contributes to its attractiveness in agricultural endeavors. Corn fiber can be utilized to form biodegradable composites which improve the mechanical properties of the composite (4). Baby corn is a healthy produce because of the lesser use of pesticides as insect infestation is lower as compared to other crops leaving lower pesticide residues in the cobs.

Integrated nutrient management involves the strategic amalgamation of organic, inorganic, and biofertilizers to enhance soil fertility and optimize crop productivity. This holistic approach mitigates the negative consequences associated with exclusive reliance on inorganic fertilizers. Soil properties are crucial and accurate computations of the quantity of fertilizers to be given is necessary. N is the essential ingredient because it influences the plant-water connections and biota in the rhizosphere (5). The deficiency of nitrogen has been found in Indian soil which varies from state to state. In Indian soil, the nitrogen use efficiency is between 30–35% in cereal crops and the remaining is lost (6). It is a vital part of many different biological molecules that are important for photosynthetic activity and agricultural output. Grain output and plant development in maize can be impacted by nitrogen availability. Physiological elements including radiation interception and efficient utilization, as well as nitrogen partitioning to reproductive organs, may be used to assess the impact of nitrogen supply on maize grain output (7). Within agricultural cropping systems, phosphorus (P) is one of the most restrictive nutrients (8). An estimated 67% of the world's land used for agricultural production is thought to have P deficiency (9). Consequently, one must take crops' P requirements into account. Compared to perennial crops, plants with intensive and short life cycles, like corn (*Zea mays* L.), need more P in solution and absorb P replenishment more quickly (10). A notable concern in Indian agricultural landscapes is the escalating prevalence of zinc (Zn) deficiency, which currently afflicts 48% of soils and is projected to further escalate. In the context of baby corn cultivation, Zn deficiency can precipitate the onset of white bud disease, underscoring the necessity of Zn supplementation for cultivating a robust and healthy crop (11). Due to its involvement in several vital cellular activities, including ion homeostasis, enzyme activation, and metabolic and physiological processes, zinc (Zn) is an essential element for plants (12). Zinc functions as a fundamental or catalytic enzyme that affects the activity, structural integrity, and folding of many proteins (13). So, the application of Zn is necessary for better crop growth.

Sustaining soil productivity in the backdrop of intensified cropping practices and elevated chemical fertilizer usage necessitates the promotion of organic substances such as fertilizers, insecticides, and biofertilizers (14). Among these, biofertilizers play a pivotal role in upholding soil fertility and crop productivity. *Rhizobium*, for instance, contributes a substantial 50–100 kg of nitrogen per hectare, while *Azotobacter* supplements the soil with an additional 20 to 40 kg of nitrogen per hectare (15).

Employing an integrated approach that incorporates nitrogen, phosphorus, zinc, and *Azotobacter* culminates in a notable augmentation of baby corn crop yields. The adoption of integrated nutrient management not only aligns with the principles of sustainable agriculture but also safeguards soil quality for future generations. The judicious combination of nitrogen with *Azotobacter*, coupled with the integration of zinc as a micronutrient and varying phosphorus levels, synergistically enhances both yield and fertilizer utilization efficiency (16).

Baby corn is a relatively newer crop as compared to maize, thus limited research work is available in Indian conditions (17). So, finding adequate nutrient levels under Indian conditions is necessary for the widespread adoption of baby corn crops by farmers without negatively impacting the soil and environment. Motivated by the aforementioned challenges and remedies, this study aimed to identify an optimal nutrient management system that could effectively elevate baby corn productivity.

Materials and Methods

The experimental study was conducted during the Rabi season of 2021–22 at the research farm situated within Lovely Professional University, Phagwara, Punjab. The soil composition of the farm exhibited a sandy loam texture, accompanied by a pH value of 8.5. The experimental setup employed a Randomized Block Design, with three replications for each of the nine treatments. These treatments encompassed a range of variations given in Table 1.

