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Effect of Mineral and Organic Nitrogen Sources on Vegetative Development, Nutrition, and Yield of Sugarcane

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Abstract: Although sugarcane yield is directly influenced by the availability of nitrogen (N), the efficiency of mineral N (MN) fertilization is considered to be low due to nitrate leaching and ammonia volatilization. Thus, the search for alternative sources of N that are cheaper and more consistent with sustainable farming practices has been stimulated. As chicken litter is an organic waste with the potential to supply N to major crops, we tested the hypothesis that the use of this litter as a source of organic N (ON) is as efficient as the application of MN (ammonium nitrate) in promoting the growth, nutrition, and yield of sugarcane plants grown during both plant cane and ratoon cane seasons. Experiments were conducted in a $5 \times 5 \times 2$ subdivided plot scheme in the growing area of the Denusa Mill, Destilaria Nova União S/A, located in the midwest region of Brazil, with treatments consisting of five doses each of MN (0, 40, 80, 120, and 160 kg ha^{-1}) and ON (0, 2, 4, 6, and 8 T ha^{-1}), evaluated in two crop seasons (plant cane-2019/2020 and ratoon cane-2020/2021). The application of different doses of MN or ON influenced the height and number of tillers of sugar cane plants, and the application of ON, supplied by chicken litter, to this crop was as efficient as that of MN in promoting plant growth. MN and ON also increased the leaf content of N, P, and K; moreover, the absence of one source of nitrogen was compensated by the other. ON application (up to 4.8 T ha^{-1}) also increased sugarcane yield in addition to promoting growth. Furthermore, this study highlighted the superior quality of the regrowth observed in the IACSP95-5094 cultivar, which manifested in increased tillering and stem diameter, resulting in consistently higher yields in the ratoon crop.

Keywords: nitrogen fertilization; chicken manure; ammonium nitrate; organic nitrogen; sustainable agriculture

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1. Introduction

Several factors, including management practices, soil, climate, cultivars, and nitrogen fertilization, affect sugarcane yield [1,2]. The application of nitrogen (N) in this crop must be recurrent because this nutrient exhibits high mobility in the soil and is prone to leaching. Under limiting soil N concentrations due to leaching, the growth of sugarcane plants is restricted and their yield is adversely affected [3–5].

MN in the form of ammonium nitrate (NH_4NO_3) is currently the primary source of N used in major crops [6]. However, studies have shown that only 30% to 50% of the ammonium nitrate applied is used by the plants [7]. This low efficiency is attributed to losses such as nitrate leaching, ammonia volatilization, and gaseous emissions caused by microbial conversion [8,9]. In addition to the losses incurred, the current high cost of nitrogen fertilizers [10–12] and the necessity to implement more sustainable agriculture practices have prompted the search for organic alternatives that provide increased nitrogen supply to crops at a reduced cost [13].

In Brazil, ammonium nitrate is an imported, high-cost raw material; however, some Brazilian regions, such as the midwest, are major producers of poultry and generate substantial amounts of poultry waste known as chicken litter or poultry litter [14,15]. Chicken litter is a rich source of organic nitrogen that becomes available to plants upon mineralization via soil microbiota [16]. Thus, chicken litter has been suggested as an excellent alternative for N supply and could contribute to sustainable, economically viable, and environmentally friendly N management strategies [17,18]. Based on this, we tested the hypothesis that the use of this litter as a source of ON is as efficient as the application of MN in promoting the growth, nutrition, and yield of sugarcane plants grown in the ratoon and plant cane in the eutrophic, clayey latosol of the midwest region of Brazil. We know that there is an extensive amount of literature dealing with the use of poultry manure and MN in agricultural crops, but we decided to develop this work because few studies are aimed at evaluating sugarcane varieties recommended for eutrophic latosols. In addition, we wanted to solve a local cultivation problem related to the demand for fertilizer.

This approach is regarded as an innovative and promising method for obtaining nitrogen (N) for crops of commercial significance [19,20]. In addition to N, the application of organic waste provides other macronutrients and micronutrients [21–23]. These residues increase soil organic matter, increasing water retention and modifying soil structure and stability [24–27]. Further, chicken litter, a mixture of feathers, feces, urine, feed scraps, and rice straw, is a waste material with considerable polluting potential, and recycling it for use as organic fertilizer is an environmentally friendly and ecologically sustainable solution [28,29].

Considering the potential of organic poultry waste to effectively substitute for nitrogen supply in sugarcane crops, thereby reducing the need for mineral fertilizers and promoting environmental sustainability, our objective was to assess the impact of varying doses of MN and ON on the biometric and nutritional characteristics and productivity of sugarcane. Our findings will aid in improving nitrogen fertilizer management for this crop.

2. Materials and Methods

2.1. Study Area and Experimental Material

The study was conducted in the experimental field of the Denusa Mill, Destilaria Nova União S/A, located at the São Pedro Farm, BR-060, Km 274, Rural zone, Jandaia, GO, Brazil. The municipality is located in the state's southwest region, at the geographical coordinates 17°15′52.6″ S (latitude), 50°08′23.2″ W (longitude), and at 519 m altitude. The region's climate is tropical humid (Aw), according to Köppen [30], characterized by a dry winter and rainy summer, with an average annual temperature of 24.1 °C and average rainfall of 1403 mm year^{-1}. The experiment was conducted during two consecutive crop seasons (plant cane in 2019/2020 and ratoon cane in 2020/2021), with 1556 and 1324 mm of rainfall occurring during the first and second crop seasons, respectively. These measurements were obtained from a rain gauge (iMetos®–model IMT300-USW, Digital Agro, Zagreb, Croatia) that was installed in the experimental field (Figure 1).

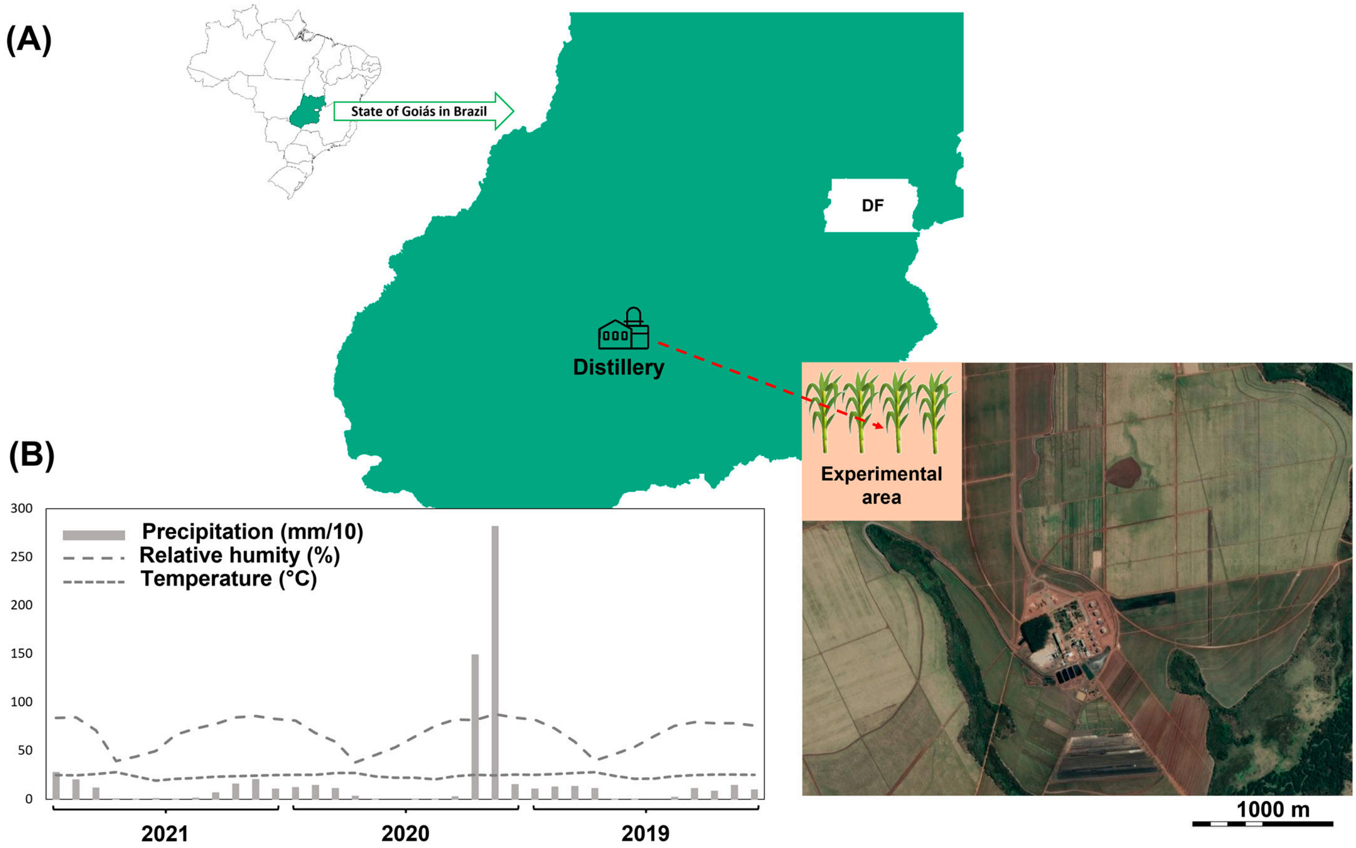

Figure 1. Area used for experimental planting of sugarcane. Area located in the south of the Goiás stage, Brazil (**A**), and the distribution of climate data in the experimental area over the years 2021, 2020, and 2019, including precipitation, humidity, and temperature (**B**).

