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Positive sweet corn response with selected climate-smart agricultural practices

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Abstract

To sustain agriculture for future generations and reduce the adverse impacts on soil health and the environment, there is a need to adopt sustainable and climate-smart agricultural practices. A field experiment was conducted to study the effects of organic amendments (chicken and dairy manures and biochar) on the soil physicochemical properties, sweet corn (*Zea mays*) growth, and yield parameters at Prairie View A&M University, Texas. Two rates of biochar (2.5 and 5 t ha^{-1}) and two types of manure (chicken and dairy) applied at three rates (0, 224, and 448 kg total N ha^{-1}) were used in a factorial design with three replications. Plant height, period for each vegetative growth stage, leaf soil plant analysis development, time to reach 50% tasseling and 50% silking stage, cob length, cob diameter, sugar content, and biomass were measured. The results showed that plant biomass was significantly affected by biochar rate, while plant height, cob length, and cob diameter were significantly affected by manure rates. Sweet corn reached tasseling and silking stages earlier in chicken manure-treated plots than the dairy manure plots. However, the sugar content was significantly affected by both biochar and manure rates. Furthermore, results revealed a strong positive correlation between plant height and cob length, diameter, and biomass; however, there was a negative correlation with tasseling and silking days. Soil phosphorus, total nitrogen, and potassium had a relatively positive correlation with plant growth parameters. Findings showed that different types and rates of amendments significantly influenced sweet corn growth parameters and soil nutrient status, highlighting the importance of adopting climate-smart agricultural practices for improved crop yield and soil health.

Abbreviations: ATP, adenosine triphosphate; CSA, climate smart agriculture; DAP, days after planting; LCC, leaf chlorophyll content; LSD, least significant difference; SPAD, soil plant analysis development.

1 | INTRODUCTION

Corn (*Zea mays*) ranks third in global crop production after wheat (*Triticum aestivum*) and rice (*Oryza sativa*) (Khan et al., 2019). The United States produces >40% of the world's corn, making it the leading producer and exporter (Eskandarnejad et al., 2013; Singh et al., 2018; Solaimalai et al., 2020). Farmers favor high-value sweet corn for its short growing period (60–100 days) and high economic returns (Cummins & Motsenbocker, 2022; Daniels, 2013). Commercial varieties offer better color, flavor, and quality (Kumari et al., 2006), with sweetness being a key consumer preference. Sweet corn is consumed fresh or processed (Abuzar et al., 2011; Oktem et al., 2003) and is rich in sugar, protein, vitamins, minerals, and phytochemicals (Ibrahim & Juvik, 2009).

Sustaining healthy soil is fundamental to crop production, making efficient fertilizer management a key strategy for optimizing crop productivity and ensuring the long-term sustainability of agricultural systems. It also plays a key role in maximizing farm economic returns and minimizing the negative effects of nutrients. Previous research reported that using organic manures could help enhance crop productivity by reversing the long- and short-term losses of organic matter (Diacono & Montemurro, 2011). Organic manures, used as fertilizers since ancient times, provide plants essential macronutrients and trace elements. Chicken manure is rich in nutrients such as nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), and copper (Cu), while dairy manure supplies N, P, K, magnesium (Mg), sulfur (S), and other micronutrients (Chambers et al., 2001; Celik et al., 2010; Pain, 2000; Sims, 1995). Reports have demonstrated that the use of organic amendments increased soil carbon (C), N, K, Mg, and calcium (Ca) (Ayoola & Makinde, 2008). Also, organic manures improve the soil water-holding capacity, cation exchange capacity, nutrient content, soil structure, and beneficial microbes (Mwangi, 2010).

Climate change and global warming are major concerns, with global temperatures rising by 0.08˚C per decade (NOAA, 2023). Projections indicate a potential 6˚C increase in global temperature by the end of the 21st century due to greenhouse gases (Ma et al., 2022). This warming leads to more hot days and nights and changes in extreme weather events (Spinoni et al., 2019). Corn yields could decrease significantly with each degree rise in temperature, potentially reducing by 24% (Jägermeyr et al., 2021; Sharma et al., 2022). With the global population expected to reach 9.7 billion by 2050 (Desa, 2019; Gu et al., 2021), climate change and population growth pose challenges to future food security, necessitating changes in agricultural practices.

Climate Smart Agriculture (CSA) is an integrated approach designed to address the challenges posed by climate change to agriculture, aiming to enhance food security, increase resilience, and reduce greenhouse gas emissions (Lipper et al., 2017). CSA encompasses a variety of practices and technologies that improve agricultural productivity while promoting environmental sustainability. Conservation tillage and residue management are pivotal components of climate-smart agriculture, enhancing soil health and carbon sequestration (Ahmad, Virk, Nizami, et al., 2024; Ahmad, Virk, Hafeez, et al., 2024; Delandmeter et al., 2024; Schreiner-McGraw et al., 2024). One example of CSA is the use of organic amendments like manure and biochar to improve soil health and carbon sequestration (Joona et al., 2024; Kottegoda et al., 2023). Using soil organic amendments like manure improves soil water absorption, promotes corn root growth, and increases grain and biomass yields (Zougmoré et al., 2006). Organic manures release nutrients gradually, providing a lasting impact (Sharma & Mittra, 1991). Corn is a heavy fertilizer-requiring crop that requires continuous nutrients throughout its growth cycle, especially N, for optimal growth (Jat et al., 2013). However, <50% of applied N fertilizers are utilized by crops, with the rest lost through volatilization, denitrification, or leaching (Jat et al., 2013). Effective management requires synchronizing nutrient release with crop demand.