The nutrient requirement of baby corn is higher than normal maize crops. So, to find the appropriate doses of nutrients, the RDF of maize and increased N and P doses were used. However, the potassium availability under the Punjab condition is already high, the recommended K (60 kg/ha) dose was used in all treatments. The plot dimensions were set at 5 m in length and 4 m in width. Nitrogen inputs were introduced using urea, while phosphorus was sourced from DAP, which incidentally contains nitrogen as well. Adjustments in urea dosages were made accordingly. Full doses of DAP and MOP were applied at the time of sowing, urea was applied in two splits at 10 DAS and 25 DAS. Zinc deficiency is a common problem under Punjab conditions, so the recommended dose of zinc is 6 kg (PAU, Ludhiana) was utilized to check the difference with and without the use of Zn. Approximately 80% Zn was applied through soil

Table 1. Various treatment combinations of the experiment.

Sr. No.	Symbol	Treatment
1	T_1	NPK (120:80:60 kg ha^{-1})
2	T_2	140 kg N + 100 kg P + 6 kg Zn
3	T_3	140 kg N + 100 kg P + 6 kg Zn + *Azotobacter*
4	T_4	140 kg N + 120 kg P + 6 kg Zn
5	T_5	140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*
6	T_6	160 kg N + 100 kg P + 6 kg Zn
7	T_7	160 kg N + 100 kg P +6 kg Zn + *Azotobacter*
8	T_8	160 kg N + 120 kg P + 6 kg Zn
9	T_9	160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*

application and to avoid the Zn deficiency at a later stage spraying of Zn EDTA was done. Zinc supplementation involved the application of 5.33 kg Zn/ha through soil incorporation which was done at 15 DAS, supplemented with an additional 0.61 kg Zn/ha via foliar spray using Zn EDTA at 30 DAS. Notably, *Azotobacter* biofertilizer (*Azotobacter* spp.) is a non-symbiotic atmospheric nitrogen fixer. The minimum bacterial count was 5×10^7 cells g^{-1} and carriers were 1×10^8 carrier mL^{-1}. It was applied as a seed treatment at a rate of 250 g of biofertilizer/10 kg seed. The 250 g of biofertilizer was mixed in 1 L of water, and then thoroughly mixed with the seed. It was then left in the shade for 2 hrs to dry and then seed sowing was done.

Observations were recorded from four randomly selected plants within each plot. For data concerning baby corn cobs, the harvested cobs from designated plants underwent three separate pickings. Soil testing involved the collection of samples from each plot to a depth ranging between 15 to 20 cm. Then, each sample was dried in the hot air oven at 105°C and sieved with a 2 mm sieve for further processing. These samples were subjected to NPK analysis, alongside measurements of soil pH, electrical conductivity (EC), and organic carbon content. The collected data underwent meticulous analysis to discern the varying effects of the different treatments on all the observed parameters related to baby corn growth and development.

Protein content (%)

1 g dried cob sample was taken and digested in a Kjeldahl flask with 1:10 of cupric sulphate and potassium sulphate and 10 mL concentrated H_2SO_4 was added. Distillation with NaOH was done which releases ammonia followed by titration.

Protein content = Percent N_2 × factor used 6.25 (Eqn. 1)

TSS (Total soluble solids)

A hand refractometer (1° – 30°) was used to measure the TSS. The juice of the sample was put on a refractometer to check the result. The refractometer was held against the light.

Fibre content (%)

Samples were oven-dried at 1000°C for 20 min. After cooling, 2 g of the sample was weighed, put in the capsule, and transferred to the extraction cup. 200 mL of 1.25% H_2SO_4 was added to it. For acid-free residue, boiling for half an hour in hot water was done. Followed by alkali washing with 1.20% NaOH for 30 min and again washing with hot water. After that capsule was oven-dried for 2 hrs at 1300°C and then placed in a muffle furnace for 5 hrs at 550°C. After cooling, the sample was weighed for crude fiber.

$$\text{Crude fibre (\%)} = \frac{\text{weight after drying} \times 100}{\text{initial sample weight}} \quad \text{(Eqn. 2)}$$

Statistical analysis

The statistical data analysis was conducted; the mean and standard deviation were computed. The data were subjected to an Analysis of Variance (ANOVA) using the OPSTAT software. For all the data, a 5% level of significance was used. The data is presented as mean along with standard error (SEM±) and critical difference (C.D.).