Soil samples for chemical and physical analysis were obtained at a depth of 0.0–0.20 m (Table 1). These analyses classified the soil as typical eutrophic red latosol [31], with a clayey texture, and the relief had a flat topography.

Table 1. Chemical and physical characteristics observed for the soil cultivated with sugarcane in an experimental area at Denusa Mill, Destilaria Nova União, rural zone of Jandaia municipality, GO, Brazil, at a depth of 0.0–0.2 m.

Ca	Mg	Ca + Mg	Al	H + Al	K		P (Resin)		$CaCl_2$
		cmolc dm^{-3}					mg dm^{-3}		pH
4.14	0.87	5.01	0.0	2.32	0.17		1.60		5.25
Fe	Mn	Cu	Zn	B		CTC [a]	SB [b]	V% [c]	m% [d]
		Micronutrients (mg dm^{-3})				cmolc dm^{-3}		Sat. Bases	Sat. Al
12.64	5.95	3.60	0.81	0.51		7.50	5.18	68.23	0.0
	Clay		M.O. [e]	Ca/Mg	Ca/K	Mg/K	Ca/CTC	Mg/CTC	K/CTC
	(g kg^{-1})		g dm^{-3}			Relationship between bases			
	57.39		27.10	4.75	24.35	5.12	53.95	11.89	2.85

[a] Cation exchange capacity (pH 7.0); [b] base sum; [c] base saturation; [d] aluminum saturation; [e] organic matter.

The sugar cane genotype IACSP95-5094 was used for this study. This medium-cycle genotype was selected owing to its high performance under the soil and climate conditions of this region. Before the installation of the experiment, the soil was prepared by subsoiling, plowing, and harrowing to a depth of 0.40 m. Potassium was applied as potassium chloride (KCl) at a dose of 80 kg ha^{-1} of K_2O, following Sousa and Lobato [32] recommendations; it was applied directly at the time of planting during the plant cane season and 13 months after the first cut in the ratoon cane season.

Each experimental plot was 150 m^2, consisting of ten 10 m-long rows of sugarcane at 1.5 m spacing. A 2 m track was installed between each plot. The crop variety was propagated through vegetative means and planted on 11 June 2019, in furrows of 0.25 m depth. The irrigation method used in this study followed the established practices of the Denusa Mill, wherein only a total depth of 60 mm was applied after plant emergence, using the self-propelled sprinkler technique.

The biometric, nutritional, and yield analyses were conducted at the maturity stage in the six central rows of each plot, disregarding two rows at each end, totaling 90 m^2 per plot (usable area).

2.2. Fertilization Treatments

Fertilization treatments consisted of making N available through an ON or MN source. Five doses of ON were considered, namely 0, 2, 4, 6, and 8 T ha^{-1}, equivalent to 0, 50.8, 101.6, 152.4, and 203.2 kg ha^{-1} of N, respectively, as well as five doses of MN at 0, 40, 80, 120, and 160 kg ha^{-1}, equivalent to 0, 12.8, 25.6, 38.4, and 51.2 kg ha^{-1} of N, respectively. The ON and MN doses were applied directly in the furrow in the 2019/2020 crop season (plant cane), or beside the crop row in the 2020/2021 crop season (ratoon cane). The doses were applied manually and then incorporated into the soil using a shovel.

The ON was provided through chicken litter from a chicken farm in the municipality of Palmeiras de Goiás, GO. We used litter obtained from the first batch of chickens, which was aged and possessed using the following composition (average of applications): 2.54% N, 0.74% P, 0.85% K, 67.32% organic material, 7.58% Ca, 0.91% Mg, 1.52% S, 41.30% C.O, 32.69% mineral material, 0.03 g kg^{-1} g B, 0.28 g kg^{-1} g Zn, 2.50 g kg^{-1} g Fe, 0.52 g kg^{-1} g Mn, 0.34 mg kg^{-1} g Cu, 0.52 g kg^{-1} g Mn, and 17.36% humidity at 105 °C. Conversely, MN was supplied in the form of granules (2–4 mm in size) of ammonium nitrate, containing 32% N.

2.3. Biometric, Nutritional, and Yield Analyses

The height of the plants, number of tillers, average stem diameter, leaf concentration of macro and micronutrients, and yield in tons of stalks per hectare (TSH) were evaluated in each crop season. The height of the plants was measured using a metric tape graduated in centimeters as the distance from the ground surface up to the top visible auricular region of the leaf +1. The number of tillers was counted the day before the plot was cut. The mid-stalk diameter was evaluated using a digital caliper graduated in mm at the base, mid-point, and apex of the sugarcane.

Foliar nutrient analysis was performed six months after planting in the case of plant cane and six months after the first harvest in the case of ratoon. The samples were prepared using 20 cm of the central portion of 15 leaves +3 random leaves. The laboratory analyses were carried out according to the methodology proposed by Malavolta et al. [33], and the levels of the macronutrients N, P, and K were determined.

The cane yield per hectare (CYH) was calculated based on the production of the useful area. The plants were cut at ground level using a John Deere tracked harvester, model 3520, and then transported on a transfer truck equipped with a load cell device attached to a digital scale. Weight was calculated in kg and subsequently converted to tons per hectare (T ha^{-1}).

2.4. Experimental Design and Statistical Analysis

The experiment was designed in randomized blocks. For this, a 5 $\times$ 5 $\times$ 2 sub-subdivided plot scheme with 4 replications was set up. The treatments were five doses of NO (0; 2; 4; 6 and 8 T ha^{-1}) and five doses of NM (0; 40; 80; 120 and 160 kg ha^{-1}), evaluated in two crop seasons ((season 1 (2019/2020) and season 2 (2020/2021)). The data were submitted to analysis of variance (ANOVA), with an F test at the 5% probability level and, in cases of significance, the analysis of regression for NO and NM doses. The effect of the crop harvest, when significant, was compared using Tukey's test ($p < 0.05$). All statistical analyzes were conducted using the SISVAR® software, version 5.6 [34].

3. Results

The application of different doses of MN and ON affected the height of sugarcane plants. There was also an effect of harvest on this variable, as well as an interaction of MN and ON doses with the crop season (Table 2).

Table 2. Summary of the analysis of variance for plant height (HEI), number of tillers (NT), stem diameter (SD), leaf N content (LNC), leaf P content (LPC), leaf K content (LKC), and yield (YIELD) of sugarcane fertilized with different doses of organic nitrogen (ON) and mineral nitrogen (MN) in the sugarcane plant and ratoon cycles.