Core Ideas

- Biochar applied at a 5 t ha^{-1} rate increased plant biomass, cob diameter, and sugar content.
- Manure applied at the 448 kg N ha^{-1} rate increased plant height, vegetative growth stage, cob length, and sugar content.
- Chicken manure facilitated earlier flowering (tasseling and silking) in corn compared to the other treatments.

The rapid breakdown of organic material in the soil leads to short-term nutrient benefits (Abbasi & Anwar, 2015). In contrast, the recalcitrant nature of biochar makes it more resistant to microbial degradation, remaining in soil up to 100 times longer than most organic matter (Duku et al., 2011). Therefore, the incorporation of biochar into soils has the potential to act as a carbon sink and enhance nutrient availability. Biochar is also recognized as a cost-effective way to stabilize organic carbon and reduce greenhouse gas emissions (De Gryze et al., 2010; Read, 2012). Additionally, biochar improves soil's physical, chemical, and biological properties, including water-holding capacity and nutrient retention due to its porous nature (Ding et al., 2016; Lin et al., 2016; Nigussie et al., 2012; Rollon et al., 2017).

Numerous studies have demonstrated the benefits of organic amendments, such as chicken and dairy manure (Goldan et al., 2023; Rastogi et al., 2023; Sani et al., 2024; Verma et al., 2024), and biochar (Kaur et al., 2024; Pandian et al., 2024; Sharma & Chhabra, 2024), in improving soil health, crop productivity, and environmental sustainability. However, there is still a need for a comprehensive understanding of their effects when manure is used in combination with biochar. Specifically, the interaction between organic manures and biochar in influencing soil nutrient dynamics and sweet corn growth under varying climatic conditions has not been fully explored. Furthermore, although CSA practices have been promoted as solutions to mitigate the impacts of climate change on agriculture, empirical data on their effectiveness, especially in the context of organic amendment strategies, remains limited. This knowledge gap is critical as global climate change and population growth continue to pose significant threats to food security. Therefore, the main goal of this study was to evaluate the combined effects of three organic amendments (biochar and chicken and dairy manures) at different rates (two for biochar: 2.5 and 5 t ha^{-1} and three for the manures: 0224 and 448 kg N ha^{-1}) on the fate of added soil organic carbon in the growth parameters of sweet corn grown under southeast Texas conditions. It was hypothesized that the combined application of higher rates of manure and biochar would improve soil nutrient content and corn growth parameters compared to the treatments that did not receive the same. The specific objectives of this study were (i) to explore the combined effect of these amendments on soil nutrient status and (ii) to evaluate their impact on the agronomic and productive traits of sweet corn.

2 | MATERIALS AND METHODS

The field experiment was conducted at the College of Agriculture, Food, and Natural Resources farm (Latitude: 30°5′33.95″ N, Longitude: 95°58′43.14″ W), Prairie View A&M University, Prairie View, Texas, during the 2022 corn growing season. The mean annual rainfall is 1126 mm based on monthly rainfall data from 1980 to 2018 (PRISM data: http://www.prism.oregonstate.edu/, accessed on October 2, 2022), with mean minimum and maximum temperatures of 14.9 and 25.6°C, respectively. The experimental site's main soil type is Wockley fine sandy loam. According to the US Soil Taxonomy, the taxonomic classification of the Wockley Series is as follows: fine-loamy, siliceous, semiactive, hyperthermic Plinthaquic Paleudalfs. To access information regarding the characteristics of Wockley fine sandy loam soil, please refer to Awal, Hassan, et al. (2021) or refer to the Web Soil Survey (https://websoilsurvey.nrcs.usda.gov/app/). The field had a crimson clover (*Trifolium incarnatum*) grown as a cover crop without fertilizer. The soil was plowed 3 weeks before planting the sweet corn, and the cover crop was incorporated into the soil. Surface soil samples at a depth of 0–15 cm were randomly collected to gauge the initial fertility level of the site 3 weeks after incorporating the cover crop on the day of planting corn. Twenty soil samples were collected using a soil sampling core to cover the experimental plots and were thoroughly mixed. The combined soil sample was then dried at 60°C for 48 h, ground, and sieved through a 0.15 mm mesh. Soil pH and electrical conductivity were measured in deionized water at a soil-to-water ratio of 1:2. Soil nutrients C, N, and S were analyzed using a CHNS analyzer (Elementar Americas, Inc.), while the concentrations of P, K, Ca, Mg, B, Cu, Fe, Zn, and Mn were determined using an ICP-OES instrument (Agilent Company).

The land was first plowed to a depth of 15 cm to break up the soil and incorporate the crimson clover biomass. This was followed by harrowing to further refine the soil structure, improving soil aeration, and facilitating rapid decomposition of the crimson clover. The experiment was carried out in 2 × 2 × 3 factorial combinations of two rates of biochar (2.5 and 5 t ha^{-1}), two types of organic manure (chicken and dairy), and three rates of manure (0, 224, and 448 kg N ha^{-1}) in a randomized complete block design with three replications. Each plot was 3 × 2.5 m long, with 2 m paths separating within row plots while blocks were kept 3.5 m apart. Manures and biochar in each plot were mixed in the top 15 cm of the soil using hoes and rakes. Sweet corn seeds were seeded at 30 cm apart within rows and 60 cm between rows, resulting in a seeding rate of 7.62 kg ha^{-1}. A four-line drip irrigation system per replication was installed. We applied 675 mm of irrigation water during the growing season. IrrigWise, a web-based irrigation scheduling tool, was used to quantify the accurate irrigation requirements based on near-real-time site-specific rainfall, reference evapotranspiration, soil water content, and plant growth stage (Awal, Fares, et al., 2021). Manual weeding was performed throughout the growing season. The nutrient content of soil and organic amendments are summarized in Table 1.

