



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 679-687
Received: 07-03-2026
Accepted: 09-04-2026

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Effect of integrated nutrient management on growth, yield and economics of sweet corn (*Zea mays* L. saccharata)

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6i.5764>

Abstract

Sweet corn (*Zea mays* L. saccharata) is a high-value vegetable crop requiring intensive nutrient management, yet excessive reliance on chemical fertilizers undermines soil health and farm profitability. Integrated Nutrient Management (INM) combining inorganic fertilizers with organic and biological inputs offers a sustainable alternative, but location-specific validation remains limited for subtropical India. A field experiment was conducted during Rabi 2025-26 at Prayagraj (25°13'N, 81°46'E) in a Randomized Block Design with 12 treatments and 3 replications. Treatments comprised varying combinations of recommended dose of fertilizer (RDF: 120-60-60 kg NPK + 25 kg ZnSO₄ ha⁻¹), vermicompost (N-equivalent basis), and *Azospirillum* seed inoculation. Growth attributes, yield components, green cob and stover yields, kernel quality (sugar, starch), post-harvest soil fertility and economic returns were assessed. The treatment T₁₀ (75% RDF + *Azospirillum* + 25% vermicompost) consistently outperformed all other treatments. T₁₀ produced the tallest plants (197.2 cm at harvest), highest leaf area index (5.46), maximum dry matter accumulation (193.54 g plant⁻¹), and superior crop growth rate during the terminal growth interval. Yield attributes cobs plant⁻¹ (3.58), grains cob⁻¹ (611), cob length (20.1 cm), and seed index (30.98 g) were significantly greater under T₁₀ than the absolute control (T₁). Green cob yield (102.40 q ha⁻¹) and biological yield (298.40 q ha⁻¹) under T₁₀ exceeded the control by 74.2% and 62.7%, respectively. Kernel sugar and starch content varied non-significantly; however, T₁₀ recorded numerically highest values (16.48% sugar; 52.57% starch). Post-harvest soil organic carbon and available NPKZn were numerically higher under organic-amended treatments. Economically, T₁₀ generated the maximum net return (₹202,499 ha⁻¹) and benefit:cost ratio (3.20), surpassing both the control (₹101,080 ha⁻¹; 1.96) and the full RDF treatment (₹150,941 ha⁻¹; 2.58). Partial substitution of 25% chemical fertilizer with vermicompost supplemented by *Azospirillum* inoculation (T₁₀: 75% RDF + *Azospirillum* + 25% vermicompost) is the most productive, profitable and soil-sustaining INM strategy for sweet corn under subtropical conditions. This treatment can reduce fertilizer costs while enhancing cob yield and farm income, making it a viable recommendation for resource-constrained sweet corn growers in the Indo-Gangetic Plains.

Keywords: Sweet corn, *Zea mays* L. saccharata, integrated nutrient management, vermicompost, *Azospirillum*, green cob yield, benefit: cost ratio and soil fertility

1. Introduction

Maize (*Zea mays* L.) ranks third among global cereals after rice and wheat, cultivated on ~190 million ha with ~1,124 million tonnes production (FAOSTAT, 2020) [9]. In India, maize occupies 12.84 million ha with 46.15 million tonnes production and an average productivity of 3,595 kg ha⁻¹ (DAandFW, 2024) [4]. Among its types, sweet corn (*Zea mays* L. saccharata) a *sugary-1* (*su1*) mutant that blocks sugar-to-starch conversion in the endosperm has gained premium vegetable crop status (Oktem and Oktem, 2005) [27]. Sweet corn produces green ears within 75-90 days and is valued for its 5-6% sugar, 10-11% starch, 13% protein, potassium and provitamin A (Oktem and Oktem, 2005; Devi *et al.*, 2021) [6, 27]. Rising urbanization and changing diets have increased demand for fresh, canned and frozen sweet corn in India, necessitating improved production technologies (Kaur *et al.*, 2019) [15]. Despite its potential, sweet corn productivity remains below attainable levels, primarily due to inadequate and unbalanced nutrient

management (Kaur *et al.*, 2019) ^[15]. Sweet corn is an exhaustive crop, removing substantial NPK and micronutrients; the minimum recommended dose is 120-60-60 kg NPK + 25 kg ZnSO₄ ha⁻¹ (Marschner, 2012) ^[23]. Prolonged imbalanced chemical fertilization without organic supplementation has depleted soil organic carbon, degraded soil physical properties, reduced microbial diversity and induced multi-nutrient deficiencies especially zinc, iron and sulphur in intensively cropped Indo-Gangetic maize belts (Lal, 2015; Subba Rao *et al.*, 2017) ^[20, 40]. Fageria *et al.*, (2011) ^[8] emphasized that continuous cropping without adequate nutrient replenishment induces hidden hunger and substantial yield loss, even without visible symptoms. Nitrogen drives chlorophyll, protein and nucleic acid synthesis, governing vegetative growth and photosynthetic efficiency; phosphorus is critical for root development, ATP-mediated energy transfer and photosynthate translocation to developing cobs; potassium activates over 60 enzymes involved in carbohydrate metabolism, protein synthesis and stress tolerance (Marschner, 2012; Vessey, 2003; Ghosh *et al.*, 2018) ^[10, 23, 45]. Zinc a co-factor for superoxide dismutase and auxin (IAA) biosynthesis is particularly critical in alkaline calcareous soils of Uttar Pradesh, where high pH and CaCO₃ limit its availability (Pandey and Avasthi, 2014) ^[32].