Results

Weight of cob without sheath (g)

The results, as summarized in Table 2, underscored the pronounced impact of the different treatments on cob weight without sheath. Notably, a significant influence was observed across all treatments. Among the three harvest rounds, Treatment 9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) consistently yielded the highest cob weight without sheath, followed closely by Treatment 7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*), and Treatment 8 (160 kg N + 120 kg P + 6 kg Zn) securing the third position. Conversely, the lowest cob weights without sheath were recorded under the control Treatment 1 (NPK 120:80:60 kg/ha). In the first and third pickings, Treatment 2 (140 kg N + 100 kg P + 6 kg Zn) exhibited relatively lower cob weights, while in the second picking, this trend was mirrored by Treatment 2 (140 kg N + 100 kg P + 6 kg Zn).

Interestingly, during the first and final picking stages, Treatments T6 (160 kg N + 100 kg P + 6 kg Zn), T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*), and T8 (160 kg N + 120 kg P + 6 kg Zn) demonstrated statistically comparable cob weights. However, during the second picking, no significant disparities were noted among the treatments.

The observed trend of increased cob weight without sheath in treatments featuring higher nitrogen and phosphorus levels, coupled with zinc supplementation, resonates with established knowledge. The contribution of *Azotobacter*, facilitating enhanced nitrogen availability and uptake, likely catalyzed improved metabolic processes, subsequently reflecting in augmented cob weight. This finding aligns with previous research by (18), who reported similar outcomes indicating that heightened nitrogen application in baby corn corresponded with increased fresh cob weights, with the peak observed at 200

Table 2. Weight (g) and length (cm) of cobs without husk at 1st, 2nd and 3rd picking as influenced by various treatments.

Symbol	Treatment	Weight of cobs (g)			Length of cobs (cm)		
		1st picking	2nd picking	3rd picking	1st picking	2nd picking	3rd picking
T_1	NPK (120:80:60)	15.61	16.87	10.9	12.17	12.60	10.51
T_2	140 kg N + 100 kg P + 6 kg Zn	16.16	16.73	12.46	13.12	12.84	10.94
T_3	140 kg N + 100 kg P + 6 kg Zn + *Azotobacter*	16.51	17.00	13.56	13.49	13.36	11.19
T_4	140 kg N + 120 kg P + 6 kg Zn	16.96	17.10	14.81	13.60	13.69	11.10
T_5	140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*	17.99	17.54	15.65	13.78	13.77	11.23
T_6	160 kg N + 100 kg P + 6 kg Zn	18.46	17.87	17.41	14.63	13.98	11.53
T_7	160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*	20.03	18.76	18.32	15.11	14.39	11.82
T_8	160 kg N + 120 kg P + 6 kg Zn	18.89	18.12	18.06	14.96	14.35	11.65
T_9	160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*	21.44	18.90	19.31	15.47	15.27	12.13
Mean		18.01	17.65	15.61	14.04	13.80	11.34
SEM ±		0.82	0.88	0.82	0.54	0.48	0.18
C.D. (5%)		**2.47**	**NS**	**2.47**	**1.61**	**1.43**	**0.53**

kg N/ha. Further corroboration arises from studies indicating that cob weight in baby corn rises in tandem with elevated nitrogen dosages (19, 20). Zn application in soil improves pollen viability, kernel number, and kernel weight of maize due to increased enzymatic activities (21).