Plant height was measured using a meter rod as the mean height of four plants from the middle two rows, from the base of the plant to the base of the fully emerged top leaf. Vegetative growth stage V4 to V9 leaf stage was recorded as the number of days from sowing to 50% time to reach each stage on each plot. Soil plant analysis development (SPAD) readings were taken from four randomly selected plants in each plot. For each plant, the middle portion of a fully developed leaf, avoiding the midrib, was chosen. The readings from the four plants were averaged to obtain a representative SPAD value for each plot using a chlorophyll analyzer (SPAD-502, Konica Minolta). The number of days to 50% tasseling and 50% silking stage was measured as the number of days from sowing to reaching 50% tassels and 50% silks to emerge on each plot. Cob length was measured from the tip to the base of the ear. Cob diameter was measured from the girth of the ear. For the biomass, plants were harvested, and dried weight was measured. Using a refractometer, sugar content was measured as sweet corn's total dissolved sugar levels.

TABLE 1 The concentration of plant available nutrients, pH, and electrical conductivity in soil (0- to 15-cm depth), chicken manure (CM), and dairy manure (DM) in the year 2022.

Soil/amendment	C (%)	N (%)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	S (%)	pH	EC (mS cm^{-1})
Soil	0.5	0.09	0.09	0.07	0.39	0.07	6.38	–	253	2	8	0.28	6.89	0.11
CM	27.32	3.05	9.60	27.16	16.24	5.64	50.1	817.99	2494	465	500	1.37	7.02	17.73
DM	14.62	0.5	5.75	12.60	72.28	4.79	18.98	25.23	6025	129	335	0.64	8.40	8.73
Biochar	58.71	1.46	1.08	5.45	29.95	6.68	10.96	8.9	1203	22	90	3.15	5.67	18.96

Abbreviations: B, boron; C, carbon; Ca, calcium; CM, chicken manure; Cu, copper; DM, dairy manure; EC, electrical conductivity; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; P, phosphorus; S, sulfur; Zn, zinc.

The collected data were statistically analyzed using Statistix 10 software (Analytical Software). A one-way analysis of variance was performed to assess the impact of different amendment treatments on plant growth parameters. Tukey's test at $p < 0.05$ was applied to identify significant differences among treatments. The analyzed data were presented as means, and graphs were plotted using Microsoft Excel. A correlation matrix, expressed as a heatmap, was prepared using Python software to examine the relationships between plant growth traits and soil parameters.

3 | RESULTS AND DISCUSSION

3.1 | Plant height

The plant height time series results indicate that plant height responded only to the manure application rates. Plants treated with a 448 kg N ha^{-1} manure rate had significantly greater heights than those treated with a 224 kg N ha^{-1} rate or the control. At 24 and 27 days after planting (DAP), the average plant heights for the 448 kg N ha^{-1} manure rate were 14.70 and 18.55 cm, respectively, while the control treatment plants measured 12.66 and 14.76 cm on the same dates (Table 2). Similarly, at 35 and 39 DAP, the average plant heights for the 448 kg N ha^{-1} manure rate were 37.94 and 58.69 cm, respectively, and for control, the heights were 22.96 and 34.60 cm, respectively. At 42 DAP, sweet corn plants treated with the 448 kg N ha^{-1} manure rate were 68.47% taller than the control treatment.

Plant height is a crucial growth parameter that influences corn yield and economic returns. Manures provide essential macronutrients (N, P, K) and micronutrients (Fe, Zn, Mn, Cu, and B) that are vital for plant growth, development, and yield. Hassan (2002) and Boateng et al. (2006) observed a significant increase in plant height with the application of chicken manure. Similarly, Kumar et al. (2017) found that plants receiving chicken manure grew taller than those that did not receive any manure, likely due to the availability of readily absorbable nutrients that promote rapid growth. Sebetha and Mashele (2019) also reported that plants treated with dairy manure were taller than those treated with other animal manures. However, this experiment observed no significant differences in plant height with manure type.

Nitrogen is the main constituent for cell division and enlargement along with P; however, K favors the rapid division and development of cells (Marschner, 2011; Pandey, 2018). Nitrogen has been shown to boost plant elongation by increasing both the number of nodes and the length of internodes, thereby influencing overall plant height (Luo et al., 2020). It facilitates cell multiplication and elongation (Sung et al., 2004). Ahmad et al. (2018) observed longer stems with increased N rates. Similarly, plant height increased with

TABLE 2 Effect of manure types and rates, and biochar rates on plant height of sweet corn from 24 to 42 days after planting (DAP).