Source of Variation	DF	MS						
		HEI	NP	SD	LNC	LPC	LKC	YIELD
BLOCK	3	0.087 **	46.826 **	7.965 *	0.072 ns	0.025 ns	0.83 ns	2430.748 **
MN	4	0.028 **	2.474 *	0.225 ns	2.925 ns	0.222 *	1.212 ns	181.309 ns
Residue	12	0.003	0.578	0.64	3.148	0.055	0.603	228.224
CV		2.00	5.93	3.06	9.54	8.22	5.24	10.75
ON	4	0.266 **	5.993 **	0.939 ns	2.872 ns	0.136 **	0.67 ns	1525.515 **
MN × ON	16	0.007 ns	1.483 ns	0.550 ns	5.914 **	0.146 **	1.265 ns	332.138 ns
Residue	12	0.008	0.818	1.09	1.401	0.01	1.441	246.678
CV		3.08	7.05	3.99	6.36	3.50	8.11	11.17
CROP SEASON	1	4.545 **	413.569 **	11.956 **	234.766 **	7.132 **	629.3 **	14,809.205 **
MN × CROP SEASON	4	0.015 ns	2.530 ns	1.423 ns	8.376**	0.184 ns	4.001 **	166.117 ns
ON × CROP SEASON	4	0.029 **	1.364 ns	0.398 ns	0.659 ns	0.082 ns	1.665 ns	591.820 **
ON × ON × CROP SEASON	16	0.005 ns	1.662 ns	0.600 ns	2.117 ns	0.103 ns	0.475 ns	177.177 ns
Residue	123	0.011	1.369	0.897	1.325	0.081	0.707	160.481
CV		3.75	9.12	3.62	6.19	9.96	5.68	9.01

Doses of mineral N (MN) and organic N (ON); crop season (CROP SEASON). Degree of freedom (DF), mean square (MS) and coefficient of variation (CV). ** and * significant at 1 and 5% probability level, respectively; ns, not significant via the F test at 5% probability level.

The height of sugarcane plants as a function of mineral N doses fitted the linear model with R^2 of 69.42% (Figure 2A). The data indicate a 2.27% increase in plant height with the application of 160 kg ha^{-1} of MN compared to that of 0 kg ha^{-1} of MN. The analysis of the distribution of the crop within each level of organic N dose showed that the averages of crop season 1 (2019/2020) for the doses 0, 2, 4, 6, and 8 T ha^{-1} of organic N were 2.83, 2.98, 3.09, 3.06, and 3.053 m, while for crop season 2 (2020/2021) they were 2.61, 2.69, 2.77, 2.71, and 2.718 m, resulting in a decrease of 7.57, 9.69, 10.39, 11.38, and 10.97% of the ratoon cane compared to plant cane, respectively (Figure 2B). The analysis of the distribution of the ON doses within each crop level fitted a quadratic model for both crop seasons, with R^2 of 96.28% for crop season 1 (2019/2020) and 83.08% for season 2 (2020/2021) (Figure 2C). For crop season 1 (2019/2020), the highest plant height was 3.09 m for the dose of 5.6 T ha^{-1} of organic N and the lowest was 2.83 m for the 0 T ha^{-1}; while those for crop season 2 (2020/2021) were 2.75 m for the dose of 5.1 T ha^{-1} and 2.61 m for the 0 T ha^{-1} of organic N.

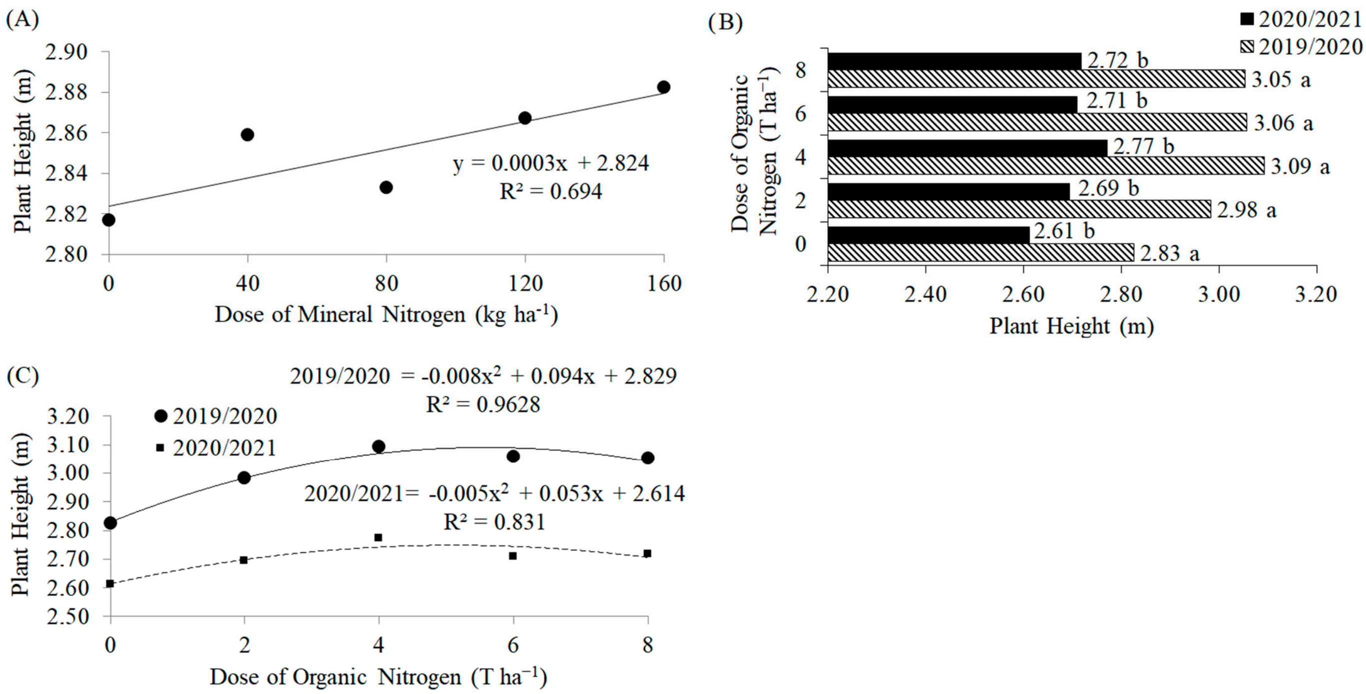

Figure 2. Sugarcane plant height as a function of mineral N doses (**A**), sugarcane plant height as a function of the distribution of crop within each organic N level (**B**), within each dose, bars followed by different letters are statistically different by the Tukey test (5% probability), and plant height as a function of the distribution of organic N within each crop level (**C**).

The number of tillers observed in the different sugarcane crop seasons was affected by the doses of MN and ON. However, it was also influenced by the crop season. The linear model fitted the behavior of tiller number in response to NO doses, with an R^2 of 89.62% (Figure 3A). A difference in the number of tillers of 6.45% was observed when comparing the 8 T ha^{-1} dose of ON with the 0 T ha^{-1} dose. The effect of the MN doses was observed to exhibit a quadratic model fit with R^2 of 91.86%, i.e., only 8.14% of the tiller number variations are not explained by MN dose variations (Figure 3B). The lowest number of tillers for MN was 12.45 observed for the 0 kg ha^{-1} dose, while the highest was 13.05 observed at the 90 kg ha^{-1} dose. For the single factor crop season, it was observed that in crop season 1 (2019/2020), the plants developed the lowest number of tillers, while in crop season 2 (2020/2021), they developed the highest number (11.39 and 14.26, respectively) (Figure 3C). However, stalk diameter was affected only by crop season, with crop season 2 (2020/2021) resulting in higher diameters (26.39 mm) compared to crop season 1 (25.90 mm) (Figure 3D).

The nitrogen (N) content in leaves was influenced by the combined effects of MN and ON doses, the crop season, as well as the interaction between ON and crop season. In the analysis of the distribution of MN doses within each level of ON doses (Figure 4A), the leaf N content of sugarcane plants as a function of the 0 T ha^{-1} dose of ON for all MN doses fitted the quadratic distribution model, with an average R^2 of 83.86%. The lowest leaf N content was found at the 0 kg ha^{-1} MN dose (16.97 g kg^{-1} g), while the dose that provided the highest N content (19.29 g kg^{-1} g) was 108 kg ha^{-1} MN per the regression equation. The ON doses of 2, 4, 6, and 8 T ha^{-1} did not fit any model and provided means of 18.47, 18.36, 18.58, and 19.01 g kg^{-1} of N. The analysis of the distribution of ON dose within each level of MN dose (Figure 4B) indicated that the foliar N content when plotted as a function of the ON doses for the 0 kg ha^{-1} MN dose fitted the quadratic model with an R^2 of 99.05%. There were increases of 8.71, 3.50, 4.85, and 3.17% in leaf N content for each increase of 2 T ha^{-1} of ON. The increasing doses of 2, 4, 6, and 8 T ha^{-1} of ON, did not fit any model and exhibited N content averages of 18.24, 18.43, 18.82, and 18.64 g kg^{-1}.