Length of cobs without sheath (cm)

The length of cobs without sheaths varied significantly across the various treatments as shown in Table 3. As detailed in Table 2, the length of cobs without sheath was notably elevated in Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) during all picking stages. Additionally, Treatments T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*), T8 (160 kg N + 120 kg P + 6 kg Zn), and T6 (160 kg N + 100 kg P + 6 kg Zn) showcased a statistically comparable performance in the first and second pickings. However, a deviation was observed in the third picking, with Treatment T6 (160 kg N + 100 kg P + 6 kg Zn) displaying non-par performance. In contrast, the minimum length of cobs without sheath was consistently recorded in Treatment T1 (NPK 120:80:60 kg/ha), followed by Treatment T2 (140 kg N + 100 kg P + 6 kg Zn) across all pickings.

Notably, the observed increase in cob length without sheath can be attributed to the intensified application of nitrogen and zinc. Research indicates that zinc supplementation, along with higher nitrogen dosages, correlates positively with the augmentation of cob length without husk (22). Moreover, the cumulative effect of elevated NPK application contributes to the elongation of baby corn cobs. The influence of phosphorus levels on cob length is also evident in the literature (23). Specifically, the introduction of phosphorus in baby corn cultivation has a discernible impact on cob length, with an observed positive correlation between phosphorus dosage and cob length (24). The rise may be the result of zinc's effect on several enzymatic pathways, which aid in accelerating growth reactions and ultimately developing more yield-attributing characteristics (25).

Cob girth (mm)

The comprehensive analysis presented in Table 3 underscored the significant impact of various treatments on cob girth. Cob girth was appreciably influenced across the diverse treatment regimens. Notably, Treatment T1 (NPK 120:80:60 kg/ha) yielded the minimum cob girth, closely followed by Treatment T2 (140 kg N + 100 kg P + 6 kg Zn). Conversely, Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) consistently yielded the maximum cob girth during all harvesting cycles. Moreover, Treatments T6 (160 kg N + 100 kg P + 6 kg Zn), T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*), and T8 (160 kg N + 120 kg P + 6 kg Zn) exhibited statistically equivalent cob girths, positioning them in a similar category. Among these, Treatment T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*) secured the second position, with Treatment T8 (160 kg N + 120 kg P + 6 kg Zn) following as the third.

Notably, the observed variations in cob girth can be attributed, in part, to the levels of phosphorus. Previous research highlights the positive correlation between increasing phosphorus levels and cob girth in maize, reinforcing the effect observed in this study (24). Furthermore, the augmented nitrogen availability to the crops likely contributed to the observed increase in cob girth. Similar findings have been reported, indicating that higher nitrogen levels in baby corn cultivation correlate with increased cob girth (19). Studies have indicated that nitrogen doses at 90 kg ha^{-1} induce greater cob girth compared to lower nitrogen doses (23). Zinc application also played a notable role in cob girth enhancement. The treatments incorporating zinc exhibited superior cob girth when compared to non-zinc treated plots, possibly due to the heightened chlorophyll concentration and consequential improvements in yield characteristics resulting from zinc supplementation (26).

Table 3. Cob girth (mm) at 1st, 2nd and 3rd picking and green fodder yield (t ha^{-1}) at harvest as influenced by various treatments.

Symbol	Treatment	1st picking	2nd picking	3rd picking	Green fodder yield (t ha^{-1})
T_1	NPK (120:80:60)	14.85	14.43	13.76	37.25
T_2	140 kg N + 100 kg P + 6 kg Zn	14.99	14.75	14.11	39.69
T_3	140 kg N +100 kg P +6 kg Zn + *Azotobacter*	15.62	15.49	14.39	40.85
T_4	140 kg N + 120 kg P + 6 kg Zn	15.40	15.18	14.23	40.08
T_5	140 kg N +120 kg P +6 kg Zn + *Azotobacter*	15.79	15.47	14.73	41.08
T_6	160 kg N + 100 kg P + 6 kg Zn	16.39	15.83	14.99	43.63
T_7	160 kg N +100 kg P +6 kg Zn + *Azotobacter*	16.77	16.35	15.35	45.07
T_8	160 kg N + 120 kg P + 6 kg Zn	16.63	16.14	15.16	44.61
T_9	160 kg N +120 kg P +6 kg Zn + *Azotobacter*	17.28	16.97	15.59	45.56
Mean		15.97	15.62	14.70	41.98
SEM ±		0.46	0.41	0.28	1.46
C.D. (5%)		**1.38**	**1.23**	**0.84**	**4.38**