Days after planting (DAP)	Manure type		Manure rate			Biochar rate	
	Chicken	Dairy	0 kg N/ha	224 kg N/ha	448 kg N/ha	2.5 t/ha	5 t/ha
24	13.86a	13.55a	12.66b	13.77ab	14.70a	13.45a	13.97a
27	16.89a	16.51a	14.76b	16.78ab	18.55a	16.27a	17.13a
31	23.23a	21.21a	18.21b	21.95b	26.49a	21.29a	23.14a
35	32.63a	28.69a	22.96b	31.07a	37.94a	29.01a	32.30a
39	50.22a	42.30a	34.60b	45.49ab	58.69a	42.57a	49.96a
42	50.48a	42.64a	34.93b	45.92ab	58.85a	42.89a	50.24a

Note: The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

higher N application rates in this experiment. Our results are consistent with other studies that have reported positive effects of N on plant height (Maqsood et al., 2001; Sharar et al., 2003). The consistently greater plant heights observed with higher manure rates compared to the control suggest that increased manure rates enhanced nutrient availability for plant uptake, thereby promoting plant growth through photosynthesis (Hossain et al., 2002; Hussain et al., 2006). The shorter plants observed in the control treatment may be due to insufficient N. These findings suggest that plant height is responsive to an adequate nutrient supply.

There was no significant effect of biochar rate on plant height, nor was there any interaction effect with manures during the growing season. Biochar enhances crop productivity and nutrient availability by improving soil water and nutrient-holding capacities, although it contributes little or no direct nutrient additions (Lehman et al., 2003). Syuhada et al. (2016) observed increased corn plant height following biochar application. Similarly, Oguntunde et al. (2004) observed improved corn growth due to increased uptake of nutrients such as P, K, Ca, and Mg after biochar application. However, our study did not observe any difference in plant height due to biochar rate.

3.2 | Growth stages

The corn growth stages V4-V9 were significantly affected only by the manure rate (Table 3). Sweet corn development under the manure rate 448 kg N ha^{-1} progressed to the next growth stage earlier compared to those under the 224 kg N ha^{-1} and control treatments. The time taken to reach the V5, V7, and V9 stages for the 448 kg N ha^{-1} manure rate was 24.58, 30.75, and 36.08 days, respectively, while for the control treatments, it was 27.33, 31.75, and 39.33 days respectively. Similarly, plants in the 224 kg N ha^{-1} rate treatments took 25.75, 32.25, and 37.58 days to reach the V5, V7, and V9 stages, respectively. The longer time required by plants to reach the next leaf stage in the 224 kg N ha^{-1} rate treatments could be due to insufficient nutrients for leaf development. Similar to our experiment, Qasim and Javed (2001) and Uwah and Iwo (2011) reported a higher number of leaves with higher amendment rates compared to control treatments. The exceptionally high number of leaves per plant observed with the 448 kg N ha^{-1} manure rate can be linked to the accelerated development caused by the increased N content provided by the 448 kg N ha^{-1} application of N and other nutrients. Khalil et al. (2005) reported that chicken manure, rich in N, fosters plant growth and enhances nutrient availability. The increase in leaf count per plant with chicken manure application is attributed to its direct role in crop nutrition, while no significant impact of manure type on the growth stage was observed in this experiment.

The manure type significantly affected the days to reach the 50% tasseling stage. Plants treated with chicken manure reached the 50% tasseling stage in an average of 40.67 days, while those treated with dairy manure took 42.11 days. In contrast, both the manure type and rate significantly influenced the days to reach the 50% silking stage. Plants treated with dairy manure took longer to reach the 50% silking stage compared to those treated with chicken manure. However, the control treatment required more days to reach the 50% silking stage than the 448 kg N ha^{-1} and 224 kg N ha^{-1} N rates. The average days to 50% silking were 46.11 days for chicken manure and 47.94 days for dairy manure, while the average days for the 448 kg N ha^{-1}, 224 kg N ha^{-1} and control treatments were 45.08, 47.58, and 48.42 days, respectively. The presence of nutrients, particularly N, likely contributed to physiological activities that produced more photo-assimilates, leading to quicker flowering (Effa et al., 2011). Our findings align with those of Nasim et al. (2012), who reported that supplying N through organic and inorganic fertilizers enhances plant growth stages, leading to earlier development of sweet corn reproductive parts. The results of this study show that plants in plots with higher manure content had fewer days to silking and tasseling compared to the control treatments, likely due to increased nutrient availability (Table 3). The longer days to silking and tasseling observed in the control treatments were likely due to the inadequate availability of essential nutrients in the soil, which was not the case for the higher manure content treatments.

TABLE 3 Effect of manure types and rates, and biochar rates on sweet corn growth at different vegetative and reproductive stages (V4 to silking).

Growth stage	Manure type		Manure rate			Biochar rate	
	Chicken	Dairy	0 kg N/ha	224 kg N/ha	448 kg N/ha	2.5 t/ha	5 t/ha
V4	22.67a	23.11a	24.17a	22.58b	21.92b	23.11a	22.67a
V5	25.72a	26.06a	27.33a	25.75b	24.58b	26.00a	25.78a
V6	27.72a	27.67a	28.75a	27.92a	26.42b	27.83a	27.56a
V7	31.78a	31.39a	31.75ab	32.25a	30.75b	31.50a	31.67a
V8	35.67a	35.50a	37.83a	35.33b	33.58c	35.94a	35.22a
V9	37.94a	37.39a	39.33a	37.58ab	36.08b	37.94a	37.39a
Tasseling	40.67b	42.11a	41.67a	41.83a	40.67a	41.44a	41.33a
Silking	46.11b	47.94a	48.42a	47.58a	45.08b	47.11a	46.94a

Note: The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

TABLE 4 Effect of manure types and rates, and biochar rates on soil plant analysis development (SPAD) reading of sweet corn from 20 to 53 days after planting (DAP).