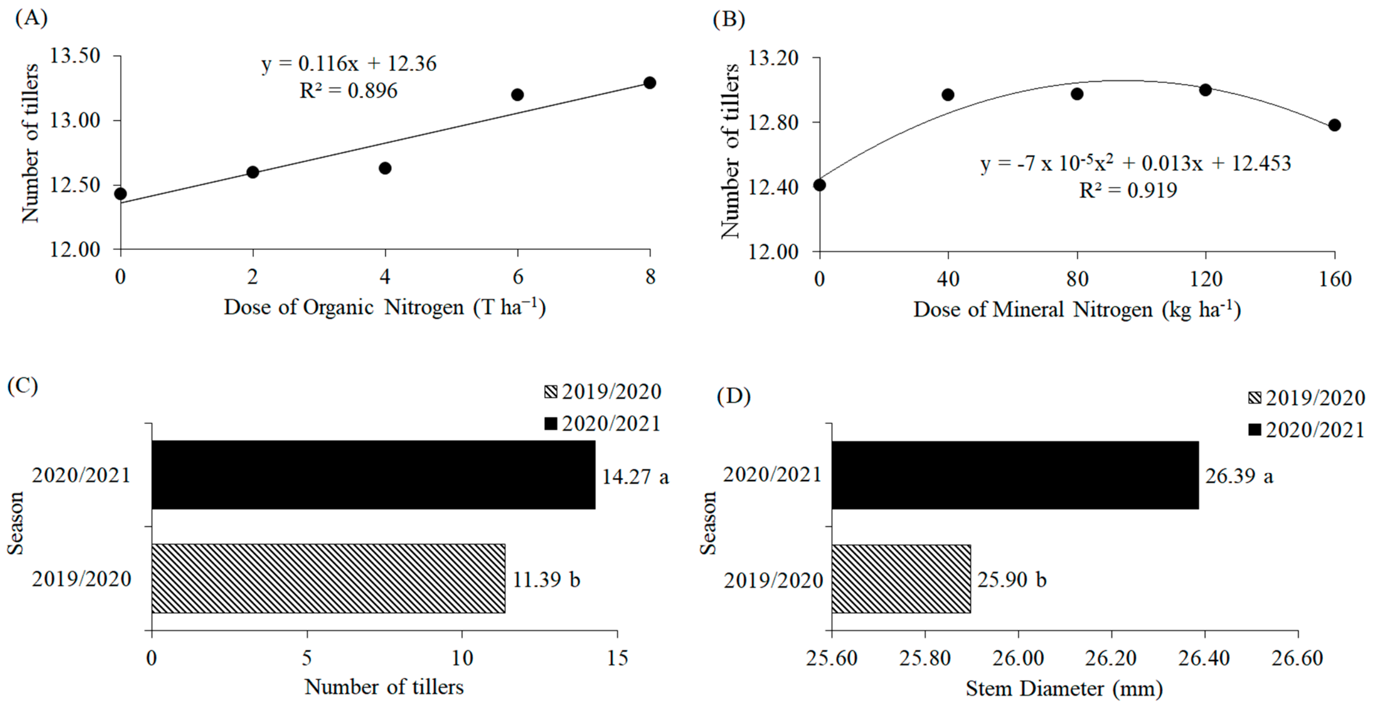

Figure 3. Number of sugarcane tillers as a function of organic N dose (**A**) and mineral N dose (**B**), number of tillers as a function of crop season (**C**) and sugarcane stem diameter as a function of crop season (**D**). In (**C**,**D**), between stations, bars followed by different letters are statistically different by the Tukey test (5% probability).

The analysis of the distribution of MN doses within each crop level showed that plants in crop season 2 (2020/2021) accumulated more foliar N than plants in crop season 1 (2019/2020) for the MN doses of 0, 40, 80, 120, and 160 kg ha^{-1}, with increments of 7.34, 6.31, 16.83, 13.70, and 10.43%, respectively (Figure 4C). The regression as a function of MN doses within each crop season displayed an R^2 of 78.6% for crop season 1 (2019/2020), where the highest value observed was 18.23 g kg^{-1} for the 0 kg ha^{-1} MN dose and the lowest value was 16.63 g kg^{-1} for the 126 kg ha^{-1} MN dose (Figure 4D). Crop season 2 (2020/2021) did not fit the model and averaged 19.689 g kg^{-1} g N content.

Foliar P content was affected individually by the MN and ON doses, the interaction between MN and ON doses, and the crop season. However, an effect in the distribution of MN doses within each level of ON doses (Figure 4E) was observed only for the 6 T ha^{-1} dose of ON, and a quadratic model was fitted for the distribution of leaf P content, with an R^2 of 88.79%. At this dose, the highest average leaf P was observed in the sugarcane plants treated with 160 kg ha^{-1} MN (3.02 g kg^{-1} g). An effect was observed within each MN level when ON doses were distributed, except for the 0 kg ha^{-1} MN dose (Figure 4F). For the 40 kg ha^{-1} dose of this mineral, the distribution behavior was linear (R^2 = 77.49%), with the highest leaf P concentration observed in plants grown with 6 T ha^{-1} of NO (3.06 g kg^{-1} g). At the 80 kg ha^{-1} dose, the highest leaf P concentration was observed in plants grown with 0 T ha^{-1} of ON (3.10 g kg^{-1} g, R^2 = 85,83%). At doses of 120 and 160 kg ha^{-1} of MN, the highest leaf P averages were observed at 4 and 6 T ha^{-1} of ON, respectively (2.88, R^2 = 88.43% and 3.02 g kg^{-1} g, R^2 = 92.18%).

When the influence of the single factor, i.e., crop season, on leaf P was evaluated, it was observed that the plants accumulated more phosphorus in the leaves (3.07 g kg^{-1} g) in crop season 1 (2019/2020) (Figure 5A). However, foliar K was affected by the crop season and the interaction of MN doses and crop season, and for crop season 2 (2020/2021), a quadratic behavior was observed in the data (R^2 = 61.78%), with the highest concentrations of foliar K observed in plants treated with 40 kg ha^{-1} of MN (13.58 g kg^{-1} g) (Figure 5B). When the crop season factor was distributed within each MN level, the highest leaf K averages were always observed in crop season 1 (2019/2020), being 16.43, 16.73, 17.14, 16.74, and 17.24 g kg^{-1} g, for increasing doses of MN. Thus, the highest overall average leaf K was observed in the plant cane crop (16.85 g kg^{-1} g) (Figure 5C,D).