Green fodder yield (t ha^{-1})

The detailed analysis presented in Table 3 underscored the notable variability in green fodder yield across the different treatments. The pre-eminent green fodder yield emerged in Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*), closely followed by Treatments T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*) and T8 (160 kg N + 120 kg P + 6 kg Zn). Remarkably, the latter two treatments exhibited statistically comparable yields with Treatment 9. Conversely, the minimum green fodder yield was recorded under Treatment T1 (NPK 120:80:60 kg/ha), followed by Treatment T2 (140 kg N + 100 kg P + 6 kg Zn). The treatments, T3 (140 kg N +100 kg P + 6 kg Zn + *Azotobacter*), T4 (140 kg N + 120 kg P + 6 kg Zn) and T5 (140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) produced more than 40 t ha^{-1} of green fodder yield. The observed escalation in green fodder yield of baby corn ranged from 6.54% to an impressive 22.30% when contrasted against the control Treatment T1.

The augment in green fodder yield could be attributed to intensified nitrogen supply through nitrogen fertilizers or the introduction of *Azotobacter*. Such interventions might have accelerated diverse physiological processes within the plant, manifesting in notable enhancements in yield characteristics (19). The synergy of chemical nitrogen application in tandem with *Azotobacter* could potentially have amplified growth and yield parameters, ultimately culminating in improved fodder yield (27, 28). Research pertaining to sweet corn underscores the correlation between elevated nitrogen levels and increased green fodder yield. Intriguingly, the application of *Azotobacter* in combination with 100% RDF (Recommended Dose of Fertilizers) for seed treatment in baby corn resulted in heightened green fodder yield, paralleling the outcomes observed with 125% RDF (29, 30).

Furthermore, phosphorus's role in facilitating energy transfer likely contributed to the enhanced green fodder yield. Improved photosynthate translocation associated with applied zinc might have spurred increased green fodder production, thereby substantiating its effect on nutrient levels (26, 31). The application of zinc to baby corn, through both soil and foliar approaches, emerges as a significant factor, augmenting green fodder yield in a statistically significant manner (31).

Protein content (%)

The intricate interplay of treatment combinations significantly influenced the protein content, as delineated in Table 4. Notably, the maximum protein content within cobs was recorded in Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*), closely trailed by Treatments T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*) and T8 (160 kg N + 120 kg P + 6 kg Zn). These treatments, with respect to protein content, were statistically analogous to Treatment 9. In contrast, the control Treatment T1 (NPK 120:80:60 kg/ha) registered the minimum protein content percentage, followed by Treatment T2 (140 kg N + 100 kg P + 6 kg Zn). The results indicate that when more than 140 kg N was used, the protein content (%) was more than 14%.

Protein content dynamics may be traced back to nitrogen levels within the plant. The application of elevated nitrogen levels, coupled with *Azotobacter*-enhanced nitrogen availability, likely bolstered nitrogen uptake by crop plants, thus engendering heightened protein content within baby corn cobs. The use of biofertilizers such as *Azotobacter* in seed inoculation has consistently demonstrated a favourable impact on crop protein content (32). This positive influence is further underscored by studies showcasing the protein content improvement resulting from increased nitrogen levels and seed treatments involving biofertilizers like *Azotobacter* or *Azospirillium* (29). Likewise, an array of studies has consistently revealed the protein content's responsiveness to shifting nitrogen doses in baby corn (33–36). Remarkably, protein content enhancement is also noted with variations in phosphorus levels (37).

