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RESEARCH ARTICLE

Field performance of sweetcorn (*Zea mays* L.) as influenced by crop establishment methods and integrated fertilizer application

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Abstract

Crop establishment methods and fertilizer application are crucial management practices that can enhance the productivity and sustainability of sweetcorn farming. A study was conducted for the Honey Star F_1 sweetcorn variety to assess the effects of crop establishment and fertilizer application with Bio-N on the growth, yield, sensory attributes, and profitability of sweetcorn. This was laid out in a split plot arranged in a Randomized Complete Block Design (RCBD) with three replications. Two crop establishment methods such as direct seeding and transplanting were designated as the main plot and five fertilizer management as subplots; namely: T_1- No fertilizer applied; T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR); T_3- 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N; T_4- 5 t ha^{-1} poultry manure + Bio-N; T_5- 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N. A significant interaction was noted on the number of days from planting to harvest, fresh stover yield (t ha^{-1}), number of marketable and non-marketable ears, total green ear yield (t ha^{-1}), and harvest index. The application of T_2, T_3, and T_4 significantly shortened the time from planting to harvest under direct seeding than transplanting. While T_5 markedly produced more marketable green ears, higher fresh stover yield under direct seeding than transplanting. Thereby, corn growers should follow the direct seeding method and adopt an integrated nutrient management to address financial constraints and climate change adaptation strategies, thereby reducing the negative impact on corn production albeit climate change situation.

Keywords: crop establishment; direct seeding; transplanting; bio-n; sweetcorn.

1. Introduction

Sweet corn is a variety of maize with a high genetic content of sugar. According to NASS 2020, it is the second-largest processing crop worldwide, accounting for 25% of the processing market and 75% of the fresh market. However, there was an abrupt reduction in sweetcorn production from 45 tons in 2019 to 25 tons in 2020, which led to a 56% decrease in output (NASS, 2020). Both biological and environmental factors were the primary cause of the decreased productivity. Pest prevalence and the unfavorable consequences (typhoons, droughts, etc.) brought about by climate change scenarios harm sweetcorn. A farmer needs to understand and implement the best crop establishment technique as well as the most suitable nutrient management strategies to reduce the negative impacts. Innovative ideas to increase output are therefore helpful in achieving self-sufficiency.

Sweetcorn is typically grown using the direct seeding method. However, it can lead to slow germination and weak seedlings, particularly in cooler soil conditions. Thus, transplanting may be a more effective method as it can help overcome these challenges and establish stronger plants. According to Adesina *et al.* (2014), the transplanting method produced earlier crop harvesting, more uniform crop stands, and consistent yields. Sweetcorn is a heavy feeder

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crop, though, and it needs nutrients for growth and development. Fertilizers, both organic and inorganic, are the only way to supply these vital nutrients to sweetcorn. Considering how costly synthetic fertilizers are these days, applying inorganic fertilizers to sweetcorn farming is expensive. Conversely, adding organic fertilizer, especially chicken dung will have a very gradual impact on the crop component that is still growing. As a result, it has been recommended to utilize both biofertilizers and organic materials because they both lower farmers' costs while gradually increasing soil fertility. One of these is the application of biofertilizers such as Bio-N.

Applying biofertilizers such as Bio-N has been considered a substitute for conventional fertilizers. Based on studies carried out at UP Los Baños, Laguna bacteria isolated from the talahib grassroots serve as the active element in the microbial fertilizer known as Bio-N® (UPLB-AGORA). By improving shoot and root development and supplying 30–50% of the total chemical nitrogen requirements of rice, corn, and vegetables, nitrogen-fixing bacteria such as *Azospirillum* may be able to transform atmospheric nitrogen into a form that rice, corn, and vegetables can use. According to UPLB research, using Bio-N can increase rice harvests by 11%. The addition of Bio-N to sweetcorn has not been extensively studied, particularly when administered in two establishment methods with both organic and inorganic fertilizers. This emphasizes the importance of obtaining information regarding this technology. Sweetcorn has not been thoroughly examined for Bio-N addition; this is especially true when it comes to two establishment approaches involving both organic and inorganic fertilizers. This highlights how crucial it is to learn about this technology. Thus, this study was carried out to determine the field performance of sweetcorn as influenced by crop establishment methods and integrated fertilizer application and to evaluate the interaction effects of crop establishment and integrated fertilizer application on sweetcorn production.

2. Materials and methods

This study was conducted at the experimental area of the Department of Agronomy, Visayas State University (VSU), Visca, Baybay City, Leyte, Philippines with a GPS coordinates of 10°44’ 59.8668” N, 124°47’ 38.1264” E from March 25 to June 2023. An area of 861m^2 was plowed and harrowed twice at weekly intervals using a tractor. This was done to pulverize the soil, remove the weeds, and provide desirable tilth for seed germination. After the second harrowing, furrows were made at 0.75 m between rows. Drainage canals were constructed around the experimental area and between replications to avoid waterlogging during heavy rains.

Before the establishment of the experiment, ten soil samples were randomly collected from the experimental area at 20cm depth before the conduct of the experiment. These were composited, air-dried, pulverized, and sieved using 2.0 mm wire mesh and were submitted for the analysis of soil pH (1:2.5 soil water ratio; ISRIC 1995), organic matter content (%) (Modified Walkley Black Method, PCARR 1980), total N (%) (Modified Kjeldahl Method, Nelson, and Sommers 1982), available phosphorous (mg kg^{-1}) (Modified Olsen Method, Olsen *et al.*, 1954) and exchangeable potassium (me/100 g) (Ammonium Acetate Method, ISRIC 1995) at the Central Analytical Services Laboratory (CASL), PhilRootCrops, VSU, Visca, Baybay City, Leyte, Philippines.

The experiment was laid out in a split plot arranged in a Randomized Complete Block Design (RCBD) with three replications. Method of crop establishment was designated as the main plot (M_1-direct seeding, M_2-transplanting) while fertilizer management as the subplot using the following: T_1- No Fertilizer Applied; T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (Recommended Rate - RR); T_3- 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N; T_4- 5 t ha^{-1} poultry manure + Bio-N; T_5- 2.5 t ha^{-}

[1] poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N. An alleyway of 0.75 m between replication and treatment plots was provided to facilitate data gathering and management.

The air-dried poultry manure was procured from Larrazabal farm, Ormoc City, Leyte Philippines, and samples were submitted to the Central Analytical Service Laboratory, PhilRootcrops, VSU, Visca Baybay City, Leyte, Philippines. Based on the test results, the poultry dung had an alkaline pH of 8.80, total N of 3.226%, total P of 1.351%, total K of 4.874%, and 20% moisture content.

Poultry manure was applied two weeks before planting for T_4 and T_5 at the rate of 5 t ha^{-1} and 2.5 t ha^{-1}, respectively. For basal application, urea was applied 30 days after planting through side dressing, T_2 was applied with an amount of 0.147 kg $plot^{-1}$ while T_3 and T_5 were applied with a similar amount of 0.073 kg $plot^{-1}$.