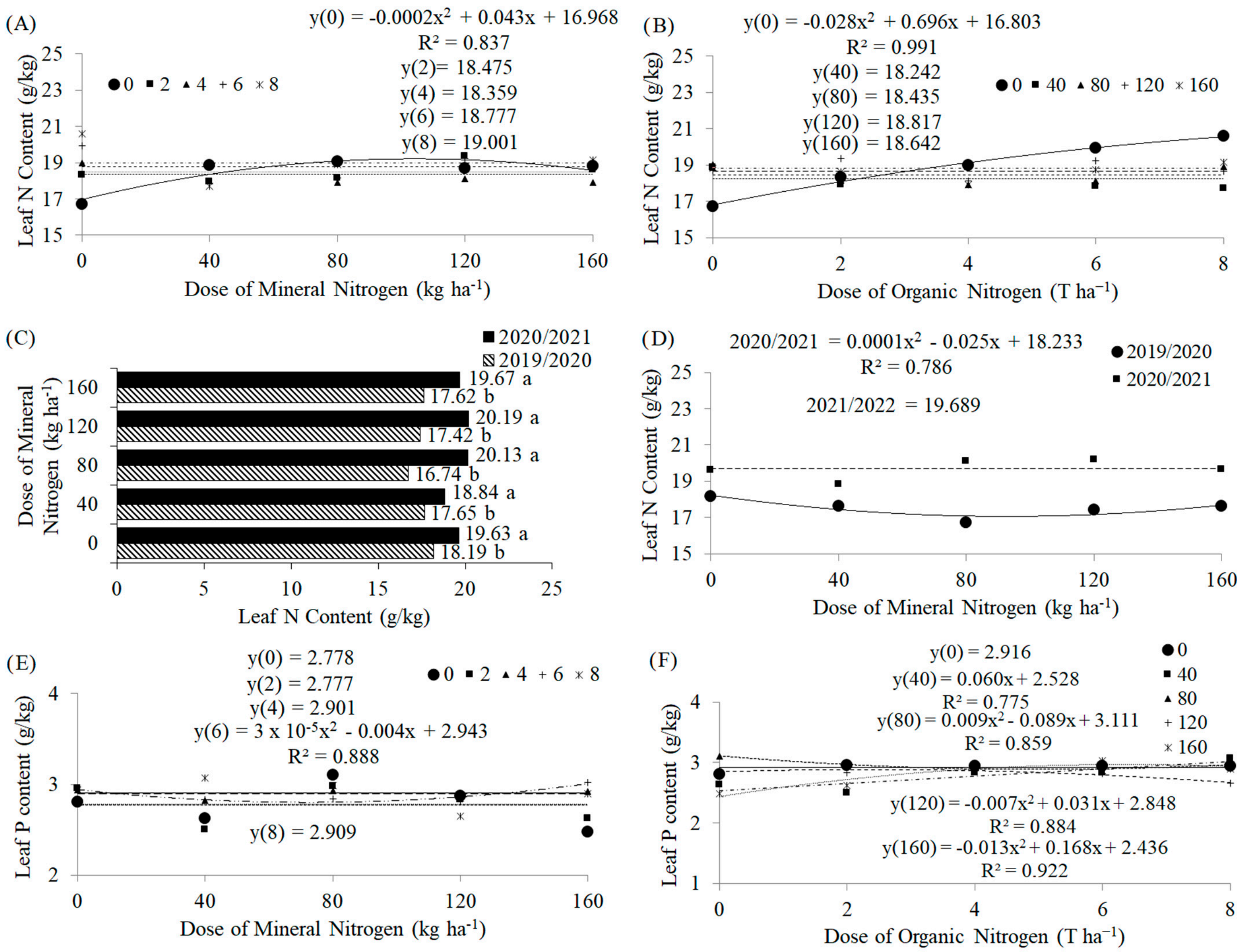

Figure 4. Foliar N content of sugarcane as a function of the interaction of doses of mineral N (MN) x doses of organic N (ON) (**A**), as a function of the interaction of ON × MN (**B**), as a function of the distribution of the crop seasons within each dose of MN (**C**) (within each dose, bars followed by different letters are statistically different by the Tukey test (5% probability)), as a function of the distribution of MN doses within each crop (**D**), foliar P content of sugarcane as a function of the interaction of MN × ON doses, with MN doses distributed at each ON level (**E**) and ON doses distributed at each MN level (**F**).

Sugarcane yield was significantly affected by the interaction of ON doses and crop season. The analysis of crop yield within each level of ON doses (Figure 5E) shows that the highest averages occurred in crop season 2 plants (2020/2021) with those for the doses 0, 2, 4, 6, and 8 T ha^{-1} of ON, being 143.87, 155.31, 150.55, 147.29, and 148.88 T ha^{-1}, respectively. For crop season 1 (2020/2021), the lowest average yields were observed for ratoon cane; 116.62, 133.42, 141.25, 137.25, and 131.32 T ha^{-1}, corresponding to an increase in 18.94, 14.09, 6.18, 6.82, and 11.80, respectively, in the ratoon cane crop compared to plant cane. For the distribution of crop season within each ON level, a quadratic model was fitted for crop season 1 (2019/2020, with R^2 of 97.93%). The equation shows that the highest yield (140.83 T ha^{-1}) was obtained with the 4.8 T ha^{-1} dose of ON, whereas the lowest yield

(117.14 T ha^{-1}) was obtained at the 0 T ha^{-1} dose (Figure 5F). The yield of crop season 2 (2020/2021) did not fit any statistical model, averaging 149.18 T ha^{-1}.

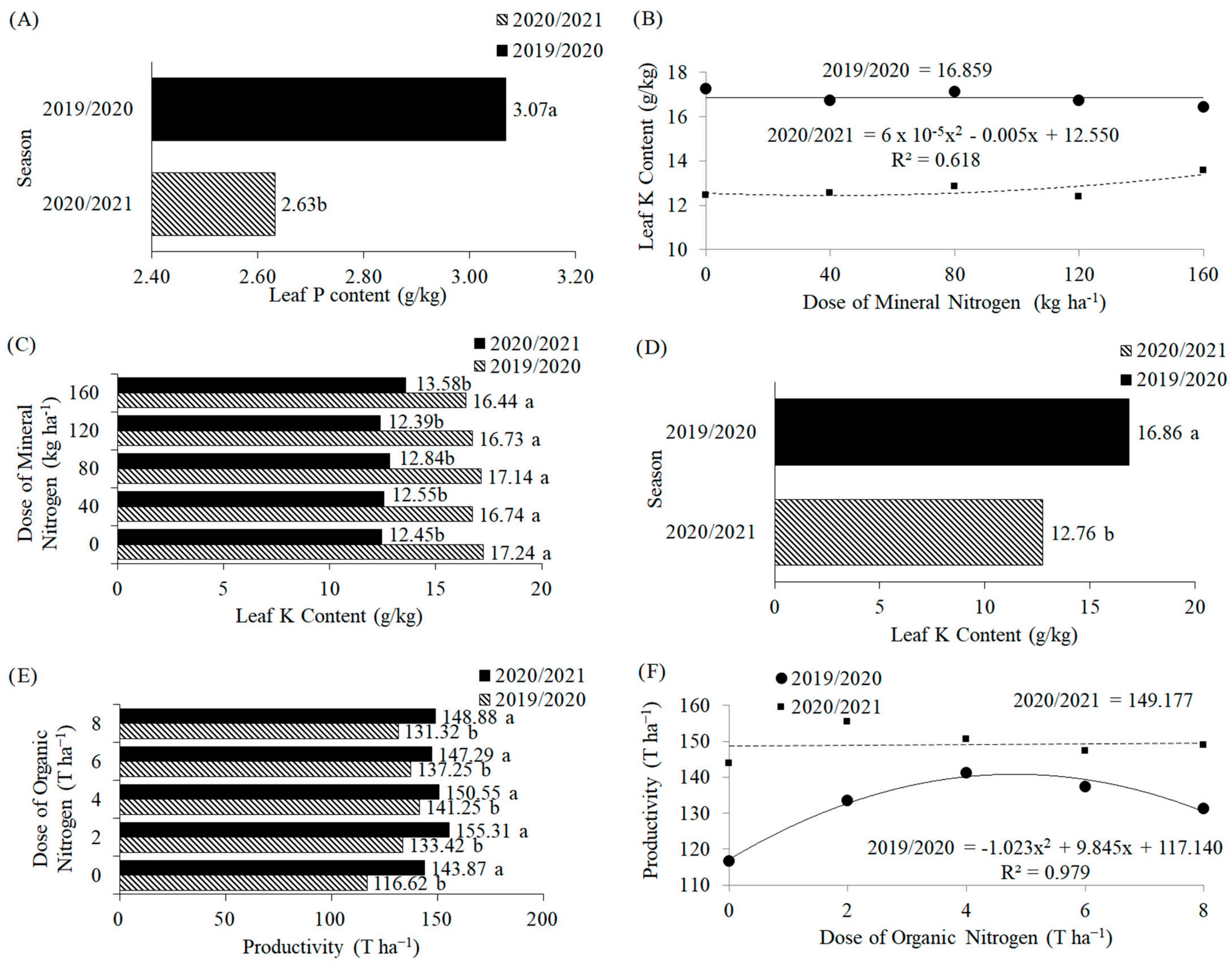

Figure 5. P foliar content of sugarcane as a function of crop season (**A**), K foliar content as a function of the distribution of MN doses within each crop season (**B**), K foliar content as a function of the distribution of crop seasons within each MN dose (**C**), K foliar content of sugarcane as a function of crop season (**D**), yield of sugarcane as a function of the distribution of the crop seasons within each dose of ON (**E**) and as a function of the distribution of the doses of ON within each crop season (**F**). In (**A**,**D**) between stations and in (**C**,**E**) within each dose, bars followed by different letters are statistically different by the Tukey test (5% probability).

4. Discussion

4.1. Application of Different Doses of MN or ON Affects the Growth of Sugarcane Plants

Sugarcane plant height increased linearly with increasing MN doses, regardless of the crop season evaluated. This indicates that despite the volatility, ammonium compounds are a significant mode of absorbing N by this crop [6]. Sugarcane defines its potential yield in the early stages of growth [35], which results in vigorous plants and consequently determines the yield of ratoon cane. These factors explain the importance of MN fertilization for crop growth. Alternatively, plants subjected to ON reached average heights of 3.09 m at the dose of 5.6 T ha^{-1} in crop season 1 (2019/2020). This yield is directly due to the mineralization of these organic residues, which makes N available to the soil and contributes to the improvement of biometric parameters [21,22,36,37].