Integrated Nutrient Management (INM) the synergistic combination of chemical fertilizers, organic manures and biofertilizers has emerged as a scientifically robust approach to address these constraints while improving nutrient use efficiency, soil health and farm profitability (Palm *et al.*, 2001; Tilman *et al.*, 2002; Subba Rao *et al.*, 2017) ^[30, 40, 43]. Vermicompost, the stabilized organic product of earthworm-microorganism interaction, supplies macro- and micronutrients in plant-available forms, contains humic acids that stimulate root growth, and hosts a diverse microbial community that mineralizes organic-bound nutrients (Arancon *et al.*, 2006) ^[1]. Vermicompost application enhances plant height, LAI, dry matter accumulation and cob yield in sweet corn compared to sole chemical fertilizer regimes (Paikra *et al.*, 2018; Shakunthala *et al.*, 2017) ^[29, 39]. Lahay *et al.*, (2019) ^[19] demonstrated that 75% RDF + vermicompost produced yields comparable to or exceeding 100% RDF, indicating potential for input reduction without yield penalty. Biofertilizers living microbial inoculants enhance nutrient availability through biological nitrogen fixation, phosphate solubilization, potassium mobilization and siderophore-mediated micronutrient chelation (Vessey, 2003) ^[45]. *Azospirillum* spp., a free-living associative nitrogen-fixing bacterium, colonizes the rhizoplane and root cortex, fixing 20-40 kg N ha⁻¹ season⁻¹ and producing phytohormones (IAA, gibberellins, cytokinins) that promote root branching and nutrient acquisition (Vessey, 2003; Mustafa *et al.*, 2019) ^[26, 45]. Kulandaivel *et al.*, (2004) ^[17] reported that *Azospirillum* inoculation significantly increased N uptake and grain yield in maize, with greater improvement when combined with organic manure. Kaur *et al.*, (2019) ^[15] and Mustafa *et al.*, (2019) ^[26] documented that *Azospirillum* + reduced RDF produced cob yields, kernel sugar and economic returns at par with or superior to full RDF.

Combined organic-inorganic nutrient management improves synchrony between nutrient release and crop uptake, reducing losses through leaching, denitrification and volatilization while sustaining productivity (Palm *et al.*, 2001) ^[30]. Vermicompost increases soil organic carbon a key determinant of aggregation, water retention and microbial biomass while *Azospirillum* enhances biological nitrogen fixation and root-induced mineralization (Lal, 2015; Ghosh *et al.*, 2018) ^[10, 20]. INM treatments combining organic, inorganic and biological

components produce significantly higher LAI, dry matter accumulation, CGR and RGR than unfertilized controls or sole chemical fertilizers (Tomar *et al.*, 2017; Raman *et al.*, 2018; Panchal *et al.*, 2018) ^[31, 36, 44]. Yield parameters cobs plant⁻¹, cob length, grains cob⁻¹, grain weight and seed index are strongly influenced by reproductive-phase nutrient supply (Dhariya *et al.*, 2018; Khan *et al.*, 2018) ^[7, 16]. Adequate P and Zn during silking and grain-filling is critical for kernel set; INM regimes supplying these nutrients through both organic and inorganic routes produce superior yield attributes (Khan *et al.*, 2018; Mustafa *et al.*, 2019) ^[16, 26]. Kernel sugar and starch content, though genetically determined, can be modulated by nutrient management (Kumar and Bohra, 2014) ^[18]. Mohammadi *et al.*, (2015) ^[25] reported that balanced NPK + vermicompost enhanced kernel soluble solids and sugar content through improved photosynthesis and sucrose translocation. Post-harvest soil fertility organic carbon, available N, P, K and Zn is consistently higher under organic-amended INM treatments (Kalhapure *et al.*, 2013; Dadarwal *et al.*, 2009; Kannan *et al.*, 2013) ^[5, 13, 14], with Pandey and Avasthi (2014) ^[32] specifically documenting vermicompost-enhanced Zn availability through organic acid chelation. Economically, INM treatments involving 75% RDF + vermicompost + biofertilizer produce the highest net returns (₹125,000-140,000 ha⁻¹) and B:C ratios (2.85-3.10), significantly exceeding 100% RDF (Tomar *et al.*, 2017; Mathukia *et al.*, 2014; Panchal *et al.*, 2018) ^[24, 31, 44]. Despite proven benefits, location-specific INM validation for sweet corn under eastern Uttar Pradesh's subtropical conditions remains limited. Sweet corn's short cycle (75-90 days), elevated N and Zn sensitivity during silking-grain-filling, and premium on cob quality necessitate optimized recommendations (Kaur *et al.*, 2019; Paikra *et al.*, 2018; Mustafa *et al.*, 2019) ^[15, 26, 29]. Therefore, this study evaluated 12 INM combinations under Prayagraj conditions (Rabi 2025-26) with objectives: (i) assess effects on growth parameters (plant height, LAI, dry matter, CGR, RGR, stem girth, SPAD index) of sweet corn var. Sugar-75; (ii) determine influence on yield components and yield (green cob, stover, biological); (iii) evaluate kernel quality (sugar, starch); (iv) assess post-harvest soil fertility; and (v) compute economics to identify the most productive, profitable and soil-sustaining INM strategy.

2. Materials and Methods

2.1 Experimental site and geographical situation

A field experiment was conducted at the Agricultural Research Farm, Prof. Rajendra Singh (Rajju Bhैया) University, Prayagraj, Uttar Pradesh, India (25°13'28" N, 81°46'25" E; 98 m above mean sea level) during the Rabi season of 2025-26. The experimental site experiences a subtropical climate characterized by hot summers, cool winters, and a well-defined monsoon season. Meteorological data including maximum and minimum temperature, relative humidity, rainfall and sunshine hours were recorded throughout the crop season from the Meteorological Observatory, SHUATS, Allahabad (U.P.) and are presented in Table 1 and Figure 3.1. Maximum and minimum temperatures recorded were 37.88 °C (March, 4th week) and 7.14 °C (December, 1st week), respectively; maximum relative humidity was 94.86% (January, 3rd week); total seasonal rainfall was 1,300 mm; and maximum sunshine hours were 9.20 hr day⁻¹ (March, 4th week). The experiment site had been under continuous cereal-based rotations for the preceding five years: rice-wheat (2020-21), groundnut-wheat (2021-22), rice-mustard (2022-23), maize-wheat (2023-24) and rice-mustard (2024-25), with sweet corn being introduced as the Rabi crop for the first time in 2025-26. This cropping history was documented to establish baseline soil

nutrient status and management context, following the approach recommended by Kaur *et. al.*, (2019) ^[15] for INM field trials in cereal crops.

