Path Analysis for Maize (*Zea mays*) Silage Cerrado-Amazon Ecotone

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Abstract— The management of nitrogen fertilization is of paramount importance for the increase of corn silage productivity, by directly participating in the processes of cell division and expansion.It is extremely important to identify the characteristics that are associated with the responsiveness of the use of nitrogen fertilization.Therefore, this study aims to identify the characteristics that most influence the total weight in maize silage production.Two trials were conducted, one with low nitrogen dosage (0 kg ha^{-1} of N in cover) and the other with a high dosage (120 kg ha^{-1} of N in cover), performed in the harvest 2017/18, in Sítio Vitória, in the municipalityof Santa Maria das Barreiras, State of Pará, located in the ecotone Cerrado-Amazon. The experimental design used was randomized blocks with eleven treatments and three replications.The treatments used were BRS 3046, M274, AG 8088, ANHEMBI, PR 27D28, P33-16, P32-11, P29-M12, P36-19, P40-8, and AG 1051. The base fertilization was performed in the groove manually supplying the needs of chemical and physical analysis. Whole plants of the useful plot were harvested and the characteristics were measured forplant height, insertion height of the first ear, culm diameter, the diameter of the ear, weight of the stem leaf, ear weight, and total plant weight. Track and variance analyses were performed through the Genes computer program. Variance analysis was performed for Low and High N, and track analyses for low N, high N, and average values conditions.

I. INTRODUCTION

The maize crop (*ZeaMays*L.) exerts great economic and social importance, due to its high adaptability to the most diverse climates, being cultivated to thousands of generations around the mute. This cereal is present in several everyday situations, from human food, as well as to animals, and more recently, as a form of biofuel [1].

In recent decades, culture has undergone profound changes, according to Contini et al. [2] from the 2000/01 crop to the 2017/18 harvest, the world's maize production increased from 591 million tons to 1.076 billion tons (representing an increase of 82%), mainly because of the use as animal feed for the production of chickens and pigs.

In Brazil, the increase in productivity occurred especially due to the decrease in the role of culture as a source of subsistence for small producers, and its improvement of the role in agricultural production.Contini et al. [2]point out that, although the Brazilian maize market has shown a sudden growth, the sector still needs to solve some obstacles that prevent greater dynamism. Among the obstacles, we highlight the lack of clarity in price formation; difficulties in achieving private funding; obstacles in marketing, especially in the process of flowing production; productivity observed in some regions.

During the last years the growing need in the exploitation of maize crop, aiming at the optimization of areas cultivated with the crop, in the search for more productive cultivars, mainly for animal feed purposes. The expected production for the crop in the 2020/21 crop is 23.6 million tons. In addition to the second and third harvests, total production could reach 105.5 million tons, 2.9% higher than in 2019/20. Brazil has stood out as the third-largest producer in the world of this cereal, second only to the USA and China respectively [3].

Grass silages have low protein content, limiting their use [4]. The production of green matter, dry matter, and grain production, both at the silage point and at maturity, are the factors that most affect the production and palatability in the digestion of the animal.

According to Paziani et al. [5], there was a certain difficulty in finding cultivars with productive efficiency in Brazil, because in many times the cost of silage production outside the profit of the animal, or was lower than the profit obtained by maize grain, so the improvement of maize focused on silage was poorly seen.

Ciappina[6] highlights that about 70% of maize production is used in animal feed, and can reach 85% in developed countries, mainly because it is a fundamental food in the diet of the animal in confinement. Being the most used grass in silage production due to high mass production, ease of fermentation inside the silo, good energy value, and high consumption by animals.

The characteristics that maize silage brings allows it to be an important food in rural cutting and milk properties. In addition to the versatility and high energy value, it is easy to manage production, storage, and supply to animals during periods of food shortages, it guarantees the maintenance of the profitability of producers [7].

A wide variety of corn hybrids with different characteristics can currently be found on the market. For silage production, the productive potentials of each hybrid should be considered, in addition to the agronomic characteristics of the plants, since they are factors that can interfere with the quality of the ensiled material [8].

The *Path analysis*, when using the unfolding in direct and indirect effects of the correlations between productivity and characters evaluated in plants, can be an important statistical methodology in genetic improvement to identify the primary and secondary characters that most contribute to productivity [9].

The success of the *Path analysis* is based on the most consistent formulation of the cause and effect factor among the variables, which leads several authors to use it in their articles in the most diverse areas of knowledge [10]. The correlation values are expressed, if positive, the response effect of productivity will have gained before the variable, if it is negative, the response effect will have a decrease in productivity [11].