DAP	Manure type		Manure rates			Biochar rate	
	Chicken	Dairy	0 kg N/ha	224 kg N/ha	448 kg N/ha	2.5 t/ha	5 t/ha
20	32.64a	31.31a	28.57b	32.83a	39.02a	30.85a	33.11a
28	32.89a	30.23a	27.58b	30.66b	36.43a	30.57a	32.54a
33	34.92a	30.78a	27.64b	31.22b	39.69a	31.73a	33.97a
42	38.09a	33.33b	32.13b	35.68ab	40.33a	35.21a	36.21a
53	45.24a	38.57b	36.28c	41.63b	47.81a	40.91a	42.91a

Note: The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

3.3 | SPAD readings

Data analysis (Table 4) showed that SPAD readings significantly responded to manure rates at all stages, except for days 42 and 53, where manure type had a significant effect. SPAD readings ranged from 27.58 to 45.24. In the control treatment, SPAD readings at 20 and 42 days were 28.57 and 32.13, respectively, while for the 448 kg N ha^{-1} treatment, they were 39.02 and 40.33, respectively. SPAD readings from chicken manure treatments were 14.28% and 17.29% higher than those from dairy manure at 53 DAP. Similarly, SPAD readings for the 448 kg N ha^{-1} and 224 kg N ha^{-1} rate treatments were 31.78% and 14.75% higher than those of the control treatment at 53 DAP.

Leaf chlorophyll content (LCC), a key indicator of photosynthetic activity, depends on the N content in green plants. It reflects crop responses to N fertilization and the overall nutrient status of the soil. Similar to our findings, Costa et al. (2001) observed significantly elevated SPAD readings with increased N levels. The decreased chlorophyll content in the control treatment may be attributed to reduced specific enzyme activities essential for chlorophyll synthesis and decreased uptake of minerals like Mg, which are crucial for pigment synthesis (Kazemi et al., 2010). Uddin et al. (2023) found that higher N levels enhance chlorophyll content in corn leaves, leading to significant increases in sweet corn yield and yield components. Manirakiza and Seker (2020) observed significant increases in LCC following compost and biochar application. Agegnehu et al. (2016) reported an increase in SPAD reading in the compost and biochar treatment by 2.6 and 2.0 units, respectively, compared to the control treatment, and similar results were reported by Çalış and Şeker (2018). Ali et al. (2021) also observed a significant increase in chlorophyll content with biochar treatment compared to the control treatment, while no significant impact of biochar rate on LCC was observed in this experiment.

3.4 | Cob length

The manure type and rate significantly affected the length of the sweet corn cobs; thus, the cobs of chicken manure treatments were 14% longer than those of the dairy manure treatments. Similarly, the manure rate significantly affected cob length. Specifically, the cobs from the control treatment were 42% and 66% shorter than those from the 224 kg N ha^{-1}

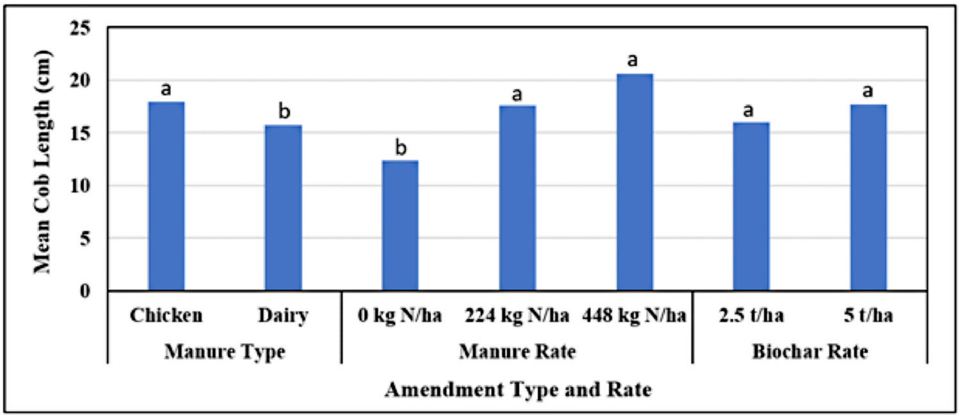

FIGURE 1 Effect of manure types and rates and biochar rates on cob length of sweet corn. The same letter indicates no significant difference among means by the least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

and 448 kg N ha^{-1} manure rates, respectively. No interaction effects were observed, indicating a consistent effect of manure rate effect across manure types. The average cob length for manure applied on 448 kg N ha^{-1}, 224 kg N ha^{-1}, and control were 20.57, 17.62, and 12.38 cm, respectively (Figure 1). The manures supplied the plants with needed nutrients compared to the control treatments, favoring higher photosynthetic rates and consequently resulting in longer cobs. Amanullah et al. (2009) observed a significant increase in the length of sweet corn cobs resulting from applying an N rate of 180 kg ha^{-1}. Similarly, Shahid et al. (2015) reported a significant increase in cob's length due to the application of organic and inorganic fertilizer mixtures. The formation and enlargement of cobs are determined by the metabolic activities of the crop, which are governed by the availability of nutrients. Phosphorus is a key component of adenosine triphosphate (ATP), which provides the necessary energy for cell division, nutrient transport, and biosynthesis processes. (Hammond & White, 2008). It helps in essential processes like photosynthesis and nutrient assimilation, ensuring the developing cob receives the resources needed for proper growth and kernel development (Neocleous & Savvas, 2019). The phosphorus content was higher in the chicken manure compared to the dairy manure (Table 1).