2.2 Soil characterization

Prior to the initiation of the experiment, composite soil samples were collected from the plough layer (0-15 cm depth) from randomly selected spots across the experimental field using a soil auger. The samples were air-dried in the shade, ground, and passed through a 2 mm sieve before analysis (Jackson, 1973) ^[12]. Physical and chemical properties of the experimental soil are summarized. The soil was sandy loam in texture (sand 60.77%, silt 21.40%, clay 17.83%), with a bulk density of 1.51 Mg m⁻³ determined by the core sampler method (Piper, 1966). The soil had a pH of 8.25 (1:2.5 soil:water suspension; Jackson, 1973) ^[12], EC of 0.19 dS m⁻¹ (Bower and Wilcox, 1965) ^[2], and organic carbon of 0.42% (Walkley and Black, 1934) ^[46]. Pre-sowing available nitrogen (181.60 kg ha⁻¹), available phosphorus (16.50 kg ha⁻¹), and exchangeable potassium (230.47 kg ha⁻¹) were determined by the alkaline potassium permanganate method (Subbiah and Asija, 1956) ^[41], Olsen's method (Olsen *et. al.*, 1954) ^[28], and 1 N NH₄OAc extraction (Hanway and Heidal, 1952) ^[11], respectively. Available zinc (7.38 kg ha⁻¹) was estimated by the turbidimetric method (Williams and Steinbergers, 1969) ^[48]. The soil was classified as low in organic carbon and available N, medium in available P and K, and adequate in available Zn, indicating the need for balanced nutrient management consistent with the soil fertility characterization protocols described by Subba Rao *et. al.*, (2017) ^[40].

2.3 Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) with 12 treatments and 3 replications, comprising a total of 36 plots. RBD was chosen for its efficiency in controlling soil heterogeneity across blocks in a single direction, which is the standard design for INM field experiments in cereals (Cochran and Cox, 1963; Paikra *et. al.*, 2018) ^[29]. Each net plot measured 3 m × 3 m (9 m²); the gross experimental area was 486.16 m² with a net cultivated area of 324 m². Main irrigation channels (1.0 m wide) and sub-irrigation channels (0.5 m wide) separated replication blocks, with 0.3 m bunds demarcating individual plots. The layout plan of the experiment is presented in Figure 3.2. The twelve treatments (Table 1) comprised different combinations of inorganic fertilizer [Recommended Dose of Fertilizer (RDF)], vermicompost, and *Azospirillum* biofertilizer as follows:

Table 1: Experimental treatments

Treatments	Details
T ₁	Absolute control (no fertilizer)
T ₂	100% RDF (NPKZn)
T ₃	75% RDF + 25% Vermicompost
T ₄	100% RDF + 25% Vermicompost
T ₅	50% RDF + 50% Vermicompost
T ₆	75% RDF + <i>Azospirillum</i>
T ₇	100% RDF + <i>Azospirillum</i>
T ₈	50% RDF + <i>Azospirillum</i>
T ₉	50% RDF + <i>Azospirillum</i> + 50% Vermicompost
T ₁₀	75% RDF + <i>Azospirillum</i> + 25% Vermicompost
T ₁₁	50% RDF + <i>Azospirillum</i> + 25% Vermicompost
T ₁₂	125% RDF (NPKZn)

The RDF for sweet corn comprised N: 120 kg ha⁻¹, P₂O₅: 60 kg ha⁻¹, K₂O: 60 kg ha⁻¹ and ZnSO₄: 25 kg ha⁻¹, based on the recommendations of the Uttar Pradesh State Agricultural

Department. Nitrogen was applied as urea in two splits 50% as basal and 50% at the knee-high stage which is a standard practice for maximizing nitrogen use efficiency in maize (Marschner, 2012) ^[23]. P₂O₅, K₂O and ZnSO₄ were applied as di-ammonium phosphate (DAP), muriate of potash (MOP) and zinc sulphate (36% Zn), respectively, as a full basal dose at the time of sowing. Vermicompost (N content ~1.5%, on N-equivalent basis) was incorporated into the soil at the time of field preparation, following the protocol of Arancon *et. al.*, (2006) ^[1], who established that pre-incorporation of vermicompost seven days before planting optimizes its nutrient release kinetics. The *Azospirillum* biofertilizer was applied as seed inoculation at the recommended rate prior to sowing; seed treatment with *Azospirillum* has been well documented as an effective delivery method for associative nitrogen fixation in cereals (Vessey, 2003) ^[35]. Seed rate used was 10 kg ha⁻¹.

2.4 Crop management

The variety Sugar-75, a well-adapted sweet corn hybrid for the Indo-Gangetic plains, was selected for the experiment. Seeds were pre-treated with fungicide before sowing, a standard phytosanitary measure for sweet corn (Kaur *et. al.*, 2019) ^[15]. The experimental field was prepared by one harrowing and one ploughing using a tractor-drawn cultivator, followed by secondary tillage with a rotavator to achieve fine tilth. Planking was done after each tillage operation for proper leveling, ensuring uniform seed-to-soil contact and consistent germination an approach consistent with Lahay *et. al.*, (2019) ^[19], who emphasized standardized land preparation as a prerequisite for comparable INM trial outcomes. Sowing was done on 21 October 2025 at a depth of 4-5 cm with a row spacing of 60 cm × 25 cm, giving a target plant population of approximately 66,666 plants ha⁻¹, which is within the recommended range for sweet corn in subtropical India (Paikra *et. al.*, 2018) ^[29]. Gap filling was performed manually at 10 DAS to maintain optimum plant stand and recommended intra-row spacing. Two manual weeding were carried out first on 23 November 2025 and second on 8 December 2025 and hand pulling was done on 11 February 2026 to control late-season weeds. Irrigation was provided as needed based on crop growth stage and soil moisture status. Plant protection measures followed standard recommendations uniformly across all plots to exclude pest and disease interactions as confounding factors, consistent with the methodology of Mustafa *et. al.*, (2019) ^[26]. Green cobs were harvested manually in three consecutive pickings: 2 March 2026, 5 March 2026, and 9 March 2026, with a fourth picking on 15 March 2026; stover was harvested on 23 March 2026 by cutting close to the ground using sickles.