Treatments T_3, T_4, and T_5 had Bio-N application at planting by coating the seeds in a slurry of about 33.3 grams of Bio-N mixed with a sticker (Apsa -80™) and 1.0 kg of Honey Star F_1 sweetcorn seeds and placed in a plastic bag. The coated seeds were sown immediately and kept from exposure to intense sunlight.

Table 1. Actual amount of poultry manure and inorganic fertilizers applied per plot.

TREATMENTS	AMOUNT OF FERTILIZER (g/ 22.5m^2)		
	Complete (14-14-14)	Urea (46-0-0)	Poultry manure
T_1- No Fertilizer Application (control)	-	-	-
T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	964	147	-
T_3- 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	482	73	-
T_4- 5 t ha^{-1} poultry manure + Bio-N	-	-	11,250
T_5- 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	482	73	5,630

The sweetcorn variety Honey Star F_1 was used in this study. In the transplanting method, seeds were sown in seedling trays on the same day as direct seeding. A total of 1,800 seedlings of sweetcorn were raised and were transplanted in the field nine days later at one seedling per hill. For the direct seeding method, seeds were sown at the rate of 2.0 seeds per hill. The planting distance for both methods of establishment was 0.75 m between rows and 0.25 m between hills. Thinning was done 15 days after planting leaving only one plant per hill to have the desired plant population of 1,800 plants in 861 m^2 area. Hand weeding was done to control the regrowth of the weeds.

Data gathered relative to the agronomic characteristics were the number of days from planting to emergence, number of days from planting to tasseling stage, number of days from planting to silking stage, number of days from planting to harvest (green cob stage), plant height (cm) at harvest, fresh stover yield (t ha^{-1}). However, the yield and yield components gathered were the number of ears per plant, ear length (cm), ear diameter (cm), number of marketable ears per plot, number of non-marketable ears per plot, yield of marketable green ears (t ha^{-1}), yield of non-marketable green ears (t ha^{-1}), total green ear yield (t ha^{-1}) and harvest index. Meteorological data based on total weekly rainfall, minimum and maximum temperatures, and relative humidity throughout the conduct of the study were taken from the Philippine Atmospheric Geophysical and Astronomical Services (PAGASA) Station, VSU, Visca, Baybay City, Leyte, Philippines. Then, the analysis of variance (ANOVA) of all data was done using Statistical Analysis System (SAS version 9.0). Honestly, Significant Difference (HSD) was used to compare treatment means.

3. Results and discussion

Total weekly rainfall (mm), minimum and maximum temperatures (ºC), and relative humidity (%) throughout the conduct of the study were obtained from Philippine Atmospheric Geophysical and Astronomical Services (PAGASA) Station, VSU, Visca, Baybay City, Leyte, Philippines (Fig. 1). Total rainfall of 360.8 mm was obtained which did not meet the optimum rainfall requirements of sweet corn at 610 mm. Thus, surface irrigation was done to supply the needed water requirements using a water pump. The highest amount of rainfall occurred during the second month, with an estimated 320.6 mm, resulting in sudden growth and development of the crops. The average minimum and maximum temperatures recorded were 26.06°C and 31.28°C, respectively. Sanchez *et al.* (2013) reported that sweet corn needs a temperature range of 18-30°C from planting to harvesting. Moreover, the average relative humidity recorded was 77.17%. Leipzig (1996) reported that sweet corn needs a relative humidity of 71-85%. This shows that temperature and relative humidity during the conduct of the study were within the range for the growth and development of sweetcorn.

Both direct seeded and transplanted seeds germinated in four to six days after planting. However, some seeds were damaged by ants before germination occurred. Replacement of missing hills in direct seeded plots was done fifteen days after planting. The fertilized sweet corn crops exhibited uniform and vigorous growth four weeks after planting on account of the applied complete fertilizer at planting and poultry manure which was applied two weeks before planting. During the vegetative stage, corn borer incidence was observed. This was applied with botanical pesticides made from tobacco and mild liquid soap to control infestation. *Cyperus rotundus* L. was the most predominant weed species found in the area, however, hand weeding was done two weeks during the early stages and occasional weeding was done when the plants had matured, using bolo in all treatment plots.

3.1. Soil Chemical Properties

The soil test results before planting and after the harvest of sweet corn as influenced by the method of establishment and fertilizer management are reflected in Table 2. Initial soil analysis revealed that the experimental area had a pH of 6.38 with 1.32% organic matter, 0.15% total nitrogen, and 86.50 mg kg^{-1} available phosphorus. These results indicated that the soil was slightly acidic, very low in organic matter and nitrogen, with a high amount of phosphorus (Landon, 1991).

Final soil analysis showed a decrease in pH from slightly to moderately acidic in all treatments. This result might be due to the application of both organic and inorganic fertilizers. The decomposition of organic fertilizers releases organic acids that raise soil acidity. Inorganic fertilizers, particularly those that contain ammonium nitrogen-based sources, also raise soil acidity by forming acids and releasing hydrogen ions. The high rainfall during the second month of growth might have also leached basic cations in the soil thus, becoming moderately acidic. The organic matter, total nitrogen, and phosphorus contents decreased to a level that was very low according to Landon's (1991) criteria. This may be due to surface runoff and leaching which resulted in the loss of some soluble compounds and nitrogen through leaching. Plant uptake may also cause a decrease in organic matter, nitrogen, and phosphorus content.

Table 3 shows the poultry manure results and it revealed that it had a pH of 8.80, 3.226% total nitrogen, 1.351% total phosphorus, 4.874% total potassium, and 20 % moisture content. This indicates that the poultry manure was highly alkaline, with a relatively high concentration of nitrogen and potassium, and a moderate content of phosphorus. Poultry manure at 5 t ha^{-1} contains approximately 161.3 kg ha^{-1} nitrogen, 67.55 kg ha^{-1} phosphorus, 243.7 kg ha^{-1} potassium while at 2.5 t ha^{-1} is 80.65 kg ha^{-1} nitrogen, 33.78 kg ha^{-1} phosphorus, 121.85 kg ha^{-1} potassium.