Table 4. Protein content (%), TSS (% brix) and fibre content (%) of cobs as influenced by various treatments.

Symbol	Treatment	Protein (%)	TSS (% brix)	Fibre content (%)
T_1	NPK (120:80:60)	12.7	8.5	24.1
T_2	140 kg N + 100 kg P + 6 kg Zn	13.4	8.7	26.5
T_3	140 kg N + 100 kg P + 6 kg Zn + *Azotobacter*	14.2	8.9	26.0
T_4	140 kg N + 120 kg P + 6 kg Zn	14.1	8.9	26.2
T_5	140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*	15.1	9.1	25.5
T_6	160 kg N + 100 kg P + 6 kg Zn	16.1	10.2	25.1
T_7	160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*	16.9	10.5	24.9
T_8	160 kg N + 120 kg P + 6 kg Zn	16.8	10.8	25.0
T_9	160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*	17.9	11.2	24.8
Mean		15.24	9.6	25.35
SEM ±		0.32	0.20	0.36
C.D. (5%)		**0.97**	**0.61**	**1.07**

Zinc's role extends to protein content improvement, as it amplifies nitrogen uptake by plants. This, in turn, might have contributed to the observed protein content elevation in baby corn cobs. The protein content-zinc concentration nexus is further reinforced by findings indicating that zinc application shapes both protein content and zinc concentration in the baby corn crop (38). The collective influence of increased nitrogen, phosphorus, and zinc is evident in the improved protein content observed in the cobs of sweet corn (39).

Total soluble solids (TSS % brix)

The diverse treatment combinations yielded statistically significant variations in total soluble solids (TSS). As presented in Table 4, Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) emerged as the frontrunner, recording the highest TSS level of 11.2% brix. Treatment T8 (160 kg N + 120 kg P + 6 kg Zn) closely matched Treatment T9 in TSS value. The collective TSS range spanned from 8.5% to 11.2% brix. At the lower end of this spectrum, Treatment T1 (NPK 120:80:60 kg/ha) secured the lowest TSS value of 8.5% brix, with Treatment T2 (140 kg N + 100 kg P + 6 kg Zn) closely following. The TSS value increased with increasing levels of nitrogen, the values were recorded in excess of 10 in the treatment where 160 kg N was applied with or without *Azotobacter*.

The observed elevation in total soluble sugar content in baby corn can be attributed to several factors. An enhanced photosynthetic rate, elevated chlorophyll content, and the hydrolysis of starch into soluble sugars collectively contribute to this effect. The synergy of nitrogen supplementation, including the contribution from *Azotobacter*, is pivotal in bolstering TSS levels (20). Both chemical and biofertilizer interventions augment TSS levels, underscoring the collaborative impact of nitrogen sources (*Azotobacter*) on this outcome. The seed treatment of baby corn with *Azotobacter* registers a mild yet discernible enhancement in TSS values.

Furthermore, the influence of nitrogen levels on TSS content is evident, with lower nitrogen doses translating to reduced TSS content in baby corn (40). This premise is substantiated by research illustrating the amplification of total soluble solids through the seed inoculation of baby corn with *Azotobacter*, a strategy that effectively elevates TSS content in comparison to non-treated seed treatments (41).

Fibre content (%)

The highest fibre content among the cobs was prominently observed, as depicted in Table 4, under Treatment T2 (140 kg N + 100 kg P + 6 kg Zn). In the hierarchy of treatments, Treatment T4 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*) secured the second position, closely trailed by Treatment T3 (140 kg N + 100 kg P + 6 kg Zn + *Azotobacter*). Treatments T4 (140 kg N + 120 kg P + 6 kg Zn), T3 (140 kg N + 100 kg P + 6 kg Zn + *Azotobacter*), and T5 (140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) achieved statistical parity with Treatment T2 (140 kg N + 100 kg P + 6 kg Zn). Remarkably, the lowest fiber content was recorded under the control Treatment T1 (NPK 120:80:60 kg/ha). While substantial differences were observed among the various treatments, the variance in fiber content was notably modest across all treatment groups. The lowest value recorded was 24.1% in T1 and the maximum content was 26.5% in T2.