2.5 Observations and Measurements

2.5.1 Pre-harvest growth parameters

Plant population (m⁻²): The number of plants per metre row length was counted from five randomly selected spots in each plot at 15 DAS and at final harvest; mean values were converted to plant population per m² (Paikra *et. al.*, 2018) ^[29].

Plant height (cm): Plant height was measured from the base of the plant to the tip of the topmost leaf (before tasseling) and to the tip of the tassel (after tasseling) from five randomly tagged plants per plot at 30, 60, 90 DAS and at harvest, expressed in centimeters (Tomar *et. al.*, 2017) ^[44].

Leaf Area Index (LAI): The leaf area of five randomly selected plants per plot was measured with a portable leaf area meter at 30, 60, 90 DAS and at harvest. LAI was calculated using the formula of Watson (1958):

$$LAI = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Ground area covered (cm}^2\text{)}}$$

Dry Matter Accumulation (g plant⁻¹): Five plants were randomly uprooted from each plot at 30, 60, 90 DAS and at harvest. After removal of roots, plant material was sun-dried for 2-3 days and then oven-dried at 65 °C for 72 hours until constant weight was attained. The dried material was weighed on an electronic balance and expressed as dry matter per plant (g plant⁻¹), following the protocol of Lahay *et. al.*, (2019) [19].

Crop Growth Rate (CGR, g m⁻² day⁻¹): CGR was computed from sequential dry matter data at the intervals 0-30, 30-60, 60-90 DAS and 90 DAS to harvest, using the formula of Radford (1967) [35].

$$CGR (g m^{-2} day^{-1}) = \frac{W_2 - W_1}{A(t_2 - t_1)}$$

where W_1 and W_2 are total dry weights of plants at times t_1 and t_2 , and A is the ground area.

Relative Growth Rate (RGR, g g⁻¹ day⁻¹): RGR was calculated using the formula of Radford (1967) [35].

$$RGR (g g^{-1} day^{-1}) = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Stem girth (cm): Stem girth was measured at the basal portion of the stem (~2-3 cm above ground level) using a measuring tape from five randomly tagged plants per plot at 30, 60, 90 DAS and at harvest, and expressed in centimeters (Shakunthala *et. al.*, 2017) [39].

Days to 50% tasseling and silking: The number of days from planting to 50% tasseling and 50% silking were recorded at the plot level.

Chlorophyll index (SPAD): Chlorophyll content of the flag leaf was assessed using a SPAD-502 Soil Plant Analysis Development (SPAD) meter (Minolta Co., Japan). Readings were taken from the middle portion of fully expanded, healthy leaves of five randomly selected plants per plot, avoiding the midrib, at 30, 60, 90 DAS and at harvest. SPAD values are widely used as a reliable non-destructive proxy for leaf nitrogen and chlorophyll status in maize (Marschner, 2012; Tomar *et. al.*, 2017) [23, 44].

2.5.2 post-harvest yield component studies

Post-harvest observations were recorded on five randomly selected plants per plot for the following attributes, following the methods adopted by Paikra *et. al.*, (2018) [29]:

- **Number of cobs plant⁻¹:** counted manually from five plants per plot.
- **Number of rows cob⁻¹:** counted from five randomly selected cobs per plot.
- **Number of grains cob⁻¹:** grains were separated manually and counted per cob.
- **Cob length (cm):** measured from base to tip of five randomly selected cobs using a measuring tape.
- **Grain weight per cob (g):** grain weight of five randomly selected cobs was averaged.
- **Seed index (g):** 100 seeds from each treatment were counted manually and weighed on an electronic balance; expressed as

weight of 100 seeds in grams (Mustafa *et. al.*, 2019) [26].

Seed Index (g) = Weight of 100 seeds (g)

2.5.3 Yield parameters

Green cob yield (q ha⁻¹): Fresh green cobs harvested from the net plot area (including tagged plants) were weighed and converted to q ha⁻¹ basis (Panchal *et. al.*, 2018) [31].

Stover yield (q ha⁻¹): All above-ground vegetative biomass (after cob removal) was weighed at final harvest and expressed on a q ha⁻¹ basis.

Biological yield (q ha⁻¹): Computed as the sum of green cob yield and stover yield:

Biological Yield = Green Cob Yield + Stover Yield

Harvest index (%): The ratio of economic yield (green cob) to biological yield, expressed as a percentage:

$$\text{Harvest Index (\%)} = \frac{\text{Economic Yield (kg ha}^{-1}\text{)}}{\text{Biological Yield (kg ha}^{-1}\text{)}} \times 100$$

2.5.4 Quality Parameters

Sugar content (%): Sugar content of sweet corn kernels was estimated following the titrimetric method described by Ranganna (1991) [37]. A 25 g sample of kernel powder was taken in a 250 ml flask, dissolved in 100 ml distilled water, neutralized with 1N NaOH, and filtered. Lead acetate (2 ml) was added to clarify the extract, followed by potassium oxalate (2 ml) to remove excess lead, and the volume was made up to 250 ml. Sucrose inversion was completed by boiling with 5 g citric acid in 50 ml water for 10 minutes, followed by neutralization and titration against Fehling's solution. Total sugar (%) was calculated as:

$$\text{Total Sugar (\%)} = \frac{\text{Factor} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight of sample}}$$

Starch content (%): Starch content was estimated spectrophotometrically using DNS (dinitrosalicylic acid) reagent at 575 nm on a Spectronic-20 spectrophotometer (Ranganna, 1991) [37], using a standard glucose curve. Starch was expressed using the formula:

$$\text{Starch (\%)} = \text{Reducing sugar} \times 0.95$$

These quality estimation procedures are consistent with those employed in INM studies on sweet corn by Kumar and Bohra (2014) [18] and Mohammadi *et. al.*, (2015) [25].