3.5 | Cob diameter

Biochar, manure type, and application rate had statistically significant effects on cob diameter (Figure 2). Plots treated with chicken manure produced significantly larger cobs compared to those treated with dairy manure. Additionally, the biochar applied at 5 t ha^{-1} resulted in a significantly larger cob diameter compared to the 2.5 t ha^{-1} application rate. Cob diameter also increased linearly with manure rates; 448 kg N ha^{-1} manure rate produced the largest cobs, and also the 224 kg N ha^{-1} rate produced larger cobs than the control treatment. The average cob diameters for 5 t ha^{-1} and 2.5 t ha^{-1} biochar rates were 14.49 cm and 12.93 cm, respectively, while the diameters for the 448,224 kg N ha^{-1}, and control manure treatments were 16.26, 13.98, and 10.89 cm, respectively. The higher rates of manure and biochar continuously supplied nutrients that supported corn growth. Gokila and Baskar (2015) reported the highest cob weight when biochar was applied at 5 t ha^{-1} in combination with other fertilizers. The results of this study align with those of Oktem et al. (2001), who found that increased N application rates led to larger cob diameters. The greater cob volume observed with higher manure application rates could be attributed to a favorable soil environment and increased nutrient availability, which are essential for improved crop yield. Sunlight and adequate nutrient levels enhance photosynthesis and the translocation of photosynthates to the cob, thereby improving cob parameters.

3.6 | BRIX

The results showed that BRIX, a measure of sugar content, was significantly affected by both biochar and manure rates (Figure 3). BRIX values ranged from 17% to 26.3%, with significantly higher BRIX observed under treatments with higher biochar and manure rates compared to lower rates. Specifically, the average BRIX for 5 t ha^{-1} biochar rates was 23.40%, while it was 20.11% for 2.5 t ha^{-1} biochar rates. Similarly, BRIX values for 448,224 kg N ha^{-1}, and control manure treatments were 22.85, 22.40, and 20.01%, respectively. The sugar content of sweet corn is influenced by various factors, including the variety used and the maturity stage at harvest (Haddadi, 2016). In this experiment, differences in flowering dates were observed, which likely contributed to variations in sugar content; early-flowered corn tends to develop sugar

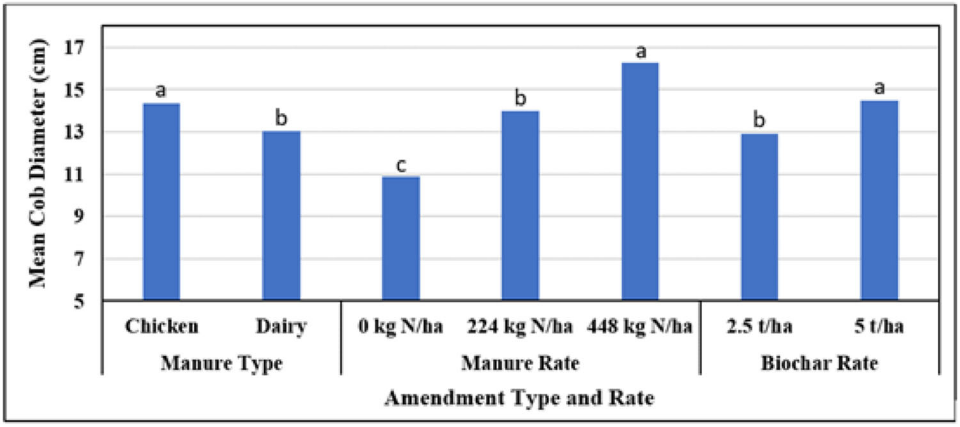

FIGURE 2 Effect of manure types and rates and biochar rates on cob diameter of sweet corn. The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

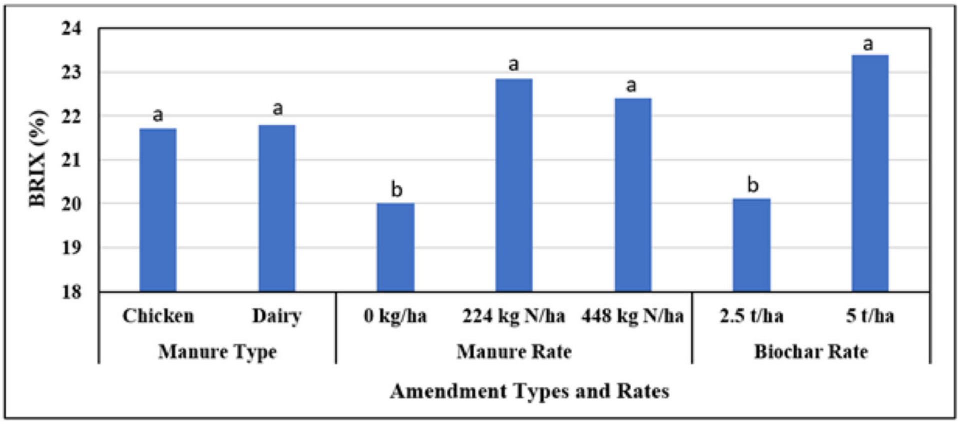

FIGURE 3 Effect of manure types and rates, and biochar rates on BRIX of sweet corn. The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

content earlier than late-flowered plants. Subaedah et al. (2021) found that corn harvested at 65 DAP had the highest sugar content, while corn harvested at 70 DAP had the lowest.