In the agrarians sciences, the path analysis is used to measure the correlation of parameters for different cultures, such as canola [12], sunflower [13], jabuticaba fruit [14], soy [15], sorghum [16]. When it comes to silage, it can be highlighted in the maize crop [4, 17, 18], and other crops, such as sorghum, elephant grass, and soybeans [19, 20, 21, 16].

Therefore, the present study aims to analyze the attributes that best represent the total mass of maize silage under high and low nitrogen conditions, through the *Path analysis*, allowing to establish correlations between these variables, which are indicative of maize yield and quality.

II. MATERIALS AND METHOD

The tests were conducted in the 2017/18 crop harvest at Sítio Vitória, located (8º18'32"S 50º36'58") in the municipality of Santa Maria das Barreiras, Pará State region located in the Cerrado-Amazon ecotono. The climate of the region is type Aw according to the Köppen

classification, which indicates tropical climate with the dry season in winter [22].

The State of Pará has high rainfall variability, resulting from the performance of different atmospheric systems that act on the State. The identification of homogeneous areas of rainfall in Pará directly diverges to the environmental dynamics, where the delimitation of periods and areas of higher and lower rainfall concentration become important for the determination of good productivity [23].

Two competition trials of maize cultivars were installed, one installed under low nitrogen, with 0 kg ha^{-1} of N, and the other under high nitrogen, with 120 kg ha^{-1} of N, both in cover. The doses were determined according to the lowest and highest expected productivity for maize[24].

The experimental design used in each assay was randomized blocks with eleven treatments and three replications. The treatments used were BRS 3046, M 274, AG 8088, ANHEMBI, PR 27D28, P33-16, P32-11, P29-M12, P36-19, P40-8, and AG 1051.

The experimental plot used was composed of four rows of 5.0 m, spaced 0.9 m between rows. The useful area of the plot was only the two central rows, discarding 0.5 m from the ends of these rows.

The soil preparation was carried out with a gentler grill followed by the use of a leveling grid. The base fertilization was performed manually, using 300 kg ha^{-1}of N-P$_2$O$_5$-K$_2$O, formulation 5-25-15 + 0.5% Zn, based on the characteristics obtained in the chemical and physical analysis of the soil, expressed in Table 1 [24].

Table 1. Chemical and physical characteristics of the soil of the experimental area (Depth: 0–20 cm) at Sitio Vitória, in Santa Maria das Barreiras, Pará State, 2017/18.

Clay %	pH CaCl$_2$	O.M. dag kg^{-1}	P mg dm^{-3}	K$^+$ mg dm^{-3}	Ca^{2+} cmol$_c$ dm^{-3}	Mg^{2+} cmol$_c$ dm^{-3}	Al^{3+} cmol$_c$ dm^{-3}	CEC cmol$_c$ dm^{-3}
15	4,8	1,7	4,9	43	1,7	0,3	0,20	5,21

O.M.: Organic Matter. CEC: Cation Exchange Capability.

Sowing was performed on November 14, 2017, in a groove, manually. After emergence, thinning was performed leaving an average spacing of 0.2 m between plants, obtaining a population of 55,555 plants ha^{-1}.

The management for the control of weed plants, pests, and diseases was carried out according to the technical recommendations found in the literature for maize crops[25].

The cover fertilization was performed with 150 kg ha^{-1} of N in the Alto N assay. The source used was urea (45% N),totaling 333.33 kg ha^{-1} of urea, it was divided into two stages, the first in Stage V4 and the second in stage V8 (classification used in Brazil)[26].

The harvest was performed when the plants reached the ideal physiological stage (fifth stage of the reproductive phase) for silage yield with maximum nutritional efficiency. The whole plants of the useful plot were harvested and the characteristics were measured for Plant Height (PH), Insertion Height of the first ear (IH), Stem Diameter (SD), Ear Diameter (ED), Stem Leaf Weight (SLW), Ear Weight (EW) and Total Plant Weight (TPW) [17].

After data collection, variance analysis was performed for low N, high N, and both environments at the same time. Pearson's correlation coefficients were then estimated between the characters.Correlations with values of $R^2 \geq 0.6$ or $R^2 \leq -0.6$, derived from the methodology proposed by Dancey et al. [27], were significant, where R^2 above 0.6 is considered moderate to strong. Then, *path analysis* was performed, and correlations were unfolded in direct and indirect effects of the variables (independent variables) on the weight of the total plant (TPW) (Wright,1921).