2.5.5 Soil Analysis (Pre-Sowing and Post-Harvest)

Representative soil samples were collected from the 0-15 cm depth, both before sowing and after crop harvest, from each experimental plot. Samples were air-dried in shade, powdered, and passed through a 1 mm sieve before laboratory analysis. The following parameters were analyzed:

- **Organic carbon (%):** Walkley and Black (1934) [46] wet oxidation method (Jackson, 1973) [12].
- **Available nitrogen (kg ha⁻¹):** Alkaline potassium permanganate method (Subbiah and Asija, 1956) [41].
- **Available phosphorus (kg ha⁻¹):** Olsen's method using

sodium bicarbonate as extractant (Olsen *et al.*, 1954) ^[28], which is the standard method for neutral to alkaline soils (Lindsay and Norvell, 1978) ^[21].

- **Exchangeable potassium (kg ha⁻¹):** 1 N ammonium acetate (NH₄OAc) extraction method (Hanway and Heidal, 1952; Jackson, 1973) ^[11, 12].
- **Available zinc (kg ha⁻¹):** DTPA (diethylenetriaminepentaacetic acid) extraction followed by turbidimetric determination (Lindsay and Norvell, 1978; Williams and Steinbergers, 1969) ^[21, 48].

These soil analytical methods are internationally validated and have been widely used in INM studies on cereals and maize (Kannan *et al.*, 2013; Kalhapure *et al.*, 2013; Dadarwal *et al.*, 2009) ^[5, 13, 14].

2.6 Economic analysis

The economic viability of each treatment was assessed on a per-hectare basis following the method described by Pinjari (2007) ^[33] and Mathukia *et al.*, (2014) ^[24]. Cost of cultivation (₹ ha⁻¹) was computed by itemizing all input costs (seed, fertilizers, vermicompost, biofertilizer, labour for sowing, gap filling, weeding, irrigation, harvesting) and mechanical operation costs, multiplied by prevailing market rates. Gross return (GR, ₹ ha⁻¹) was calculated as:

$$\text{GR (₹ ha}^{-1}\text{)} = [\text{Green cob yield (q ha}^{-1}\text{)} \times \text{Price (₹ q}^{-1}\text{)}] + [\text{Stover yield (q ha}^{-1}\text{)} \times \text{Price (₹ q}^{-1}\text{)}]$$

Net return (NR, ₹ ha⁻¹) was derived as:

$$\text{NR (₹ ha}^{-1}\text{)} = \text{GR} - \text{Cost of Cultivation}$$

Benefit: cost ratio (B:C) was calculated as:

$$\text{B:C Ratio} = \frac{\text{Net Return (₹ ha}^{-1}\text{)}}{\text{Cost of Cultivation (₹ ha}^{-1}\text{)}}$$

This economic framework follows the conventional approach employed in INM studies for cereal crops in India (Pinjari, 2007; Mathukia *et al.*, 2014; Tomar *et al.*, 2017) ^[24, 33, 44].

2.7 Statistical analysis

All data recorded during the investigation were subjected to Analysis of Variance (ANOVA) for a Randomized Block Design, as prescribed by Cochran and Cox (1963). Standard error of mean (SEm±) was computed for all parameters; critical difference (CD) at 5% level of probability ($p \leq 0.05$) was calculated using the formula:

$$\text{SEm} \pm = \sqrt{\frac{\text{Error Mean Sum of Squares}}{r}}$$

$$\text{CD} = \text{SEm} \pm \times \sqrt{2} \times t_{(\text{error df}, p=0.05)}$$

where r = number of replications. Treatment means were compared using CD values; treatments recording CD values as NS (non-significant) indicated no statistically meaningful difference. This analytical approach is consistent with that used in INM field experiments on sweet corn by Paikra *et al.*, (2018) ^[29], Kaur *et al.*, (2019) ^[15], and Mustafa *et al.*, (2019) ^[26].

3. Results and Discussion

3.1 Plant height

Plant height increased progressively with crop age across all treatments, with the most rapid increment between 60 and 90 DAS. At 30 DAS, differences were non-significant (F-test: NS; SEm± 2.37), reflecting limited early nutrient demand. From 60 DAS onward, treatment effects became pronounced. T₁₀ (75% RDF + *Azospirillum* + 25% vermicompost) recorded the highest plant height at 60 DAS (184.4 cm), 90 DAS (192.4 cm) and harvest (197.2 cm), significantly superior to T₁ (148.5, 156.5 and 161.3 cm, respectively), with CD values of 18.48, 17.89 and 17.40 cm ($p \leq 0.05$). This superiority is attributable to the synergistic interaction between inorganic fertilizers, *Azospirillum*-mediated biological N₂ fixation (20–40 kg N ha⁻¹), and slow-release nutrition from vermicompost, collectively sustaining nitrogen availability the primary driver of internode elongation and apical meristem activity in maize (Marschner, 2012) ^[23]. Paikra *et al.*, (2018) ^[29] and Mustafa *et al.*, (2019) ^[26] reported analogous INM-driven enhancement in sweet corn plant height, attributing improvements to greater nitrogen use efficiency and *Azospirillum*-secreted indole-3-acetic acid (IAA) and cytokinins (Vessey, 2003) ^[45]. Lahay *et al.*, (2019) ^[19] and Dhariya *et al.*, (2018) ^[7] documented similar trends where combined INM regimes increased plant stature relative to sole chemical fertilizers.