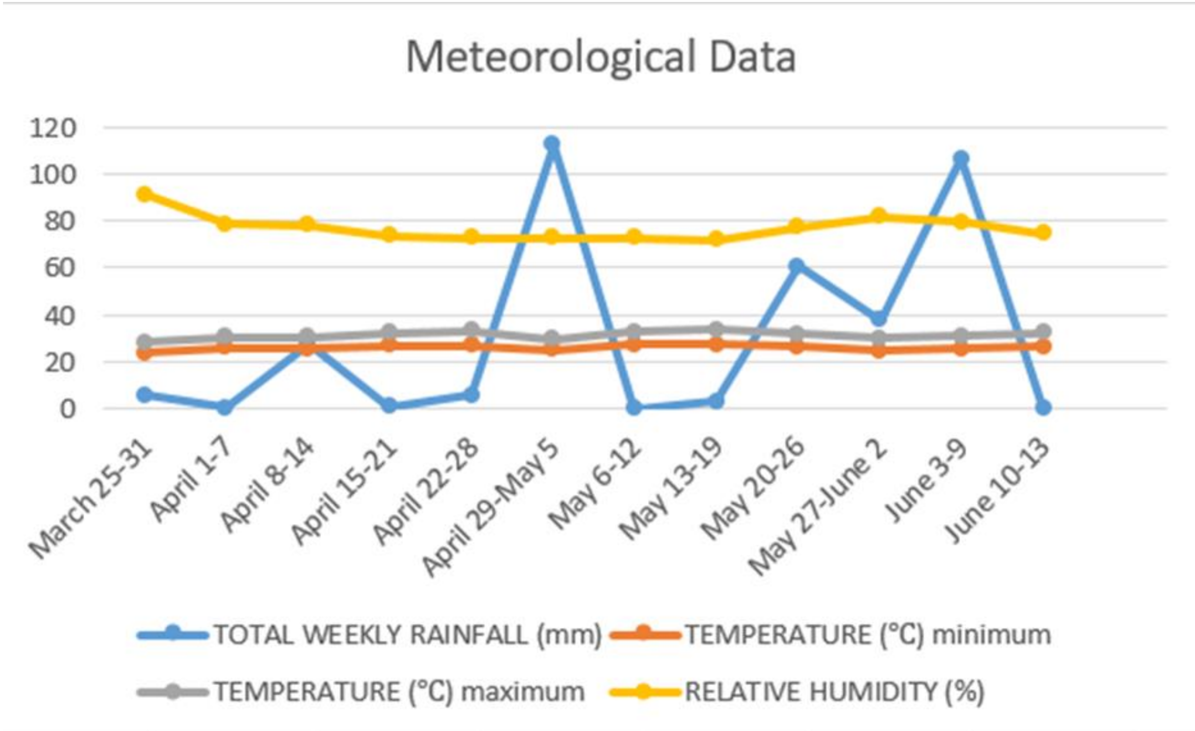

Figure 1. Total weekly rainfall (mm), average weekly minimum and maximum temperatures (°C), and relative humidity throughout the experiment from March 25 to June 13, obtained from the Philippine Atmospheric Geophysical and Astronomical Services (PAGASA) Station, Visayas State University (VSU), Visca, Baybay City, Leyte, Philippines.

Table 2. Soil test results before planting of sweet corn (*Zea mays* L.) as influenced by crop establishment method and integrated fertilizer application

Soil Analysis	Soil pH	Organic Matter (%)	Total N (%)	Available P (mg kg^{-1})
Initial	6.38	1.32	0.15	86.50

Table 3. Poultry manure results

Poultry Manure Analysis	pH	Total Nitrogen (%)	Total Phosphorus (%)	Total Potassium (mg kg^{-1})	Moisture Content (MC)
	8.80	3.226	1.351	4.874	20%

3.2. Agronomic Characteristics of Sweetcorn

Statistical analysis revealed that only the number of days from sowing to tasseling significantly differed between methods of crop establishment (Table 4). However, the fertilizer management significantly influenced the number of days from sowing to tasseling and at the green cob stage. A significant interaction between methods of establishment and fertilizer management was noted in the number of days from sowing to green cob stage and fresh stover yield (Table 4, and Figures 2 & 3).

Transplanting took longer (53.87 DAS) time to tassel compared to direct seeding (52.60 DAS) irrespective of fertilizer management. Relative to fertilization, sweetcorn in T_3 and T_4 were tasseled earlier than without fertilizer regardless of methods of establishment. This was comparable to 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) and with the application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5). Early tasseling may have resulted from applying 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N. Nitrogen encouraged rapid foliage growth and enhanced plant meristematic and physiological activities that supported the synthesis of more photoassimilates and early crop flowering (Effa et al 2011). In terms of days to harvest, sweetcorn with 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3), and 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) were harvested earlier at 75.17 DAS and 75.50 DAS, respectively compared to no fertilizer application (T_1). This may be due to the inclusion of inorganic fertilizer at the rate of 45-30-30 kg ha^{-1} N, P_2O_5, and K_2O in such treatments. The result corresponds with Chen's (2006) findings that corn grows and develops more readily when combined organic manure and inorganic fertilizers are applied, thus sweetcorn can be harvested earlier. Corn plants applied with 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3) significantly produced heavier fresh stover yield (22.92 t ha^{-1}) when compared to unfertilized plants (T_1) with 14.70 t ha^{-1} and corn plants applied with 5 t ha^{-1} poultry manure + Bio-N (T_4) with 16.77 t ha^{-1}. However, this was comparable to corn plants applied with 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) and 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) at 19.23 t ha^{-1} and 18.70 t ha^{-1}, respectively.

Table 4. Agronomic characteristics of sweet corn (*Zea mays* L.) as influenced by crop establishment method and integrated fertilizer application with Bio-N

	NUMBER OF DAYS FROM SOWING				Plant height (cm)	Fresh Stover Yield (t ha^{-1})
	Emergence	Tasseling	Silking	Harvest (Green Cob)		
Crop Establishment Method (CEM)						
M_1= Direct Seeding	4.33	52.60^b	57.40	75.47	189.64	18.39
M_2 = Transplanting	3.87	53.87^a	57.87	76.47	194.80	18.54
Mean	4.10	53.24	57.64	75.97	192.22	18.47
Fertilizer Management (FM)						
T_1-No fertilizer application (Control)	4.33	54.83^a	58.33	77.33^a	180.00	14.70^b
T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	4.33	54.00^{ab}	57.83	76.00^{ab}	196.30	19.23^{ab}
T_3 -45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	4.00	52.50^b	57.00	75.17^b	202.77	22.92^a
T_4-5 t ha^{-1} poultry manure + Bio-N	4.00	52.00^b	57.50	75.83^{ab}	198.30	16.77^b
T_5-2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	3.83	52.83^{ab}	57.50	75.50^b	183.73	18.70^{ab}
Mean	4.10	53.23	57.63	75.97	192.22	18.46
ME x FM	ns	ns	ns	*	ns	*
CV (a) %	11.78	1.24	1.14	1.10	7.73	16.70
CV (b) %	12.60	2.22	1.45	1.23	7.81	15.61

Means within a column with the same letter and those without letter designations are not significantly different at the 5% level, based on HSD.