Sugarcane exhibits a positive response to ON treatment by increasing the number of tillers, which is comparable to the response observed after MN treatment up to a dose of 90 kg ha^{-1}. Responses to N in tiller production can be explained physiologically by changes in plant growth and biomass production, as N is responsible for chlorophyll formation [38], protein metabolism [39,40], and root growth [35,41]. Aside from N from organic matter, other factors can affect the response of sugarcane to N fertilization, such as soil preparation and texture, land use, and management history, among others [3,42–44].

Unexpectedly, the doses of MN and ON did not affect the diameter of the sugarcane plant cane stalk but the diameter was affected by crop season. The plants in crop season 2 (2020/2021) exhibited a larger diameter than those sampled in crop season 1 (2019/2020). Thus, low and maximum N doses do not affect this yield characteristic of sugarcane.

4.2. MN and ON Increase the Leaf N Content of Sugarcane Plants Similarly, and the Lack of One Is Compensated for by the Effect of the Other

There was a correlation between different doses of MN and ON with the leaf N content observed in the plants. However, the best dose of MN to increase leaf N was 108 kg ha^{-1} when the dose of ON was 0 T ha^{-1}, which resulted in an N content of 19.29 g kg^{-1}. Conversely, the best dose of ON to increase leaf N was 8 T ha^{-1}, when the mineral N dose was 0 kg ha^{-1}, which resulted in a N content of 20.562 g kg^{-1}. Thus, in the absence of ON, plants were efficiently stimulated to utilize N made available in the mineral form, and in the absence of MN, they were stimulated to utilize N made available in the organic form. This is because different N sources stimulate specific metabolic pathways. Ammonium nitrate, when applied to soil in the presence of oxygen and water, forms nitrates, oxygen, and water. This is due to the action of *Nitrosomonas* and *Nitrosococcus* bacteria, which convert ammonia (NH_3) to nitrite (NO_2^-) and *Nitrobacter*, which convert nitrite (NO_2^-) to nitrate (NO_3^-) [45–47]. These bacteria are important components of the MN metabolism. In contrast, chicken litter, rich in ON, undergoes mineralization processes in the soil, making this N available to plants [16]. The mineralization of ON consists of an enzymatic process associated with the soil microbial biomass, which transforms it into inorganic, plant-available forms [48,49]. Thus, the establishment of specific microbiota in the rhizosphere can influence the availability of N from different sources.

Fertilization with ON and MN also influenced the accumulation of P and K in the leaves of sugarcane plants. This is due to the high availability of one nutrient in the soil-plant system impacting the uptake of another. High concentrations of N in the leaf tissues, provided by fertilization, may require the plant to take up more P and K to ensure total growth. Notably, it was observed that plants from crop season 1 that accumulated more P and K exhibited better growth. However, this growth and nutrient allocation did not result in higher average yields.

4.3. Sugarcane Plants Subjected to MN or ON Fertilization Grew More and Accumulated More P and K in Crop Season 1 (2019/2020), but Those Treated with ON Had Higher Yields in Crop Season 2 (2020/2021)

Although applying MN and ON increased plant height and leaf N content, ON also increased crop yield. Studies show that ON affects nutrition and the chemical and physical characteristics of the soil [50,51], consequently resulting in improved sugarcane yield. When applied along with MN, ON helps to reduce N losses by ammonia volatilization. Further, chicken litter also aids in increasing the amount of organic matter in the soil over time by stimulating the N-mineralization processes [52–54].

We also observed an interaction effect between the different doses of MN and the evaluated crop seasons on the leaf N content, with the highest levels always observed in crop season 2 (2020/2021), regardless of the MN dose. In contrast, for the different ON doses, the yield was consistently higher in plants sampled in crop season 2 (2020/2021). Thus, in crop season 2, the ON-treated plants grew less and accumulated less P and K, but tillered more, had increased stalk diameter, and had higher yields. N uptake may have been facilitated by the abiotic growing conditions observed in this crop season, confirmed by the higher N content observed in the leaves. In crop season 1 (2019/2020), the occurrence of atypical rainfall may have caused the leaching of the applied N. Losses by leaching can reach $\geq$50% of applied N, making it one of the primary mechanisms of N losses in agricultural systems [55,56].

However, during crop season 2 (2020/2021), sugarcane yield was not affected by the dosage of ON. This could be attributed to the effect of applying ON in the row crop, which was associated with a low occurrence of rain during that period. As a result, losses due to volatilization occurred during the ratoon cane crop. The observed increase in yield and tillering can also be explained by the characteristics of the sugarcane cultivar IACSP95-5094, which is known for its ability to regrow, increasing the number of tillers in the second cut and, consequently, the yield, compared to the plant cane [57,58]. The yield is directly associated with increased tillering and cane diameter, which are promoted by higher N uptake. N is closely related to plant growth and development, affecting cell regulation and metabolism [59]. Different rates of N application can affect the activities of crucial nitrogen assimilation enzymes in sugarcane [35,59]. The activity of N assimilation enzymes significantly affects the metabolic rate of N, leading to increased yield. The activities of the key N assimilation and metabolism enzymes, including glutamine synthetase (GS), glutamate synthetase (GOGAT), and glutamate dehydrogenase (GDH), reflect the strength of N assimilation and improve yield [59,60].

In addition to the crop season effect, the application of MN or ON positively affected the growth of sugarcane plants, with ON supply up to 4.8 T ha^{-1} increasing yield. The application of MN and ON during the critical period of crop demand can increase fertilizer efficiency and improve N supply. Chicken litter, a low-cost agricultural waste, can be used as an alternative to conventional nitrogen fertilizers; it not only enhances the uptake of nitrogen by plants but also improves sugarcane yield.

5. Conclusions

The hypothesis that the application of ON to the sugarcane crop supplied through chicken litter is as efficient as the application of MN in promoting plant growth was confirmed. The application of ON up to a dose of 4.8 T ha^{-1} increased crop yield. This study provides evidence that chicken litter can be utilized as a cost-effective alternative for the fertilization of sugarcane in eutrophic soils in the central-west region of Brazil. This work will contribute to the solution of a local problem, characterized by the low availability of nitrogen sources destined for the fertilization of the sugarcane crop, increasing the list of sustainable agricultural practices in the region. Additionally, it highlights the superior regrowth properties of the cultivar IACSP95-5094, which leads to increased tillering and larger cane diameters, ultimately resulting in a higher yield of ratoon cane.