3.2 Leaf area index (LAI)

LAI was significantly influenced by INM treatments from 60 DAS onward. At 30 DAS, differences were non-significant (SEm± 0.046); T₁₀ recorded a numerically highest LAI of 1.42 versus 0.66 in T₁. At 60 DAS the period of maximum vegetative expansion T₁₀ reached a peak LAI of 6.61, significantly greater than T₁ (4.92), with CD 0.676 ($p \leq 0.05$). At 90 DAS and harvest, T₁₀ continued to record maximum LAI values (5.92 and 5.46) compared to T₁ (3.68 and 2.92). Enhanced LAI under T₁₀ reflects improved leaf expansion driven by superior nitrogen supply from vermicompost, which improves soil structure and water-holding capacity, and *Azospirillum*-mediated phytohormone production (Tilman *et al.*, 2002; Ghosh *et al.*, 2018) ^[10, 43]. These results align with Shakunthala *et al.*, (2017) ^[39] and Tomar *et al.*, (2017) ^[44], who reported significantly greater LAI under combined organic-inorganic-biofertilizer treatments in sweet corn and maize, leading to higher intercepted radiation and photosynthate accumulation.

3.3 Dry Matter Accumulation, Crop Growth Rate (CGR) and Relative Growth Rate (RGR)

Dry matter accumulation increased consistently with crop age under all treatments. Effects were non-significant at 30 DAS but highly significant at 60 DAS (SEm± 6.43; CD 18.87), 90 DAS (SEm± 5.67; CD 16.64) and harvest (SEm± 6.39; CD 18.75). T₁₀ recorded the highest dry matter at 60 DAS (98.71 g plant⁻¹), 90 DAS (161.5 g plant⁻¹) and harvest (193.54 g plant⁻¹), surpassing T₁ (61.83, 124.51 and 142.30 g plant⁻¹). This advantage reflects vermicompost-mediated improvement in soil biological activity and nutrient mineralization, coupled with *Azospirillum*-fixed nitrogen and growth-promoting metabolites (Arancon *et al.*, 2006; Vessey, 2003) ^[1, 45]. Panchal *et al.*, (2018) ^[31], Raman *et al.*, (2018) ^[36] and documented significantly superior dry matter in sweet corn under INM treatments. CGR was numerically highest under T₁₀ during 0–30 DAS (0.530 g m⁻² day⁻¹) and 30–60 DAS (2.760 g m⁻² day⁻¹), though statistical significance was reached only at 60–90 DAS, where T₁₂ (125% RDF) recorded maximum CGR (2.17 g m⁻² day⁻¹), at par with T₇ (2.16 g m⁻²

day⁻¹). During the terminal interval (90 DAS to harvest), T₁₀ achieved the highest CGR (1.184 g m⁻² day⁻¹) versus T₁ (0.593 g m⁻² day⁻¹), indicating that slow-release vermicompost nutrition sustained biosynthetic activity during grain filling when inorganic pools were depleted. RGR was significantly influenced only at the 90 DAS-to-harvest interval, where T₄ (100% RDF + 25% vermicompost) achieved the highest value (0.0068 g g⁻¹ day⁻¹) against T₁ (0.0045 g g⁻¹ day⁻¹). These observations are consistent with Dhariya *et al.*, (2018) [7].

3.4 Stem Girth and Chlorophyll Index (SPAD)

Stem girth increased significantly under INM treatments from 60 DAS onward. T₁₀ recorded the highest stem girth at 60 DAS (7.98 cm) and 90 DAS (11.12 cm), reflecting combined macronutrient supply and vermicompost-enhanced soil physical structure

facilitating root development. The chlorophyll index (SPAD) increased progressively from early vegetative growth to peak development and declined toward maturity. T₁₀ recorded significantly the highest SPAD readings at 60 DAS (55.65), 90 DAS (53.08) and harvest (48.15) compared to T₁ (40.41, 42.41 and 37.91), with differences significant from 60 DAS onward (SEM± 1.370; CD 4.01). Elevated chlorophyll under T₁₀ is consistent with enhanced nitrogen availability, as chlorophyll synthesis is directly nitrogen-regulated (Marschner, 2012) [23]. Palm *et al.*, (2001) [30] demonstrated that integrated inputs sustain plant N status beyond what inorganic fertilizers achieve alone. Paikra *et al.*, (2018) [29], Shakunthala *et al.*, (2017) [39] and Tomar *et al.*, (2017) [44] reported similar SPAD improvements under INM in sweet corn.

Table 2: Effect of integrated nutrient management on growth parameter and yield attributes of sweet corn

T. No	Treatment	Plant height	Dry matter accumulation	Stem girth	LAI	No. of cob/plant	No. of rows/cob	No. of grain/cob	Cob length (cm)	Grain weight(gm)/cob
T ₁	Absolute control	161.3	142.3	9.16	2.92	3.05	13.1	415	12.2	103
T ₂	100% RDF (NPKZn)	188.4	185.46	9.12	5.12	3.39	15.4	506	17.3	110
T ₃	75% RDF + 25% Vermicompost	186.7	180.67	9.16	5.02	3.35	15	462	16.5	108
T ₄	100% RDF + 25% Vermicompost	194.7	192.64	9.92	5.24	3.53	16.1	566	18.7	123
T ₅	50% RDF + 50% Vermicompost	187.8	183.64	10.33	5.04	3.35	15.2	493	16.8	108
T ₆	75% RDF + Bio fertilizer	178.1	172.22	10.37	4.78	3.31	14.3	449	15.3	106
T ₇	100% RDF + Bio fertilizer	190.1	188.56	11.36	5.18	3.52	16.1	543	18.3	118
T ₈	50% RDF + Bio fertilizer	169.3	160.54	11.32	4.16	3.25	14	428	13.7	104
T ₉	50% RDF + Bio fertilizer + 50% Vermicompost	195.2	191.37	10.08	5.3	3.55	16.3	591	19.5	122
T ₁₀	75% RDF + Bio fertilizer + 25% Vermicompost	197.2	193.54	11.32	5.46	3.58	16.4	611	20.1	125
T ₁₁	50% RDF + Bio fertilizer + 25% Vermicompost	179.3	175.24	11.62	4.82	3.33	14.5	461	15.9	106
T ₁₂	125% RDF (NPKZn)	190.8	187.22	8.78	5.16	3.49	16	531	17.7	111
	SEm±	5.93	6.39	0.458	0.22	0.059	0.536	22.28	0.581	3.915
	CD (P=0.05)	17.40	18.75	1.34	0.65	0.176	1.572	65.35	1.704	11.48