This result might be due to the use of inorganic fertilizer, which gave the crops easily accessible nutrients for growth and development. These corroborate with the findings of Saladaga and Bañoc (2022) who observed that corn yields produced heavier fresh stover in plots amended with combined organic and inorganic fertilizer compared to those amended with only organic fertilizer source. According to the study of Ratilla *et al.* (2014), the application of 10 t ha^{-1} of vermicast or chicken litter combined with inorganic fertilizer tasseled and developed significantly earlier than the application of organic fertilizers alone. This indicates that when inorganic fertilizers are combined with organic materials, the readily available nutrients in the latter can provide crops with a good start, promoting growth and enhancing the completion of the cultivation life cycle.

Fig. 2 shows the interaction between methods of establishment and fertilizer management on the number of days from planting to the green cob stage. Direct-seeded plants applied with fertilizer at T_2, T_3, and T_4 significantly shortened the number of days from planting to the green cob stage than when sweetcorn is transplanted and received no fertilizer at all (T_1). Transplanting generally took a significantly longer time to reach the green cob stage when not fertilized due to the time required for seedlings recovery plus there was no fertilizer application. This indicates that transplanted seedlings also need to be fertilized to hasten their maturity. The average days from planting to harvest for direct-seeded plants ranged from 74-76 days, while transplanted plants took 75-79 days to reach maturity. This might be due to the elimination of transplanting shock experienced in direct seeding leading to faster initial growth. Moreover, fertilization provides readily available nutrients promoting plant development and accelerating maturity. Inorganic fertilizers provide readily available nutrients for quick plant growth, while poultry manure and Bio-N enrich the soil for sustained nutrient release and faster plant development. This was supported by the study of Tampus and Escasinas (2019) that applying swiftlet manure to directly seeded sweetcorn significantly shortened the time to harvest compared to transplanted plants.

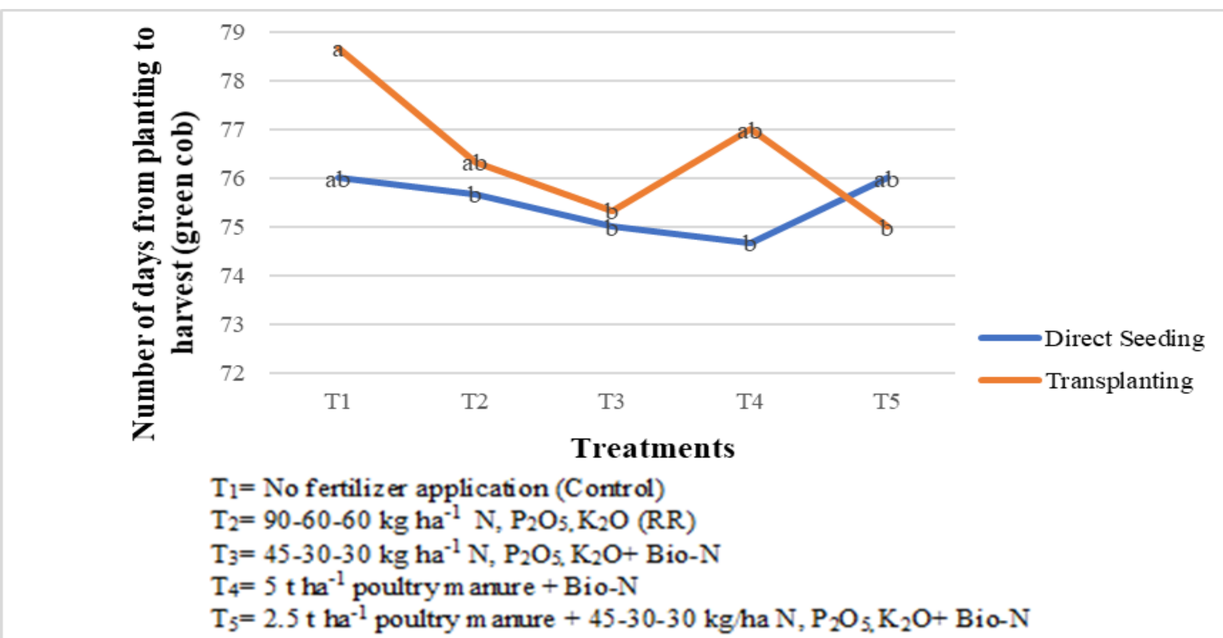

Figure 2. Interaction between the method of establishment and fertilizer management on the days from planting to harvest (green cob stage) of sweetcorn (*Zea mays* L.).

Fig. 3 shows the interaction between the method of establishment and fertilizer management on fresh stover yield of sweetcorn (*Zea mays* L.). In direct seeding, the application of T_3 had significantly a higher fresh stover yield comparable to T_4, T_5, and T_2 than T_1. In the transplanting method, no significant differences were observed among fertilizer levels. But T_3 and T_4 in the transplanting method produced significantly higher stover yield than T_1 under direct seeding. The combined application of different nutrient sources provided optimal nutrient conditions, leading to enhanced plant growth and higher biomass production. The application of Bio-N, a nitrogen-fixing organic fertilizer, and poultry manure in combination significantly increased stover yield compared to unfertilized plants. Bio-N likely improved soil nitrogen availability, complementing the readily available nutrients from the inorganic fertilizer. Additionally, poultry manure further enhanced soil fertility and sustained nutrient release, creating a favorable environment for plant growth. This observation aligns with the study of Tufa (2023) on maize, where the synergistic effect of vermicompost and inorganic fertilizer was evident in direct-seeded plants but not in transplanted ones, supporting the notion that transplanting can mask the impacts of fertilizer regimes on plant growth and yield.