Elevated soil fertility levels, driven by enriched nitrogen, phosphorus, and potassium availability, might have fostered the enhanced presence of metabolites and nutrients. Zinc's contribution, likely associated with improved nitrogen uptake, could have synergistically contributed to the overall nutritional quality enhancement of baby corn. The application of foliar zinc and NPK fertilizers has been previously associated with elevated fiber content in the baby corn crop (42).

However, it's noteworthy that treatments yield less fiber content might be attributed to higher protein content in the cobs (26, 43). The intricate balance between these nutritional components warrants further exploration to decipher the interplay influencing the crop's overall nutritional profile. However, less fiber content in some treatments can be due to higher protein content in the cobs (26, 43).

Nutrient status of soil (Post-Harvest)

The dataset outlined in Fig. 1 revealed that the diverse treatments yielded non-significant effects on electrical conductivity (EC), and organic carbon (OC) levels following harvest. Table 5 revealed that, soil pH is not affected significantly. Differential pH values could be attributed to varying nitrogen levels in the soil, as nitrogen addition tends to lower soil pH. The observed fluctuations in EC and OC levels may stem from disparate nutrient levels and the application of *Azotobacter*. Notably, pH, EC, and OC remained relatively unaffected by the application of different nutrient levels (44). In addition, organic carbon content exhibited an increase with *Azotobacter* inoculation.

Examining nitrogen availability, Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) yielded the highest availability, driven by elevated nitrogen levels and the presence of *Azotobacter* as depicted in Table 5. This was closely followed by Treatments T7 (160 kg N + 100 kg P + 6 kg Zn + *Azotobacter*) and T8 (160 kg N + 120 kg P + 6 kg Zn). Interestingly, nitrogen availability in Treatment T7 surpassed that of Treatment T8, despite the latter having higher nitrogen levels. This divergence could be attributed to *Azotobacter*'s seed treatment, known to augment soil nitrogen availability. Conversely, the least nitrogen availability was noted in the control Treatment T1 (NPK 120:80:60 kg/ha).

As presented in Table 5, phosphorus availability also demonstrated noteworthy variation among treatments. Treatment T9 (160 kg N + 120 kg P + 6 kg Zn + *Azotobacter*) exhibited the highest phosphorus availability, albeit with minor differences among the top four treatments - Treatment T9, Treatment T5 (140 kg N + 120 kg P + 6 kg Zn + *Azotobacter*), Treatment T8, and Treatment T4 (140 kg N + 120 kg P + 6 kg Zn). Notably, the differences were marginal, at 0.2 kg/ha. The lowest phosphorus availability was witnessed in the control Treatment T1.

Table 5 revealed that potassium availability displayed negligible variation among treatments, consistent with the application of a uniform potassium dose across all treatments. The observed discrepancies in potash availability might be attributed to the concurrent application of other nutrients. Notably, higher nitrogen levels' application demonstrated a modest positive impact on soil nitrogen availability (45). Furthermore, treatments featuring elevated phosphorus levels showcased higher available phosphorus compared to their lower-phosphorus counterparts (46).