3.5 Yield components

INM treatments significantly influenced all yield attributes. T₁₀ recorded maximum cobs plant⁻¹ (3.58), rows cob⁻¹ (16.4), grains cob⁻¹ (611), cob length (20.1 cm), grain weight cob⁻¹ (125 g) and seed index (30.98 g) significantly superior to T₁ (3.05, 13.1, 415, 12.2 cm, 103 g and 22.08 g, respectively), with CDs of 0.176, 1.572, 65.35, 1.704, 11.48 and 0.707 ($p \leq 0.05$). These improvements are mechanistically attributable to *Azospirillum*'s role in root proliferation, phosphorus uptake enhancement, and phytohormone (IAA, gibberellin) production promoting fleret differentiation and grain set (Vessey, 2003) [45], supplemented by vermicompost's slow-release P and micronutrients during reproductive development (Arancon *et al.*, 2006) [1]. Adequate phosphorus is critical for ATP-mediated energy transfer and sugar-starch conversion during grain filling (Marschner, 2012) [23]. Mustafa *et al.*, (2019) [26], Dhariya *et al.*, (2018) [7] and Khan *et al.*, (2018) [16] documented analogous INM-driven improvements in sweet corn yield components.

3.6 Green cob yield, stover yield, biological yield and harvest index

Green cob yield varied significantly. T₁₀ recorded the maximum green cob yield of 102.40 q ha⁻¹ a 74.2% improvement over T₁ (58.78 q ha⁻¹), with SEM± 3.321 and CD 9.74 ($p \leq 0.05$). Notably, T₃ (75% RDF + 25% vermicompost) produced 93.02 q ha⁻¹, substantially exceeding T₂ (100% RDF; 80.55 q ha⁻¹),

demonstrating that substituting 25% of chemical fertilizer with vermicompost can improve productivity beyond sole chemical inputs. This enhanced yield is attributable to complementary nutrient-supply dynamics: inorganic fertilizers ensure immediate macronutrient availability while vermicompost provides slow-release nutrients, improves cation exchange capacity and enhances rhizosphere microbial mineralization (Palm *et al.*, 2001; Ghosh *et al.*, 2018) [10, 30]. Biological N₂ fixed by *Azospirillum* (20-40 kg N ha⁻¹) further supplements the nitrogen budget (Vessey, 2003) [45]. These findings align with Kaur *et al.*, (2019) [15], Panchal *et al.*, (2018) [31], Paikra *et al.*, (2018) [29] and Mustafa *et al.*, (2019) [26]. Stover yield was highest under T₁₀ (196.00 q ha⁻¹) and lowest under T₁ (124.56 q ha⁻¹) (SEM± 7.955; CD 23.33). Biological yield peaked under T₁₀ (298.40 q ha⁻¹) versus T₁ (183.34 q ha⁻¹), consistent with cumulative gains in plant height, LAI and dry matter. Raman *et al.*, (2018) [36] and Tomar *et al.*, (2017) [44] reported parallel improvements in maize under INM. Harvest index reflecting efficiency of biomass conversion to economic yield was significantly improved (SEM± 1.393; CD 4.08). T₁₀ recorded the maximum harvest index of 39.48% compared to 31.84% under T₁, indicating superior assimilate partitioning to green cobs. Thakur *et al.*, (2010) [42] reported that INM treatments significantly improved harvest index in maize by enhancing sink strength and sugar-to-starch conversion during grain filling, supported by *Azospirillum* phytohormone activity (Vessey, 2003) [45].

Table 3: Effect of integrated nutrient management on green cob yield, stover yield, biological yield, harvest index and economics analysis of sweet corn

T. No.	Treatments	Green cob yield (q/ha)	Stover yield (q/ha)	Harvest index (%)	COC (₹/ha)	GR (₹/ha)	NR (₹/ha)	B:C Ratio
T ₁	Absolute control	58.78	124.56	31.84	51448	152528	101080	1.96
T ₂	100% RDF (NPKZn)	80.55	159.99	34.52	58442	209383	150941	2.58
T ₃	75% RDF + 25% Vermicompost	93.02	163.03	33.14	61693	240702	179009	2.90
T ₄	100% RDF + 25% Vermicompost	94.21	180.41	34.43	63442	244546	181104	2.85
T ₅	50% RDF + 50% Vermicompost	93.11	167.57	37.14	64945	241154	176209	2.71
T ₆	75% RDF + Bio fertilizer	92.00	155.01	36.21	58293	237751	179458	3.08
T ₇	100% RDF + Bio fertilizer	94.12	177.03	33.86	60042	244152	184110	3.07
T ₈	50% RDF + Bio fertilizer	88.24	148.63	35.24	56545	228032	171487	3.03
T ₉	50% RDF + Bio fertilizer + 50% Vermicompost	96.31	188.94	37.42	64145	250222	186077	2.90
T ₁₀	75% RDF + Bio fertilizer + 25% Vermicompost	102.40	196.00	39.48	63293	265792	202499	3.20
T ₁₁	50% RDF + Bio fertilizer + 25% Vermicompost	92.90	159.78	36.30	61545	240239	178694	2.90
T ₁₂	125% RDF (NPKZn)	92.44	162.21	33.36	60190	239219	179029	2.97
	SEm±	3.321	7.955	1.393				
	CD (P=0.05)	9.74	23.33	4.08				