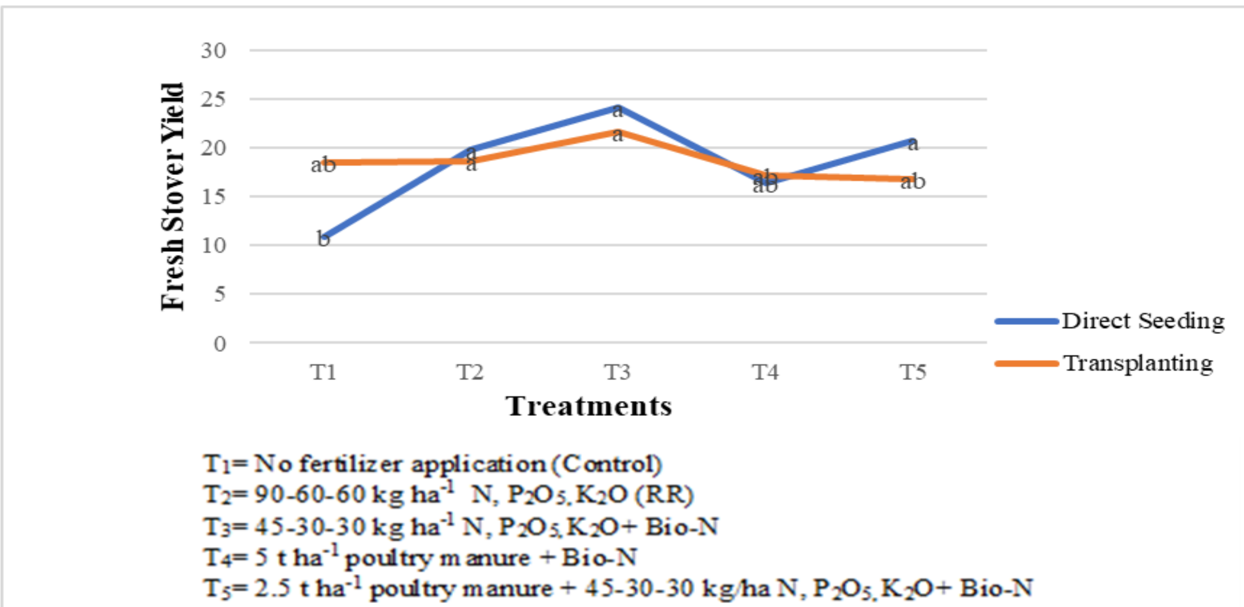

Figure 3. Interaction between the method of establishment and fertilizer management on fresh stover yield of sweetcorn (*Zea mays* L.)

3.3. Yield and Yield Components of Sweetcorn

Statistical analysis revealed that yield and yield components of Honey Star F_1 sweetcorn were not affected by methods of planting except for the weight of non-marketable green ears (Tables 5 & 6). However, ear length, ear diameter, number of non-marketable ears, weight of marketable and non-marketable green ears, total green ear yield (t ha^{-1}), and harvest index were significantly affected by fertilizer management. Analysis of variance revealed that the application of 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3), 5 t ha^{-1} poultry manure + Bio-N (T_4), and 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) did not differ significantly to the application of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) in terms of ear length and diameter. No fertilizer application (T_1) resulted in the shortest and smallest ear of sweetcorn. Non-marketable ears per plot indicated that no fertilizer application

(T_1) and the application of 5 t ha^{-1} poultry manure + Bio-N (T_4) did not differ significantly from each other. But were comparable to the application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) which gave the highest non-marketable green ear yield (t ha^{-1}) of sweetcorn. Transplanted plants had higher non-marketable green ear yield (t ha^{-1}) than direct seeding.

Table 5. Number of ears $plant^{-1}$, ear length and diameter (cm), number of marketable and non-marketable ears $plot^{-1}$ of sweetcorn as influenced by crop establishment method and integrated fertilizer application with Bio-N

	Number of ears $plant^{-1}$	EAR SIZE		Number of ears plant-1	
		Length	Diameter	Marketable	Non-marketable
Crop Establishment Method (CEM)					
M_1= Direct Seeding	1.40	18.43	4.97	64.53	7.47
M_2 = Transplanting	1.40	18.64	5.05	64.33	8.07
Mean	1.40	18.54	5.01	64.43	7.77
Fertilizer Management (FM)					
T_1-No fertilizer application (Control)	1.27	14.99b	4.50b	63.50	9.33a
T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	1.47	19.63a	5.21a	65.83	6.17c
T_3 -45-30-30 kg ha^{-1} N, P_2O_5, K_2O +Bio-N	1.47	20.11a	5.18a	65.33	6.67bc
T_4-5 t ha^{-1} poultry manure + Bio-N	1.40	18.16a	5.01a	63.17	9.00ab
T_5-2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	1.40	19.78a	5.15a	64.33	7.67abc
Mean	1.40	18.53	5.01	64.43	7.77
ME x FM	ns	ns	ns	**	**
CV (a) %	16.29	9.06	7.41	3.22	18.66
CV (b) %	9.85	6.08	3.15	2.67	18.02

Means within a column with the same letter and those without letter designations are not significantly different at the 5% level, based on HSD.

The application of 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3), and 5 t ha^{-1} poultry manure + Bio-N (T_4) were comparable to the application of 2.5 t ha^{-1} poultry manure +45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) but were significantly different to the application of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2), and no fertilizer application (T_1) in terms of total green ear yield (t ha^{-1}).

A significant interaction between the method of establishment and fertilizer management was noted in the number of marketable and non-marketable green ears, total green ear yield (t ha^{-1}), and harvest index of sweetcorn (Figures 4-7).

Fig. 4 shows the interaction between methods of planting and fertilizer management on marketable green ears per plot of sweetcorn (*Zea mays* L.). The application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) shows the highest number of marketable green ears under direct seeding than transplanting. This likely resulted from the synergistic effect of readily available nutrients from NPK and the sustained nutrient release and organic matter of poultry manure, leading to improved soil conditions, increased nitrogen fixation from Bio-N, and potentially better root exploration under direct seeding. This early access to essential nutrients likely led to rapid leaf expansion, increased photosynthetic activity, and ultimately, greater biomass production, resulting in a higher number of marketable ears. The combination of inorganic fertilizer, poultry manure, and Bio-N in T_5 provided a balanced and sustained supply of essential nutrients, ensuring that plants had the resources necessary for optimal ear development throughout the growing season. Transplanted seedlings, on the other hand, experience an initial growth setback due to transplant shock. This temporary period of stress can hinder nutrient uptake and resource utilization, potentially delaying ear development and reducing the overall number of marketable ears.

Table 6. Weight (t ha^{-1}) of marketable and non-marketable ears, total ear yield, and harvest index of sweetcorn (Honey Star F_1) as influenced by crop establishment method and integrated fertilizer application with Bio-N

	GREEN EAR YIELD (t ha^{-1})		TOTAL (t ha^{-1})	HARVEST INDEX
	Marketable	Non-marketable		
Crop Establishment Method (CEM)				
M_1 = Direct Seeding	8.17	0.77^b	8.93	0.34
M_2 = Transplanting	8.98	0.88^a	9.86	0.35
Mean	8.58	0.83	9.40	0.35
Fertilizer Management (FM)				
T_1-No fertilizer application (Control)	7.38^b	1.03^a	8.41^b	0.38^a
T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	7.45^b	0.67^b	8.11^b	0.30^b
T_3 -45-30-30 kg ha^{-1} N, P_2O_5, K_2O +Bio-N	9.73^a	0.67^b	10.40^a	0.32^{ab}
T_4-5 t ha^{-1} poultry manure + Bio-N	9.37^a	0.99^a	10.37^a	0.38^a
T_5-2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	8.93^{ab}	0.76^{ab}	9.69^{ab}	0.34^{ab}
Mean	8.57	0.82	9.40	0.26
ME x FM	ns	ns	*	**
CV (a) %	11.82	8.34	10.61	16.06
CV (b) %	10.59	19.11	10.09	10.99

Means within a column with the same letter and those without letter designations are not significantly different at the 5% level, based on HSD

