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Corn trail analysis with and without Phosphorus use

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***Abstract* –** *The present work was carried out to study, through track analysis, the characteristics that most influence grain yield in corn genotypes. The trials were conducted in 2017/18, in the municipality of Santa Maria of Barreiras – PA, a region located in the Cerrado-Amazon Ecótono. Two competition trials of maize cultivars were installed, one in low phosphorus conditions, with 50 kg ha^{-1}from P_2O_5, and another under high phosphorus, with 100 kg ha^{-1}from P_2O_5. The experimental design used in each assay was randomized blocks with three replicates and ten treatments (genotypes). The treatments consisted of cultivars found in the local market, which were AG8088PRO2, BRS3046, PR27D28, ANHEMBI, CATIVERDE, 2B655PW, BR206, AG1051, AL BANDEIRANTE, and ORION. The characteristics of plant height were evaluated (AP), height of the spike (AE), diameter of spike (DE), length of spike (CE), and number of grains in row (NGE), weight of the spike (PE) and productivity (PROD). The track analysis was done through the computer program Genes. The variable PE presented the greatest direct effect on yield in corn genotypes in the Cerrado-Amazon region, being the most indicated for indirect selection for grain yield.*

I. INTRODUCTION

Over the past few decades, maize has reached the highest agricultural crop level in the world, being the only one to have surpassed the 1 billion tons, leaving behind old competitors such as rice and wheat. Concomitantly with its importance in terms of production, the culture is still noted for its various uses. Estimates point to more than 3.500 applications of this cereal. In addition to the relevance in food safety, in human food and, mainly, animals, it is possible to produce with corn a multitude of products, such as fuels, beverages, polymers, etc. [1].

Corn is the second-largest crop of importance in agricultural production in Brazil, being surpassed only by soybeans which lead to grain production in the country. Brazil stands out as the third-largest producer behind EUA and China, respectively. In the consolidation of the three harvests of 2020/2021 corn, the expected production was 96.4million tonnes. Of this total, 24 were produced. 7

million tons in the first harvest, 69.9 million in the second harvest, and 1.7 million in the third harvest [2].

Genetic research Applied to plant breeding has undergone numerous transformations and challenges over the years. In addition to the high demand, the new needs and competitiveness of the market, the emergence of new diseases and pests, and the ability to adapt to the desired specific environments and characteristics are some examples. Genetic improvement is one of the most expressive techniques that has contributed to the increase in productivity of the corn crop. The development and use of hybrid maize provided, in a short period, a productivity gain of more than 150% [3].

Souza et al. [4] emphasize the importance of studies on trial analysis. Carvalho et al. [5] when analyzing corn hybrids, concluded that the characteristics that most contributed to the production per plant were the number of ears per plant and the grain weight. Mohammadi et al. [6] observed that grain weight and the number of grains per ear were the most important components in predicting grain yield. Other authors such as Oliveira et al. [7], Pinheiro et al. [8], Santos et al. [9], and Silva et al. [10], also studied the direct and indirect effects between corn yield and its primary components.

Track analysis (*path analysis*) consists of the study of the direct and indirect effects of explanatory variables on a basic variable, whose estimates are obtained through regression equations, in which the variables are previously standardized. Although the correlation is an intrinsic characteristic of two variables, in each experimental condition, its decomposition is dependent on the set of variables studied, which are usually evaluated by the researcher through the previous knowledge of its importance and possible interrelationships expressed in "trail diagrams" [11].

Although track analysis is widely used in several crops of great economic importance such as soybean[12 and 13], corn [7, 8, 9, 10, 14, and 15], on the beans [16].

Phosphorus is linked to physiological processes of photosynthesis and respiration but is also a constituent of proteins and coenzymes, and nucleic acids and plays a key role in the storage of energy in the plant. Phosphorus deficiency occurs initially in older leaves, which have a darker green initial color than normal. Later, they acquire reddish or purplish coloration at the tips and margins of the leaf blade and may extend to the stem, the plant also presents growth reduction [17].

However, there are still few studies of this nature involving trial analysis in corn crops with different phosphate fertilization in the State of Pará. Because of this fact, the present work was carried out to evaluate through track analysis the components that most contribute to the productivity of corn grains under high and low phosphorus conditions.

II. MATERIAL AND METHODS

The sowing was carried out on December 23, 2017, in the 2017/18 crop, at Sítio Vitória, located in (8º18’32” S 50º36’58”W) in the municipality of Santa Maria das Barreiras, State of Pará, a region located in the Cerrado-Amazon Ecótono. The climate of the region is classified as Aw according to the köppen classification, which indicates a tropical climate with a dry season in winter [18].

Two competition trials of maize cultivars were installed, one in low phosphorus conditions, with 50 kg ha^{-1} from P_2O_5, and another under high phosphorus, with 100 kg ha^{-1} from P_2O_5. Both doses were applied at sowing, immediately before planting, using the simple superphosphate fertilizer.

The experimental design used in each assay was randomized blocks with ten treatments and three replications. The treatments consisted of 10 genotypes, all of open pollination AG8088PRO2, BRS3046, PR27D28, ANHEMBI, CATIVERDE, 2B655PW, BR206, AG1051, AL BANDEIRANTE and ORION, cultivars found in the local market, described in Table 2.