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References

1. Bhatt, R. Resources management for sustainable sugarcane production. In *Resources Use Efficiency in Agriculture*; Kumar, S., Meena, R.S., Jhariya, M.K., Eds.; Springer: Singapore, 2020; pp. 647–693. [CrossRef]
2. Xu, F.; Wang, Z.; Lu, G.; Zeng, R.; Que, Y. Sugarcane ratooning ability: Research status, shortcomings, and prospects. *Biology* **2021**, *10*, 1052. [CrossRef] [PubMed]
3. Bordonal, R.D.O.; Carvalho, J.L.N.; Lal, R.; de Figueiredo, E.B.; de Oliveira, B.G.; La Scala, N. Sustainability of sugarcane production in Brazil. A review. *Agron. Sustain. Dev.* **2018**, *38*, 13. [CrossRef]
4. Ferreira Gomes, F.H.; Soares, F.A.L.; Teixeira, M.B.; Sousa, A.E.C.; da Silva, E.C.; Vidal, V.M.; Bastos, A.V.S.; Silva, N.F.; Cunha, F.N.; Morais, W.A.; et al. Sources and doses of nitrogen in plant cane production and residual effect on the first ratoon of sugarcane in a savannah Red Oxisol. *Aust. J. Crop Sci.* **2021**, *15*, 708–715. [CrossRef]
5. Kumar, N.; Kumar, V. Production potential and nitrogen fractionation of sugarcane-based cropping system as influenced by planting materials and nitrogen nutrition. *Sugar Tech* **2020**, *22*, 622–629. [CrossRef]
6. Robinson, N.; Brackin, R.; Vinall, K.; Soper, F.; Holst, J.; Gamage, H.; Paungfoo-Lonhienne, C.; Rennenberg, H.; Lakshmanan, P.; Schmidt, S. Nitrate paradigm does not hold up for sugarcane. *PLoS ONE* **2011**, *6*, e19045. [CrossRef]
7. Xu, A.; Li, L.; Xie, J.; Wang, X.; Coulter, J.A.; Liu, C.; Wang, L. Effect of long-term nitrogen addition on wheat yield, nitrogen use efficiency, and residual soil nitrate in a semiarid area of the loess plateau of China. *Sustainability* **2020**, *12*, 1735. [CrossRef]
8. Dougherty, W.J.; Collins, D.; Van Zwieten, L.; Rowlings, D.W. Nitrification (DMPP) and urease (NBPT) inhibitors had no effect on pasture yield, nitrous oxide emissions, or nitrate leaching under irrigation in a hot-dry climate. *Soil Res.* **2016**, *54*, 675–683. [CrossRef]
9. Fagodiya, R.K.; Kumar, A.; Kumari, S.; Medhi, K.; Shabnam, A.A. Role of nitrogen and its agricultural management in changing environment. In *Contaminants in Agriculture: Sources, Impacts and Management*; Naeem, M., Ansari, A.A., Gill, S.S., Eds.; Springer: Cham, Switzerland, 2020; pp. 247–270. [CrossRef]
10. Corcioli, G.; Medina, G.D.S.; Arrais, C.A. Missing the target: Brazil's agricultural policy indirectly subsidizes foreign investments to the detriment of smallholder farmers and local agribusiness. *Front. Sustain. Food Syst.* **2022**, *5*, 796845. [CrossRef]
11. Da Silva Medina, G.; Pokorny, B. Agro-industrial development: Lessons from Brazil. *Land Use Policy* **2022**, *120*, 106266. [CrossRef]
12. Randive, K.; Raut, T.; Jawadand, S. An overview of the global fertilizer trends and India's position in 2020. *Miner. Econ.* **2021**, *34*, 371–384. [CrossRef]
13. Liu, Z.; Ying, H.; Chen, M.; Bai, J.; Xue, Y.; Yin, Y.; Batchelor, W.D.; Yang, Y.; Bai, Z.; Du, M.; et al. Optimization of China's maize and soy production can ensure feed sufficiency at lower nitrogen and carbon footprints. *Nat. Food* **2021**, *2*, 426–433. [CrossRef]
14. Da Silva Mendes, J.; Fernandes, J.D.; Chaves, L.H.G.; Guerra, H.O.C.; Tito, G.A.; de Brito Chaves, I. Chemical and physical changes of soil amended with biochar. *Water Air Soil Pollut.* **2021**, *232*, 338. [CrossRef]
15. Lucena, N.T.; Santos, E.M.; Oliveira, J.S.; Perazzo, A.F.; Cruz, G.F.; Pereira, D.M.; Pereira, G.A.; Macêdo, A.J.S.; Ramos, R.C.S.; Nogueira, M.S. Agronomic traits and chemical composition of forage sorghum plants fertilized with poultry litter and fermentative profile of silages. *Chil. J. Agric. Res.* **2021**, *81*, 575–584. [CrossRef]
16. Briedis, C.; de Moraes Sá, J.C.; Ferreira, A.O.; Ramos, F.S. Efeito primário e residual de resíduos orgânicos de abatedouro de aves e suínos na produtividade do trigo. *Rev. Verde* **2011**, *6*, 221–226.
17. Bolan, N.S.; Szogi, A.A.; Chuasavathi, T.; Seshadri, B.; Rothrock, M.J.; Panneerselvam, P. Uses and management of poultry litter. *World Poult. Sci. J.* **2010**, *66*, 673–698. [CrossRef]
18. Hirzel, J.; Matus, I.; Novoa, F.; Walter, I. Effect of poultry litter on silage maize (*Zea mays* L.) production and nutrient uptake. *Span. J. Agric. Res.* **2007**, *5*, 102–109. [CrossRef]
19. Bryant, R.B.; Endale, D.M.; Spiegal, S.A.; Flynn, K.C.; Meinen, R.J.; Cavigelli, M.A.; Kleinman, P.J. Poultry manureshed management: Opportunities and challenges for a vertically integrated industry. *J. Environ. Qual.* **2022**, *51*, 540–551. [CrossRef]
20. Tao, Y.; Liu, T.; Wu, J.; Wu, Z.; Liao, D.; Shah, F.; Wu, W. Effect of combined application of chicken manure and inorganic nitrogen fertilizer on yield and quality of cherry tomato. *Agronomy* **2022**, *12*, 1574. [CrossRef]
21. Bhatnagar, N.; Ryan, D.; Murphy, R.; Enright, A.M. A comprehensive review of green policy, anaerobic digestion of animal manure and chicken litter feedstock potential–Global and Irish perspective. *Renew. Sustain. Energy Rev.* **2022**, *154*, 111884. [CrossRef]
22. Izydorczyk, G.; Mikula, K.; Skrzypczak, D.; Witek-Krowiak, A.; Mironiuk, M.; Furman, K.; Gramza, M.; Moustakas, K.; Chojnacka, K. Valorization of poultry slaughterhouse waste for fertilizer purposes as an alternative for thermal utilization methods. *J. Hazard. Mater.* **2022**, *424*, 127328. [CrossRef]
23. Mbatha, K.C.; Mchunu, C.N.; Mavengahama, S.; Ntuli, N.R. Effect of poultry and goat manures on the nutrient content of Sesamum alatum leafy vegetables. *Appl. Sci.* **2021**, *11*, 11933. [CrossRef]
24. Adeyemo, A.J.; Akingbola, O.O.; Ojeniyi, S.O. Effects of poultry manure on soil infiltration, organic matter contents and maize performance on two contrasting degraded alfisols in southwestern Nigeria. *Int. J. Recycl. Org. Waste Agric.* **2019**, *8*, 73–80. [CrossRef]