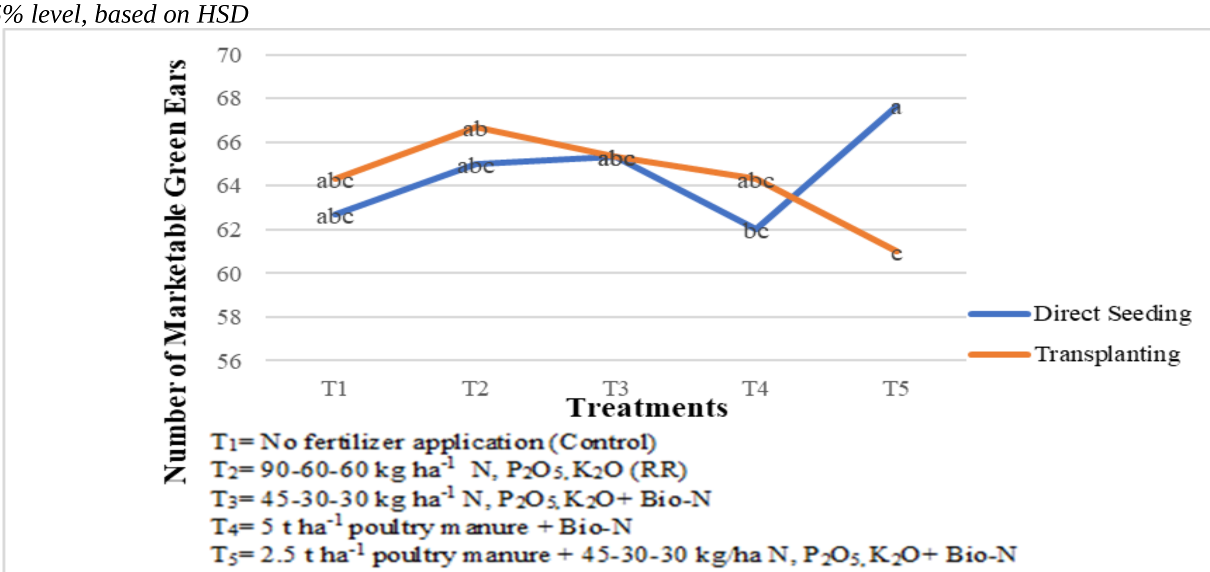

Figure 4. Interaction between the method of establishment and fertilizer management on several marketable green ears of sweetcorn (*Zea mays* L.)

Fig. 5 shows the interaction between the method of establishment and fertilizer management on the number of non-marketable green ears of sweetcorn per plot. Results revealed that the number of non-marketable green ears per plot relatively decreased with the application of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) in both methods of planting but slightly increased with the application of 5 t ha^{-1} poultry manure + Bio-N (T_4). When applied with 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5), it markedly increased the non-marketable green ears per plot of transplanted plants and decreased the non-marketable green ears per plot of direct seeded plants. The application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) increased the number of non-marketable green ears in transplanting, this may be due to the insufficient water supply during the first three weeks of sweetcorn. Even if there is a complete application of nutrients to the plants because of insufficient water supply, the nutrients do not dissolve and the plants cannot utilize them for their development which results in water stress, stunted growth, and reduced vigor, leading to uneven ear development, smaller kernels, and decreased quality. In direct seeding, there is a reduction in the number of non-marketable green ears because the seeds had the opportunity to germinate and establish their root systems in their intended growing environment from the start which helps the plants to cope better with the specific soil conditions. The roots could supply enough moisture for nutrient dissolution so that the plants can uptake it. By allowing for optimal root development, efficient water usage, and consistent growth, direct-seeded crops are more likely to produce a lower number of non-marketable ears compared to transplanted crops even if there is an insufficient amount of rainfall. This is consistent with Tampus and Escasinas' (2019) study, which found that direct seeding's high marketable and total yield, but low non-marketable yields may have been caused by the increased nitrogen content's ability to produce longer, bigger ears and more kernel rows. According to Ojeniyi (2002), using both organic and inorganic fertilizers together can greatly increase corn crop yields. Applying inorganic fertilizer at half the prescribed rate could have supplied easily absorbed plant nutrients, leading to increased productivity and output of maize.

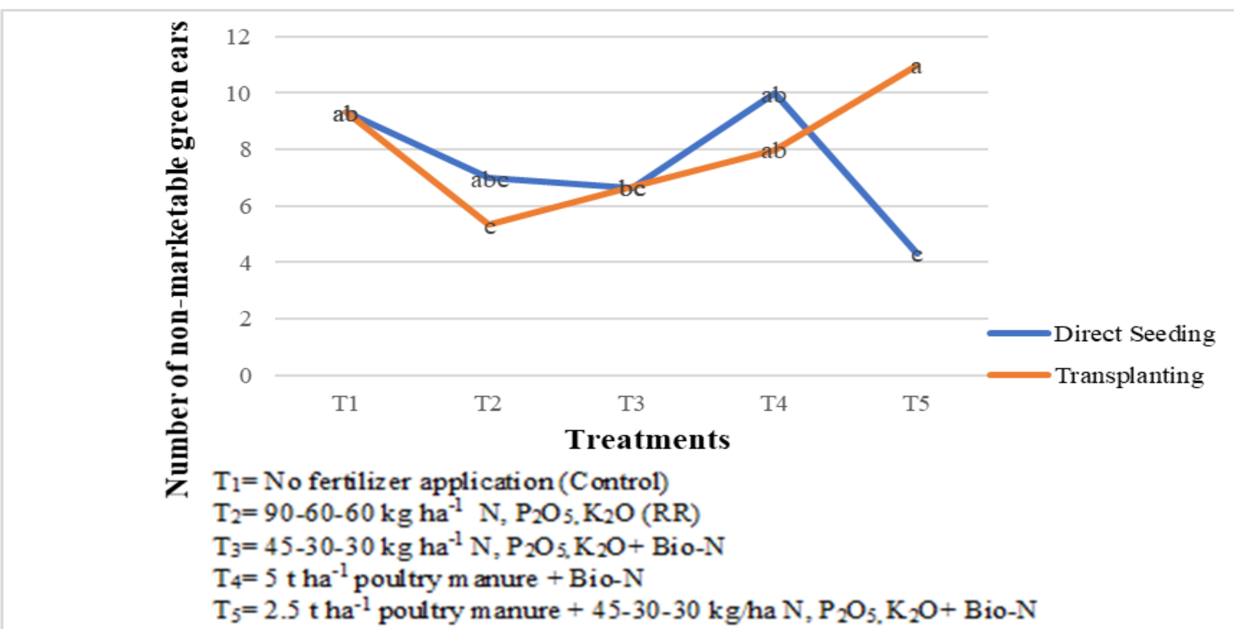

Figure 5. Interaction between the method of establishment and fertilizer management on several non-marketable green ears of sweetcorn (*Zea mays* L.)