Nutrient availability also plays a crucial role in determining sugar levels. Nitrogen, for example, is a key component of amino acids and influences the taste of corn kernels. Adequate N can enhance carbohydrate metabolism, leading to increased sugar levels in seeds (Sirajuddin & Lasmini, 2010). Although studies by Stephen Mason et al. (2010) and Pangaribuan and Sarno (2020) have shown that chicken manure can increase the sweetness of corn, no significant differences in sugar content due to chicken manure application were observed in this experiment. Additionally, Pangaribuan et al. (2016) demonstrated that N applied at 150 kg ha^{-1} increased corn's sugar content. Potassium is another important factor, as it plays a role in sucrose synthase activity, affecting sweet corn's taste by influencing sugar formation and translocation within the crop (Hu et al., 2015). Phosphorus is also essential for promoting stalk and stem development, influencing flowering and seed formation, and improving overall crop yield and quality (Malhotra et al., 2018). The P and K content in biochar may have contributed to the increased sweetness observed in this study's sweet corn.

3.7 | Biomass

Manure rates had a statistically significant effect on plant biomass (Figure 4). The plant biomass ranged from 181.3 to 476.3 kg ha^{-1}. The biomass for the 448 kg N ha^{-1} and 224 kg N ha^{-1} rate treatments was 162.6% and 69.2% greater than that of the control treatment. The incorporation of organic manure, such as chicken manure, enhances the availability of N, P, K, Ca, and Mg to crops, leading to an overall increase in biomass production (Piperno et al., 2009; Postma et al., 2014). Dry matter production increased with 448 kg N ha^{-1} of manure application throughout the growth stages of sweet corn. The 448 kg N ha^{-1} manure rate treatments provided

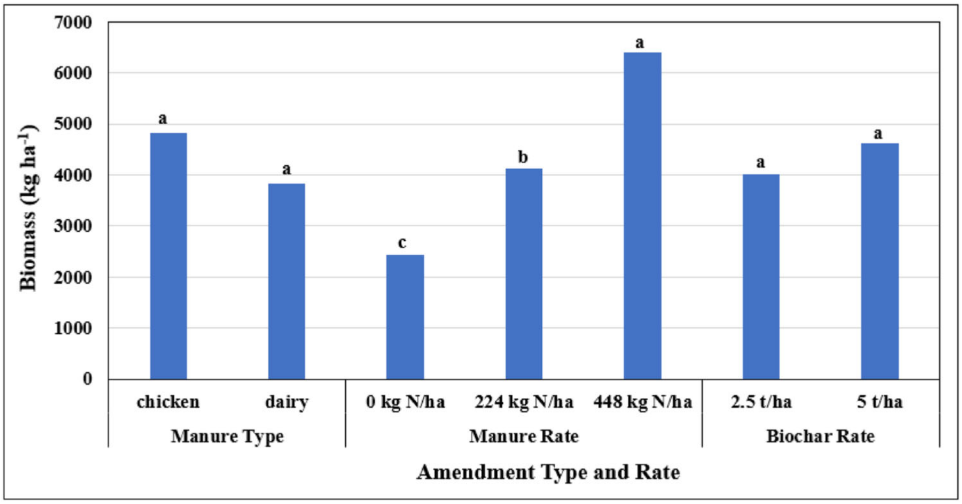

FIGURE 4 Effects of manure types and rates and biochar rates on biomass of sweet corn. The same letter indicates no significant difference among means by least significant difference (LSD) comparison of means at $\alpha = 0.05$. Letters are within manure type, manure rate, and biochar rate.

plants with greater availability of macro and micronutrients, likely contributing to the increased biomass. This effect is likely due to the improved soil physical, chemical, and biological properties associated with higher manure application rates. Wang et al. (2009) reported that organic manure application leads to improvements in soil health. Schulz et al. (2013) also showed that crop biomass increased with the increase in the level of compost and biochar rate. Many studies suggest that biochar improves plant growth by improving the soil's physical and chemical properties (Glaser et al., 2002; Qiao-Hong et al., 2014). Biochar's porous nature and high surface area allow it to retain more nutrients and reduce nutrient leaching, which could enhance crop growth (Glaser et al., 2002; Laird et al., 2010). Manolikaki and Diamadopoulos (2019) found that corn biomass increased by 155% in sandy loam soil and 436% in loam soil with the application of biochar combined with compost. Similarly, Butnan et al. (2015) witnessed a surge in corn biomass ranging from 115% to 600% with biochar application. However, a meta-analysis involving 177 biochar studies indicated no significant change in corn growth (Jeffery et al., 2011). Our experiment also did not observe any significant effect of biochar rate on biomass. The use of pelleted biochar in this study may explain the lack of impact on biomass, as it may require time to break down and release nutrients.

3.8 | Correlation matrix for plant growth traits and soil parameters

The correlation analysis revealed that plant height had a strong positive correlation with cob length, cob diameter, biomass, P, and K but a negative correlation with days to 50% silking and tasseling. SPAD readings also showed positive correlations with most variables, with the strongest correlation being with biomass (Figure 5). Among the soil nutrients, P was positively correlated with plant height, cob length, cob diameter, and biomass. In contrast, days to 50% silking and tasseling were negatively correlated with P. Plant height is an important growth parameter influencing corn yield. Munawar et al. (2013) and Fadhli et al. (2020) reported a positive correlation between yield and plant height in relation to cob weight. Similarly, Ahmadi et al. (2014) reported a positive correlation between biomass and cob length. The SPAD value indicates the absolute chlorophyll content in the leaf. An increase in SPAD value is strongly correlated with chlorophyll content, thereby increasing photosynthetic activity and vegetative growth (Song & Banyo, 2011). Sunlight and an adequate amount of nutrients generate photosynthates, and the translocation of these photosynthates to the cob increases cob parameters. Additionally, P contributes to the development of cob and seed size, as it is essential for ATP formation.