The analyses were performed using the Computer Genes program, version 2007 [28].

III.   RESULTS AND ANALYSIS

The choice of the GENES program for the trail analyses took into account the intrinsic factor that the program brings to the variables the direct and indirect effects, positive and negative, between the characteristic taxed as main and those taxed as second-parents, besides being a genuinely Brazilian program[28].

Table 2. Analysis of variance for seven characteristics, in eleven maize genotypes in low and high N.

Source of variation	DF	Medium Squares						
		PH	IH	SD	ED	SLW	EW	TPW
Low N								
Block	2	18.39	0.48	0.24	6.78	611.39	17.45	843.76
Genotypes	10	426.41*	405.29*	8.14	63.57*	7016.62	6152.28*	23214.74*
Residue	20	15.06	17.12	0.57	2.85	363.23	116.42	839.96
Mean		182.24	87.85	15.36	43.17	216.88	131.55	348.42
CV (%)		2.13	4.71	4.93	3.91	8.79	8.20	8.32
High N								
Block	2	0.21	6.39	0.12	1.05	348.09	20.82	493.30
Genotypes	10	320.42	364.94*	8.89*	50.28*	17472.02*	17576.52*	63276.33*
Residue	20	19.68	6.39	0.38	1.60	122.32	46.78	194.77
Mean		208.52	106.58	18.69	53.49	371.82	257.73	629.67
CV (%)		2.13	2.37	3.30	2.36	2.97	2.65	2.22

* significant at 5% probability, by f-test. DF: Degree of freedom. CV: Coefficient of variation

Nitrogen plays a fundamental role, being the element required in greater quantity because it constitutes many plant components in the plant, consequently contributes to the greatest effect on productivity, being evident in the analysis of variance (Table 2), where the coefficient of variation found for all variables studied is considered low. Due to the influence of nitrogen fertilization, the coefficient of variation found is considerably lower in High N, besides demonstrating more concise mean values among the eleven maize genotypes [26, 29].

The coefficient of determination (R^2), expressed in Tables 3, 4 and 5, revealed that the total plant weight (TPW) can be explained by the effect of the variables analyzed, which revealed that 99.99% of the determination of total weight can be explained by the other variables. Being higher than that obtained by other authors [5, 18, 20, 30].

The effect of the residual variable for low N, high N, and the medium was 0.9%, 0.5%, and 0.21%, respectively, which reaffirms the high degree of reliability of the data obtained from the model for silage yield.

Table 3. Estimation of the direct and indirect effects involving the main variable, Total Plant Weight (TPW), and the explanatory effects, Plant Height (PH), Insertion Height of the first ear (IH), Stem Diameter (SD), Ear Diameter (ED), Stem Leaf Weight (SLW), Ear Weight (EW), for 11 maize genotypes, Low N.

Effects		Estimates of variables in Low N					
		PH	IH	SD	ED	SLW	EW
Direct	ViaTPW	0.0022	-0.0032	0.0026	0.0074	0.5479	0.5077
Indirect	Via PH	-	0.0017	0.0010	0.0008	0.0014	0.0007
	Via IH	-0.0025	-	-0.0016	-0.0014	-0.0018	-0.0007
	Via SD	0.0012	0.0013	-	0.0015	0.0008	0.0017
	Via ED	0.0028	0.0032	0.0044	-	0.0059	0.0068
	Via SLW	0.3498	0.2984	0.3869	0.4393	-	0.4188

Via EW	0.1560	0.1172	0.3236	0.4657	0.3881	-
Total	0.5094	0.4187	0.7169	0.9133	0.9434	0.9349
R²						0.9999
Effect of residual variable						0.0096

Under N (table 3), the weight of the stem leaf (SLW) and the ear weight (EW) showed high correlation and high direct effect, both positive, indicating a strong relationship between the variablesunder study, demonstrating that the correlation alone explained this relationship.In this case, SLW and EW can be used in indirect selection for grain production.

The stem diameter(SD)and the ear diameter (ED) showed high correlation and low and positive direct effect on the total plant weight, and the indirect effect via SLW and EW were responsible for the high correlation, which confirms theimportance of SLW and EW in the selection process aiming at increasing production under low N. Beleze et al. [31] highlights that plants with higher DS and ED tend to directly influence the content of green mass and dry mass.

The characteristics of plant height (PH) and ear (IH) showed correlations of low magnitude and negligible direct effect on TPW. Calonego et al. [32] and Kappes et al. [33] highlight that the height of the plant has great influence, where plants with high height have longer nodes, with smaller stem diameter (SD), which leads to undernutrition of the ear (< ED), consequently in the reduction of EW, the higher risk of bedtime.