25. De Melo, T.R.; Figueiredo, A.; Machado, W.; Tavares Filho, J. Changes on soil structural stability after in natura and composted chicken manure application. *Int. J. Recycl. Org. Waste Agric.* **2019**, *8*, 333–338. [CrossRef]
26. Feng, G.; Adeli, A.; Read, J.; McCarty, J.; Jenkins, J. Consequences of pelletized poultry litter applications on soil physical and hydraulic properties in reduced tillage, continuous cotton system. *Soil Tillage Res.* **2019**, *194*, 104309. [CrossRef]
27. Mau, V.; Arye, G.; Gross, A. Poultry litter hydrochar as an amendment for sandy soils. *J. Environ. Manag.* **2020**, *271*, 110959. [CrossRef]
28. Antonious, G.F. Biochar and animal manure impact on soil, crop yield and quality. In *Agricultural Waste and Residues*; Aladjadjiyan, A., Ed.; IntechOpen Limited: London, UK, 2018; pp. 45–67. [CrossRef]
29. Gerber, P.F.; Gould, N.; McGahan, E. Potential contaminants and hazards in alternative chicken bedding materials and proposed guidance levels: A review. *Poult. Sci.* **2020**, *99*, 6664–6684. [CrossRef]
30. Köppen, W.; Geiger, R. *Klimate der Erde*; Verlag Justus Perthes: Gotha, Germany, 1928.
31. Santos, H.G.; Jacomine, P.K.T.; Anjos, L.H.C.; Oliveira, V.A.; Lumbreras, J.F.; Coelho, M.R.; Almeida, J.A.; Cunha, T.J.F.; Oliveira, J.B. Sistema brasileiro de classificação de solos. In *Centro Nacional de Pesquisa de Solos*, 5th ed.; Embrapa Solos: Brasília, Brazil, 2018; p. 588.
32. Sousa, D.M.G.; Lobato, E. *Cerrado: Correção do Solo e adubação*, 2nd ed.; Embrapa Informação Tecnológica/Embrapa-CPA: Brasília, Brazil, 2004; p. 416.
33. Malavolta, E.; Vitti, G.C.; Oliveira, S.A.D. *Avaliação do Estado Nutricional das Plantas: Princípios e Aplicações*; Potafos: Piracicaba, Brazil, 1997; p. 319.
34. Ferreira, D.F. Sisvar: A computer statistical analysis system. *Ciênc. Agrotec.* **2011**, *35*, 1039–1042. [CrossRef]
35. Boschiero, B.N.; Mariano, E.; Azevedo, R.A.; Trivelin, P.C.O. Influence of nitrate-ammonium ratio on the growth, nutrition, and metabolism of sugarcane. *Plant Physiol. Biochem.* **2019**, *139*, 246–255. [CrossRef]
36. Erhunmwunse, A.S.; Olayinka, A.; Atoloye, I.A. Nutrient mineralization from nitrogen-and phosphorus-enriched poultry manure compost in an ultisol. *Commun. Soil Sci. Plant Anal.* **2019**, *50*, 185–197. [CrossRef]
37. Farni, Y.; Prijono, S.; Suntari, R.; Handayanto, E. Pattern of N mineralization and nutrient uptake of *Tithonia diversifolia* and *Saccharum officinarum* leaves in sandy loam soil. *Indian J. Agric. Res.* **2022**, *56*, 65–69. [CrossRef]
38. Bassi, D.; Menossi, M.; Mattiello, L. Nitrogen supply influences photosynthesis establishment along the sugarcane leaf. *Sci. Rep.* **2018**, *8*, 2327. [CrossRef]
39. Lian, L.; Lin, Y.; Wei, Y.; He, W.; Cai, Q.; Huang, W.; Zheng, Y.; Xu, H.; Wang, F.; Zhu, Y.; et al. PEPC of sugarcane regulated glutathione S-transferase and altered carbon–nitrogen metabolism under different N source concentrations in Oryza sativa. *BMC Plant Biol.* **2021**, *21*, 287. [CrossRef]
40. Yang, Y.; Gao, S.; Su, Y.; Lin, Z.; Guo, J.; Li, M.; Wang, Z.; Que, Y.; Xu, L. Transcripts and low nitrogen tolerance: Regulatory and metabolic pathways in sugarcane under low nitrogen stress. *Environ. Exp. Bot.* **2019**, *163*, 97–111. [CrossRef]
41. Quassi de Castro, S.G.; Graziano Magalhães, P.S.; Coutinho Junqueira Franco, H.; Mutton, M.Â. Harvesting Systems, Soil Cultivation, and Nitrogen Rate Associated with Sugarcane Yield. *Bioenerg. Res.* **2018**, *11*, 583–591. [CrossRef]
42. Lourenço, K.S.; Rossetto, R.; Vitti, A.C.; Montezano, Z.F.; Soares, J.R.; de Melo Sousa, R.; Carmo, J.B.; Kuramae, E.E.; Cantarella, H. Strategies to mitigate the nitrous oxide emissions from nitrogen fertilizer applied with organic fertilizers in sugarcane. *Sci. Total Environ.* **2019**, *650*, 1476–1486. [CrossRef]
43. Otto, R.; Mariano, E.; Mulvaney, R.L.; Khan, S.A.; Boschiero, B.N.; Tenelli, S.; Trivelin, P.C.O. Effect of previous soil management on sugarcane response to nitrogen fertilization. *Sci. Agric.* **2019**, *76*, 72–81. [CrossRef]
44. Santos, R.L.D.; Freire, F.J.; Oliveira, E.C.A.D.; Freire, M.B.G.D.S.; West, J.B.; Barbosa, J.D.A.; Moura, M.J.A.; Bezerra, P.D.C. Nitrate reductase activity and nitrogen and biomass accumulation in sugarcane under molybdenum and nitrogen fertilization. *Rev. Bras. Ciênc. Solo* **2019**, *43*, e0180171. [CrossRef]
45. Gee, C.S.; Pfeffer, J.T.; Suidan, M.T. Nitrosomonas and Nitrobacter interactions in biological nitrification. *J. Environ. Eng.* **1990**, *116*, 4–17. [CrossRef]
46. Ma, S.; Zhang, D.; Zhang, W.; Wang, Y. Ammonia stimulates growth and nitrite-oxidizing activity of Nitrobacter winogradskyi. *Biotechnol. Equip.* **2014**, *28*, 27–32. [CrossRef]
47. Fumasoli, A.; Bürgmann, H.; Weissbrodt, D.G.; Wells, G.F.; Beck, K.; Mohn, J.; Morgenroth, E.; Udert, K.M. Growth of Nitrosococcus-related ammonia oxidizing bacteria coincides with extremely low pH values in wastewater with high ammonia content. *Environ. Sci. Technol.* **2017**, *51*, 6857–6866. [CrossRef]
48. Schimel, J.P.; Bennett, J. Nitrogen mineralization: Challenges of a changing paradigm. *Ecology* **2004**, *85*, 591–602. [CrossRef]
49. Li, Z.; Tian, D.; Wang, B.; Wang, J.; Wang, S.; Chen, H.Y.; Xu, X.; Wang, C.; He, N.; Niu, S. Microbes drive global soil nitrogen mineralization and availability. *Glob. Chang. Biol.* **2019**, *25*, 1078–1088. [CrossRef] [PubMed]
50. Tauqeer, H.M.; Turan, V.; Farhad, M.; Iqbal, M. Sustainable agriculture and plant production by virtue of biochar in the era of climate change. In *Managing Plant Production Under Changing Environment*; Hasanuzzaman, M., Ahammed, G.J., Nahar, K., Eds.; Springer: Singapore, 2022; pp. 21–42. [CrossRef]
51. Uddin, S.; Williams, S.W.; Aslam, N.; Fang, Y.; Parvin, S.; Rust, J.; Zwieten, L.V.; Armstrong, R.; Tavakkoli, E. Ameliorating alkaline dispersive subsoils with organic amendments: Are productivity responses due to nutrition or improved soil structure? *Plant Soil* **2022**, *480*, 227–244. [CrossRef]

52. Ashworth, A.J.; Chastain, J.P.; Moore, P.A., Jr. Nutrient characteristics of poultry manure and litter. In *Animal Manure: Production, Characteristics, Environmental Concerns, and Management*; Waldrip, H.M., Pagliari, P.H., He, Z., Eds.; Springer: Singapore, 2020; pp. 63–87. [CrossRef]
53. Hoang, H.G.; Thuy, B.T.P.; Lin, C.; Vo, D.V.N.; Tran, H.T.; Bahari, M.B.; Vu, C.T. The nitrogen cycle and mitigation strategies for nitrogen loss during organic waste composting: A review. *Chemosphere* **2022**, *300*, 134514. [CrossRef] [PubMed]
54. Li, Y.; Ma, J.; Yong, X.; Luo, L.; Wong, J.W.; Zhang, Y.; Wu, H.; Zhou, J. Effect of biochar combined with a biotrickling filter on deodorization, nitrogen retention, and microbial community succession during chicken manure composting. *Bioresour. Technol.* **2022**, *343*, 126137. [CrossRef]
55. Christie, K.M.; Smith, A.P.; Rawnsley, R.P.; Harrison, M.T.; Eckard, R.J. Simulated seasonal responses of grazed dairy pastures to nitrogen fertilizer in SE Australia: N loss and recovery. *Agric. Syst.* **2020**, *182*, 102847. [CrossRef]
56. Musyoka, M.W.; Adamtey, N.; Muriuki, A.W.; Bautze, D.; Karanja, E.N.; Mucheru-Muna, M.; Fiaboe, K.K.M.; Cadisch, G. Nitrogen leaching losses and balances in conventional and organic farming systems in Kenya. *Nutr. Cycl. Agroecosyst.* **2019**, *114*, 237–260. [CrossRef]
57. Rossetto, R.; Ramos, N.P.; de Matos Pires, R.C.; Xavier, M.A.; Cantarella, H.; Guimarães de Andrade Landell, M. Sustainability in sugarcane supply chain in Brazil: Issues and way forward. *Sugar Tech* **2022**, *24*, 941–966. [CrossRef]
58. Tischler, A.L.; Jeronimo, E.M.; Lúcio, A.D.C.; Sari, B.G.; Melo, P.J.D.; Boesso, F.F.; Tartaglia, F.D.L. Sugarcane harvest time for processing and technological quality of brown sugar. *Pesqui. Agropecuária Bras.* **2021**, *56*, e02435. [CrossRef]
59. Yang, Y.; Gao, S.; Jiang, Y.; Lin, Z.; Luo, J.; Li, M.; Que, Y. The physiological and agronomic responses to nitrogen dosage in different sugarcane varieties. *Front. Plant Sci.* **2019**, *10*, 406. [CrossRef]
60. Lal, M.A. Nitrogen metabolism. In *Plant Physiology, Development and Metabolism*; Bhatla, S.C., Lal, M.A., Eds.; Springer: Singapore, 2018; pp. 425–480. [CrossRef]