The negative correlation between tasseling and silking stages and plant height suggests that taller plants might quickly reach the tasseling and silking stages. The negative correlation between SPAD readings and tasseling and silking stages also suggests that plants with higher chlorophyll content (indicative of better photosynthetic activity) might reach the tasseling stage sooner. This may be because healthier plants with sufficient chlorophyll can progress through growth stages more efficiently, leading to more effective reproductive development.

4 | CONCLUSION

A field experiment was conducted to investigate the effects of organic amendments (chicken and dairy manures and biochar)

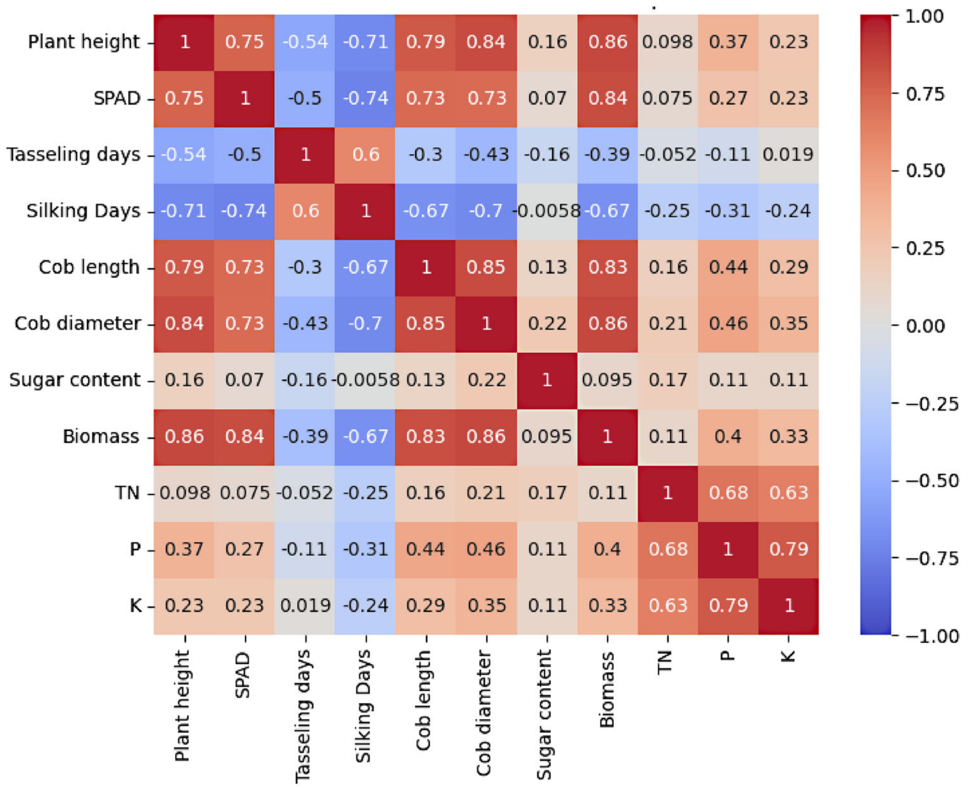

FIGURE 5 Correlation Heatmap showing relationships among plant height, soil plant analysis development (SPAD), tasseling and silking days, cob traits, sugar content, biomass, and soil nutrient (TN, P, and K) in sweet corn. Positive (red color) or negative (blue color) correlations between plant growth traits and soil parameters are identified by color (+1.00 to −1.00). Total nitrogen (TN), Phosphorus (P), and Potassium (K) are soil parameters.

on the soil physicochemical properties and sweet corn growth and yield parameters. Applying chicken and dairy manures at 448 kg N ha^{-1} rate resulted in rapid plant growth, increased plant height, and longer cob length. However, cob diameter and sugar content increased with higher rates of biochar and manure. Although chicken manure-treated plots performed better overall, a significant impact of manure type was only observed in the days to 50% tasseling and silking stages. Chicken manure-treated plots flowered earlier compared to those receiving dairy manure. Additionally, organic amendments improved soil health by enhancing the soil's physical and chemical properties, contributing to sustainable agriculture. Future research should focus on long-term studies to assess how these organic amendments affect carbon cycling and nutrient dynamics to understand improvements in crop growth parameters. Future studies could also explore the economic and environmental impacts, examine effects on different crops and regions, and determine optimal application rates. Employing climate-smart agricultural techniques and disseminating knowledge to farmers could enhance outcomes and promote sustainability.

AUTHOR CONTRIBUTIONS

Binita Thapa: Conceptualization; data curation; formal analysis; investigation; methodology; software; validation; visualization; writing—original draft; writing—review and editing. **Ripendra Awal**: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; writing—review and editing. **Ali Fares**: Conceptualization; funding acquisition; investigation; methodology; project administration; supervision; validation; writing—review and editing. **Anoop Veettil**: Investigation; methodology; writing—review and editing. **Almoutaz Elhassan**: Investigation; methodology. **Atikur Rahman**: Investigation; Writing—review and editing. **Nigus Melaku**: Investigation. **Selamawit Woldesenbet**: Investigation.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest statement.

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