There was a significant interaction between the crop establishment method and fertilizer management on total green ear yield (t ha^{-1}) (Fig. 6). Transplanted plants applied with 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) increased the total green ear yield and lowered in direct seeded plants. In transplanted plants, T_5 increased total green ear yield, possibly due to improved nutrient availability and uptake or compensatory growth after overcoming transplanting stress. Conversely, direct-seeded plants experienced a decrease in total green ear yield with T_5, potentially caused by excessive nutrient application leading to imbalances or luxury consumption, or differential root system development affecting nutrient uptake efficiency. According to Galkovskyi *et al*. (2012), *Azospirillum* has improved crop yields of wheat, corn, rice, and sugarcane. Similarly, *Azospirillum*-inoculated plants had shorter root lengths, but more side roots formed due to IAA production. It enables increased root development and greater access to nutrients in the soil for the plants. These changes were linked to increased plant biomass and nutrient intake, which increased tolerance to restricted nutritional conditions (Hungria *et al.*, 2010; Mehnaz *et al.*, 2015). The study conducted by Rozier *et al.* (2017) on the impact of different N fertilization levels related to *A. lipoferum* inoculation showed that grain yields of maize were improved by *A. lipoferum* inoculation and N fertilizer. A mean of 651.58 kg ha^{-1} was the difference in maize yield between inoculated and uninoculated treatments (Zeffa *et al.*, 2018). A potential technique is the use of *Azospirillum* as a biofertilizer, particularly in situations where N stress is present (Antonella *et al.*, 2017; Herrera *et al.*, 2016; Oliviera *et al.*, 2017).

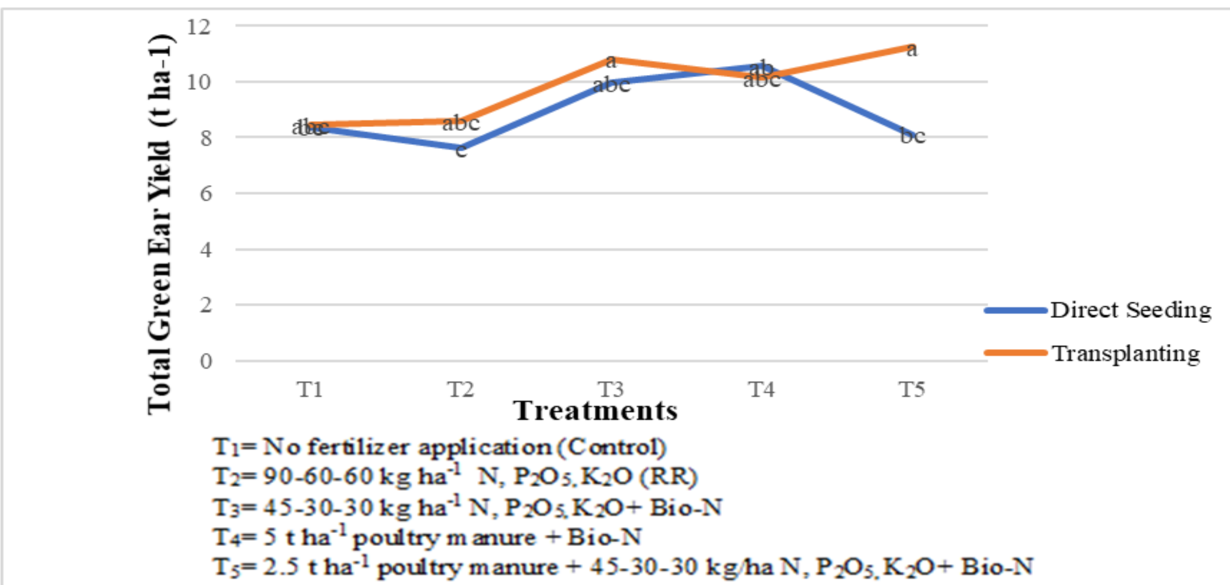

Figure 6. Interaction between the method of establishment and fertilizer management on total green ear yield (t ha^{-1}) of sweetcorn (*Zea mays* L.)

Fig. 7 shows the interaction between the method of establishment and fertilizer management on the harvest index (HI) of sweetcorn. Results revealed that the application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) obtained higher harvest index value in transplanted plants than in direct seeded where the lowest HI value was observed. This could be due to improved nutrient availability and uptake in transplanted plants overcoming transplanting stress, or compensatory growth prioritizing grain development after initial stress. Conversely, direct-seeded plants with T_5 might have experienced nutrient imbalances or luxury consumption, by diverting resources away from grain production, or developed a less extensive root system limiting nutrient uptake efficiency, both contributing to a lower HI. Nutrient imbalances can lower the harvest index by disproportionately impacting grain yield, while excess N can delay stover senescence and decrease the harvest index. A higher HI value indicates a higher ear yield than stover yield. This suggests that the application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5), direct seeded and transplanted plants responded in opposite directions. The application of 2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) displayed a decrease in the harvest index for the direct seeding method. The balanced and sustained nutrient supply from the fertilizer combination might further optimize resource utilization toward yield. Transplanting can induce a more extensive and deeper root system, offering greater access to water and nutrients. This improved resource acquisition might particularly benefit transplanted plants under T_5, where readily available and long-term nutrient sources are provided, enabling them to achieve higher HI. Transplanted seedlings may initially experience a period of slower vegetative growth compared to direct-seeded plants. This could potentially give them a head start in allocating resources towards reproductive development once they establish, contributing to the observed higher HI under T_5. Berdjour *et al.* (2020) reported that the combined application of organic manure and NPK increased HI compared to organic manure alone, highlighting the importance of readily available nutrients for enhancing resource utilization and grain production. El-Ghamry *et al.* (2020) found that transplanting stress can initially affect plant growth, but efficient nutrient management strategies can mitigate this effect and promote efficient resource allocation toward grain yield. Li *et al.* (2009) reported that excessive N application can decrease yield and HI in maize, emphasizing the potential negative effects of imbalanced nutrient management on resource utilization.