3.7 Post-Harvest soil parameters

Post-harvest soil analysis revealed positive trends in soil organic carbon (OC) and available macro- and micronutrient status under INM treatments, though differences were statistically non-significant given the single-season duration. Soil OC ranged from 0.35% (T₁) to 0.42% (T₁₀), available N from 134.34 (T₁) to 140.53 kg ha⁻¹ (T₁₀), available P from 15.22 (T₁) to 18.74 kg ha⁻¹ (T₁₀), available K from 207.5 (T₁) to 215.14 kg ha⁻¹ (T₁₀) and available Zn from 1.20 (T₁) to 1.28 kg ha⁻¹ (T₁₀). The numerically higher OC under T₁₀ reflects vermicompost-borne organic matter, which decomposes slowly and incrementally elevates the carbon pool (Lal, 2015) [20]. Vermicompost supplies humic acids and enzymes that enhance microbial biomass and accelerate nutrient cycling (Ghosh *et al.*, 2018) [10]. *Azospirillum* inoculation further contributes to soil microbial biomass through rhizodeposition and biological N₂ fixation, helping maintain the post-harvest available N pool (Subba Rao *et al.*, 2017) [40]. Kannan *et al.*, (2013) [14] confirmed that INM treatments consistently improved post-harvest OC and available NPK over sole chemical fertilizer regimes, with improvement scaling with the proportion of organic inputs. Kalhapure *et al.*, (2013) [13] and Dadarwal *et al.*, (2009) [5] reported comparable improvements in post-harvest available N, P and K under INM in maize and sorghum. Pandey and Avasthi (2014) [32] specifically documented increased post-harvest available Zn under vermicompost-amended treatments, attributed to organic acid-mediated Zn chelation an outcome consistent with the present study.

3.8 Quality parameters sugar and starch content

No statistically significant differences in kernel sugar (%) or starch (%) were observed among treatments (F-test: NS; SEM± 0.656 and 1.813, respectively), consistent with the genetic determination of sugar accumulation in *su1* gene sweet corn varieties. Nevertheless, T₁₀ recorded numerically the highest sugar (16.48%) and starch (52.57%) compared to the lowest under T₁ (13.84% and 49.64%). The marginally elevated sugar under T₁₀ may reflect enhanced photosynthetic efficiency indicated by the highest SPAD values augmenting the sucrose pool available for endosperm translocation (Kumar and Bohra, 2014) [18]. Saha *et al.*, (2017) reported that INM treatments maintaining balanced N:P:K alongside organic inputs produced significantly higher soluble sugar in sweet corn. Kaur *et al.*, (2019) [15] and Khan *et al.*, (2018) [16] noted that biofertilizer-enriched INM treatments numerically improved kernel sugar, attributing the trend to enhanced nitrogen nutrition supporting sucrose phosphate synthase activity. Mohammadi *et al.*, (2015) [25] reported that

vermicompost application increased total soluble solids in sweet corn kernels, consistent with the present numerical trend under T₁₀.

3.9 Economic analysis

Economic evaluation confirmed the agronomic superiority of T₁₀ in financial returns. Cost of cultivation ranged from ₹51,448 ha⁻¹ (T₁) to ₹64,945 ha⁻¹ (T₅), with T₁₀ incurring a moderate ₹63,293 ha⁻¹ reflecting biofertilizer and vermicompost procurement costs. Despite not being the lowest-cost treatment, T₁₀ generated the highest gross return (₹265,792 ha⁻¹), highest net return (₹202,499 ha⁻¹) and highest B:C ratio (3.20), compared to the lowest in T₁ (₹152,528 ha⁻¹; ₹101,080 ha⁻¹; 1.96). Compared to T₂ (100% RDF; net return ₹150,941 ha⁻¹; B:C 2.58), T₁₀ delivered 34.2% higher net returns while using only 75% of the recommended inorganic fertilizer dose underscoring the economic benefit of partial chemical input substitution with biologically active organic amendments. The high B:C of T₁₀ reflects the compounding effect of reduced input cost (saving 25% chemical fertilizer) and increased green cob yield the primary revenue-generating product. These observations align with Pinjari (2007) [33] and Mathukia *et al.*, (2014) [24], who reported that INM treatments invariably produced higher B:C ratios than sole chemical fertilizer treatments in maize and sweet corn, highlighting INM's economic viability for smallholder farmers facing rising fertilizer prices.

Conclusions

The findings of this investigation conclusively demonstrate that integrating organic (vermicompost), biological (*Azospirillum*) and inorganic nutrient sources can sustain and, in several respects, surpass the productivity achieved with 100% chemical fertilizer in sweet corn. Treatment T₁₀ (75% RDF + *Azospirillum* + 25% vermicompost) emerged as the most effective combination, recording the highest values for all growth parameters (plant height, LAI, dry matter, chlorophyll index), yield components (cob number, length, grain set and seed weight), green cob yield (102.40 q ha⁻¹), biological yield (298.40 q ha⁻¹) and harvest index (39.48%). The 74.2% increase in green cob yield over the control, coupled with a benefit:cost ratio of 3.20, underscores the dual agronomic and economic superiority of this treatment. The substitution of 25% of the chemical fertilizer dose with vermicompost without yield penalty represents a tangible reduction in synthetic input costs, which is particularly relevant in the context of rising fertilizer prices and evolving subsidy regimes. Although post-harvest soil parameters did not reach

statistical significance in a single-season trial, the numerically higher organic carbon and available NPKZn under T₁₀ point toward incipient soil fertility improvement, consistent with long-term INM studies. The comparable kernel sugar and starch content across treatments confirms that INM does not compromise cob quality while offering systemic benefits to soil biology and farm economics. Based on the evidence generated, the treatment combination of 75% RDF + *Azospirillum* seed inoculation + 25% vermicompost (T₁₀) is recommended for commercial sweet corn cultivation under the subtropical agro-climatic conditions of Prayagraj and similar ecologies of eastern Uttar Pradesh. Long-term, multi-location trials with varying vermicompost quality and *Azospirillum* strains are needed to refine the recommendation and assess cumulative impacts on soil organic matter dynamics and nutrient cycling.

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