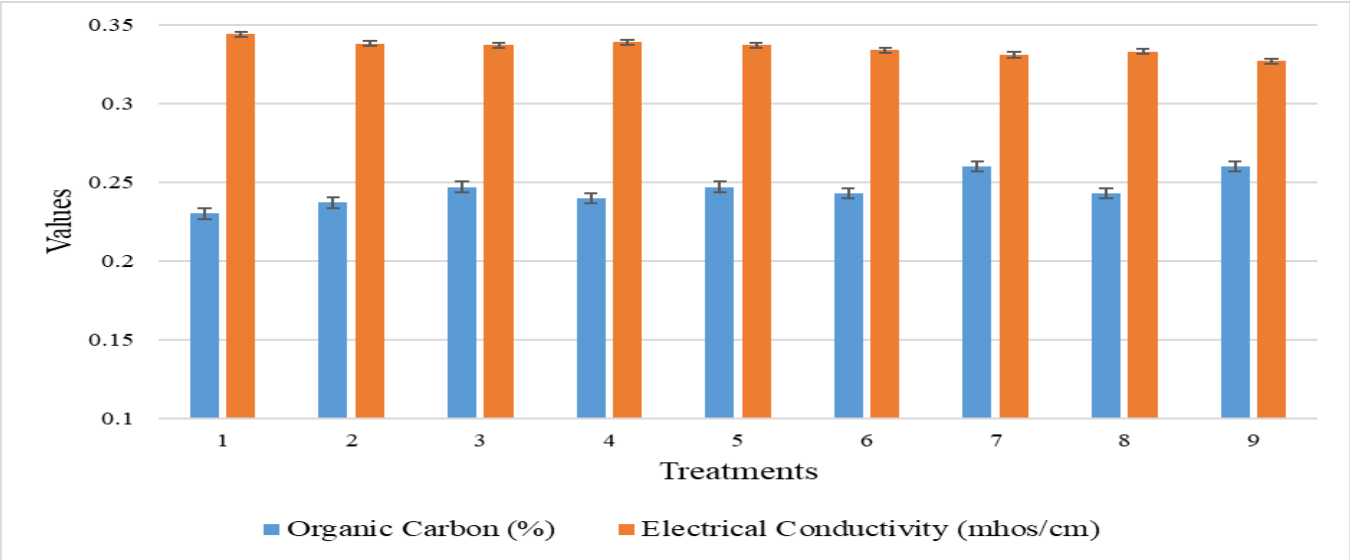

Fig. 1. Electrical conductivity and organic carbon as influenced by various treatments.

Table 5. Available N, available P, and available K in soil as influenced by various treatments.

Treatment	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	8.52	253.2	18.2	224.0
T_2	8.5	256.6	20.3	225.2
T_3	8.48	261.8	20.5	225.2
T_4	8.49	259.0	24.1	224.6
T_5	8.43	267.0	24.2	224.7
T_6	8.34	272.4	20.6	225.0
T_7	8.31	277.2	20.9	225.1
T_8	8.24	272.1	24.1	224.9
T_9	8.17	277.1	24.3	225.1
Mean	8.39	266.3	21.9	224.9
SEM ±	0.08	4.10	0.82	0.80
C.D. (5%)	**NS**	**12.31**	**2.45**	**NS**

Conclusion

In summary, the integration of key nutrients, coupled with zinc supplementation and the inclusion of biofertilizer *Azotobacter*, not only exhibited a positive impact on the green fodder yield of the baby corn crop but also contributed to a discernible increase in soil organic carbon levels and available soil nitrogen content. This integrated approach presents a promising avenue for fostering sustainable agricultural practices. Additionally, the assimilation of nutrients yielded a notable enhancement in the quality of baby corn cobs, consequently elevating their nutritive value. Crucially, the utilization of integrated nutrient management in the cultivation of baby corn demonstrated its superiority over sole reliance on chemical fertilizers. While chemical fertilizers may offer immediate yield gains, they carry the risk of long-term soil fertility degradation and decreased productivity. In contrast, integrated nutrient management safeguards both higher yield levels and improved quality while fostering higher soil quality, all while minimizing environmental and soil pollution. By embracing integrated nutrient management, farmers can attain a harmonious balance between productivity, environmental conservation, and long-term soil health, thereby steering agricultural practices toward a sustainable and resilient future.

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Authors' contributions

RS is the first author who has done the research work under the guidance and help of RG. RG did editing, corrections, and formatting of the manuscript. MC and MP performed the statistical analysis and lab testing. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None.

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