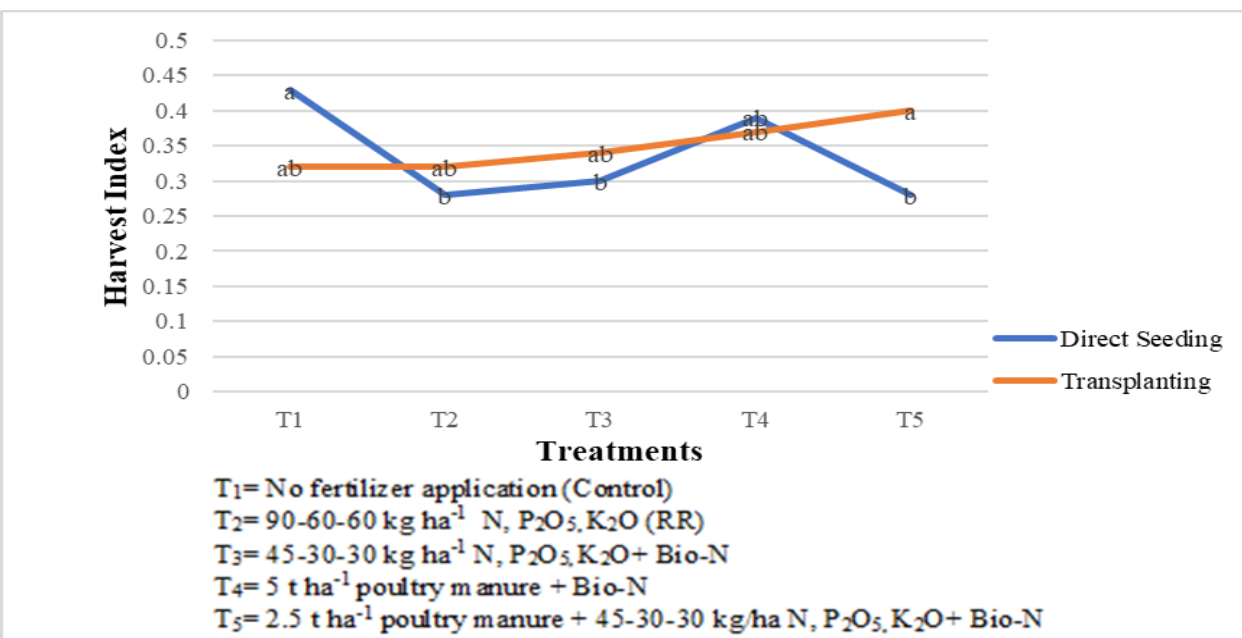

Figure 7. Interaction between the method of establishment and fertilizer management on harvest index of sweetcorn (*Zea mays* L.)

3.4. Harvest Index

Results on the harvest index of sweetcorn as influenced by crop establishment method and integrated fertilizer application with Bio-N revealed that methods of establishment did not affect the harvest index of sweetcorn (Table 6). The application of 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3), and 2.5 t ha^{-1} poultry manure +45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_5) obtained higher HI value but were comparable to the application of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2). This increase may be due to the application of complete fertilizers to the growing plants. Khan *et al.* (2008) claim that nitrogen made maize plants more active in photosynthesizing, which lengthened their ears. A relative increase might also be linked to *Azospirillum's* capacity to fix nitrogen, improve nutrient absorption, and engage in photosynthesis, which resulted in the production of photoassimilates that were subsequently stored in corn ears, thickening the ear. The inoculation of maize seeds with *Azospirillum spp.* was confirmed by Guimaraes *et al.* (2012) which produced ears with a larger diameter when combined with nitrogen fertilization. Longer and wider ears generally have more space for kernels, leading to a higher number of kernels which influences the higher weight of ears per plant and higher harvest index (Effa *et al.*, 2011). According to Burr (1979), sweetcorn needed a minimum of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O. Ojeniyi (2002) also found that combining organic and inorganic fertilizers can greatly increase corn crop yields. Applying inorganic fertilizer at half the prescribed rate could have supplied easily absorbed plant nutrients, leading to increased productivity and output of maize. The findings suggest that increased rates of fertilization and seed inoculation had an impact on the length, diameter, and weight of sweetcorn ears, which in turn led to an increased harvest index.

Table 7. Marginal cost and return analysis of sweetcorn (Honey Star F_1) as influenced by crop establishment method and integrated fertilizer application with Bio-N

	Green Ear Yield (t ha^{-1})	Gross Income (USD)	Total Variable Cost (USD)	Net Margin (USD)	ROI (%)
Crop Establishment Method (CEM)					
M_1= Direct Seeding	8.17	5,098.93	1,953.70	3,145.24	160.99
M_2 = Transplanting	8.98	5,604.46	2,383.79	3,220.66	135.11
Fertilizer Management (FM)					
T_1-No fertilizer application (Control)	7.38^{b}	4,605.89	1,849.84	2,756.04	148.99
T_2- 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (RR)	7.45^{b}	4,649.58	2,409.76	2,239.82	92.95
T_3 -45-30-30 kg ha^{-1} N, P_2O_5, K_2O +Bio-N	9.73^{a}	6,072.53	2,198.27	3,874.26	176.24
T_4-5 t ha^{-1} poultry manure + Bio-N	9.37^{a}	5,847.86	2,084.15	3,763.71	180.59
T_5-2.5 t ha^{-1} poultry manure + 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N	8.93^{ab}	5,573.25	2,301.70	3,271.55	142.14

Gross margin is based on the farm gate price at USD 0.62 per kilogram

3.5. Marginal Cost and Return Analysis

For crop establishment, direct seeding provides a higher return on investment (ROI) of 160.99% than transplanting since it requires less production expenditures. The transplanting method led to a higher cost of production due to the additional cost of seedling trays and labor. The application of 45-30-30 kg ha^{-1} N, P_2O_5, K2O

+ Bio-N (T3) yielded a net margin of USD 3,874.26 which is USD 110.55 less than the application of 5 t ha^{-1} poultry manure + Bio-N (T_4). Its higher ROI of 180.59%, which was 4.35% greater than the ROI achieved with the application of 45-30-30 kg ha^{-1} N, P_2O_5, K_2O + Bio-N (T_3), led to the observation that it was more economically advantageous. This resulted from the prior treatment's cheaper production costs. The application of 90-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) had the lowest return on investment (ROI) at 92.95% because of the higher production cost (USD 2,409.76) that was incurred. This was followed by T_5 and T_1 with an ROI of 142.14% and 148.99%, respectively.

4. Conclusion

All the agronomic characteristics, yield, and yield components of sweet corn were not affected by crop establishment, except tasseling and weight of non-marketable ears. However, the number of days from sowing to tasseling, green cob, ear length, ear diameter, and number of marketable and non-marketable green ears were significantly affected by fertilizer management. A significant interaction between the method of establishment and fertilizer management was noted in the number of days from sowing to harvest (green cob), fresh stover yield (t ha^{-1}), number of marketable and non-marketable ears, total green ear yield (t ha^{-1}) and harvest index. T_3 produced the heaviest marketable ears in both methods of establishment but were comparable to T_4 and T_5.

Recommendations

It is recommended to measure the nutrient uptake of the Honey Star F_1 sweetcorn to evaluate their differences in nutrient absorption. A similar study be conducted in locations with similar climatic conditions but assessing its root morphology as its focus to verify the effects of Bio-N fertilizer.

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All authors are contributed in this research

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Data presented in this study are available on fair request from the respective author.
Ethics Approval and Consent to Participate
Not applicable
Consent for Publication
Not applicable.
Conflicts of Interest
The authors disclosed no conflict of interest.

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