The variables SLW and EWexerted a greater influence on the weight of the total plant since a well-developed stem will produce ears with higher protein content and higher weight for silage [26, 34, 35]. Besides, these variables are influenced by all the other variables and together constitute the total weight of the plant [26].

In conditions of high N (table 4), similar to that which occurred in low N, the weight of the stem leaf (SLW) and the ear weight (EW) showed a high correlation and high direct effect with silage productivity (TPW), indicating a strong relationship between the variables understudy, demonstrating that the correlation alone explained such relationship, Farinelli&Lemos[36] demonstrated that this relationship is intensified as the increase in nitrogen fertilization increased.

The stem diameter (SD) and the diameter of the ear (ED) also presented high correlation and low direct effect ViaTPW, this is due to the linear conditions provided by the increase of nitrogen fertilization, thus found by other authors [34, 35].

The indirect effect via SLW andEW those responsible for the high correlation, which confirms the importance of SLW and WS in the selection process aiming at increasing production under high N. Again, the characteristics of plant height (PH) and ear height (IH), presented correlations of low magnitude and negligible direct effect on TPW, a factor necessary for plants to develop more in diameter and consequently in green matter quality [1].

Table 4. Estimation of the direct and indirect effects involving the main variable, Total Plant Weight (TPW), and the explanatory effects, Plant Height (PH), Insertion Height of the first ear (IH), Stem Diameter (SD), Ear Diameter (ED), Stem Leaf Weight (SLW), Ear Weight (EW), for 11 maize genotypes, in High N.

Effects		Estimates of variables in High N					
		PH	IH	SD	ED	SLW	EW
Direct	Via TPW	-0.00095	-0.00019	0.00250	-0.00043	0.52517	0.52615
Indirect	Via PH	-	-0.00072	-0.00033	-0.00028	0.00015	0.00006
	Via IH	-0.00014	-	0.00001	0.00001	0.00006	0.00004
	Via SD	0.00087	-0.00011	-	0.00208	0.00126	0.00173
	Via ED	-0.00013	0.00003	-0.00036	-	-0.00022	-0.00027
	Via SLW	-0.08198	-0.16301	0.26374	0.26411	-	0.42229
	Via EW	-0.03067	-0.11270	0.36310	0.32732	0.42308	-
Total		-0.1130	-0.2767	0.6287	0.5928	0.9495	0.9500

R²	0.99997
Effect of residual variable	0.0050

For the variables PH and IH to exert a positive influence on silage, thus improving its palatability, as the dose of N did not exceed the recommended for the crop, there is no exaggerated presentment of the stem, which guarantees main levels in the diameters of the stem and ear. For the total weight of the plant to rising, that is, it must be sought through the improvement of materials with such characteristics [31].

When the two environments (High and low N) (Table 5) were studied together, the correlations and direct effect of each variable about productivity were of similar magnitude and signal to those derived from low (table 3) and high N (table 4), confirming that the SLW and EW can be used in indirect selection for silage production.

Table 5. Estimation of direct and indirect effects involvingthe main variable, Total Plant Weight (TPW), and the explanatory effects, Plant Height (PH), Insertion Height of the first ear (IH), Stem Diameter (SD), Ear Diameter (ED), Stem Leaf Weight (SLW), Ear Weight (EW), for 11 maize genotypes.

Effects		Mean estimate of variables					
		PH	IH	SD	ED	SLW	EW
Direct	Via TPW	-0.00044	-0.00036	0.00174	0.00002	0.49820	0.53777
Indirect	Via PH	-	-0.00036	-0.00020	-0.00016	-0.00009	-0.00008
	Via IH	-0.00030	-	-0.00010	-0.00008	0.00000	0.00001
	Via SD	0.00078	0.00047	-	0.00144	0.00124	0.00132
	Via ED	0.00001	0.00000	0.00001	-	0.00001	0.00001
	Via SLW	0.10532	-0.00249	0.35427	0.37534	-	0.42775
	Via EW	0.09164	-0.01608	0.40650	0.42435	0.46173	-
Total		0.1970	-0.0188	0.7622	0.8009	0.9611	0.9668
R²							0.999996
Effect of residual variable							0.0021

IV.   CONCLUSIONS

1 Nitrogen doses did not influence the magnitude of phenotypic and genotypic correlations and direct and indirect effects on silage production.

2 The weight of the stem and the weight of the ears can be used in indirect selection for silage production.

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