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

The soil preparation was carried out with a goaler grill followed using a leveling grid. According to the crop requirement, phosphate fertilization was performed manually on the day of planting and applied directly to the groove. The doses were according to the recommendation for the use of correctives and fertilizers 5 the Approximation [19], according to the characteristics obtained in the chemical and physical analysis of the soil, expressed in Table 1.

Table 1 - Chemical and physical characteristics of the soil of the experimental area (Depth: 0-20 cm) at Sítio Vitória, in Santa Maria Of Barreiras, Pará State, 2017/18.1

Clay %	pH $CaCl_2$	M.O. $dagkg^{-1}$	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}	CTC $cmol_c$ dm^{-3}

15	4.8	1.7	4.9	43	1.7	0.3	0.20	5.21

M.O.: Organic matter.

Nitrogen fertilization was done in cover, with a dose of 150 kg ha^{-1} N divided into two applications, the first being performed in stage V4 and the second in V8 (four and eight completely open sheets), having as source the urea (43% of N), totaling 348.83 kg ha^{-1} urea.

Potassium fertilization was covered with a dose of 90 kg ha^{-1}from K_2O divided into two applications, the first being performed in stage V4 and the second in V8 (four and eight completely open leaves), having as source potassium chloride (60% from K_2O), Totaling 150 kg ha^{-1} potassium chloride.

The management for the control of weeds, pests, and diseases was carried out according to the technical recommendations found in the literature for corn crops [19].

Table 2. Agronomic characteristics of corn cultivars used in the experiment.

Trade name	Genetic basis	Transgenics	Cycle	Purpose of use	Technological level
AG8088PRO2	HS	PRO2	P	G/SPI	A
BRS3046	HT	C	SMP	G/MV/SPI	M/A
PR27D28	HD	C	SP	G/SPI	B/M
ANHEMBI	PPA	C	P	G/SPI	B/M
CATIVERDE	PPA	C	SP	MV/SPI	M
AG1051	HD	C	SMP	G/SPI/MV	M/A
AL BANDEIRANTE	PPA	C	P	G/SPI	B/M
ORION	HD	C	P	G	B/M
BR206	HD	C	P	G/SPI	M/A
2B655PW	HT	PW	P	G/SPI	B/M

HS: Simple hybrid; HD: Double hybrid; HT: Triple hybrid; PRO2: Technology VT PRO 2™; PW: Tecnologia Powercore™; C: Conventional; P: Precocious; SMP: Semiprecocious; SP: Superprecocious; G: Grain; MV: Green corn; SPI: Silage of the whole plant; A: High; M: Medium and B: Low.
Fonte: Pereira Filho & Borghi [20].

The harvest was performed when the plants reached the ideal physiological stage (R6) for grain production. Based on the useful area of the plot, the characteristics for Plant Height were evaluated (AP), Height of the Spike (AE), Diameter of the spike (DE), Length of the spike (CE), Number of grains in a row (NGE), Weight of the spike (PE) and Productivity (PROD) [21]. Yield: grain mass of each plot corrected to 13% moisture and transformed into kg ha^{-1}.

For each dose of phosphorus (low P and high P), the correlations between the characteristics with grain yield were estimated. Then, these correlations were unfolded in direct and indirect effects, with grain yield being the basic variable [22].

The analyses were performed using the Computational Genes program [23].

The choice of the GENES program for the trial analysis considered the intrinsic factor that the program brings to the variables the direct and indirect effects, positive and negative, between the characteristic taxed as the main and those taxed as secondary [24].

III. RESULTS AND DISCUSSION

The coefficients of trail determination in Table 3 (low P) and Table 4 (high P) explained well the strong cause and effect relationships related to productivity, indicated by the high model determination value, both for low P (0.9999), for high P (1.0000) and by the low residual effect (0.0071) for low P and high P (0.000), indicating that the variables explain the variation found in grain yield.

Table 3 - Estimation of the direct and indirect effects involving the main variable, grain yield in kg ha^{-1} (PROD), and the explanatory (AE, AP, DE, CE, NGE,and PE), for 10 maize genotypes, in Low P.

Characters	Association effects	Estimate
AE	Direct about PROD	-0.0027
	Indirect way AP	0.0012
	Indirect way DE	0.0006
	Indirectway CE	-0.0029
	Indirectway NGE	0.0007
	Indirectway PE	-0.1619
	Full	-0.1651
AP	Direct about PROD	0.0027
	Indirect way AE	-0.0012
	Indirect way DE	-0.0037
	Indirect way CE	0.0018
	Indirect way NGE	0.0003

	Indirect way PE	-0.4019
	Full	-0.402
DE	Direct about PROD	0.0109
	Indirect way AE	-0.0002
	Indirect way AP	-0.0009
	Indirect way CE	-0.0031
	Indirect way NGE	0.0016
	Indirect way PE	0.4363
	Full	0.4446
CE	Direct about PROD	0.0115
	Indirect way AE	0.0007
	Indirect way AP	0.0004
	Indirect way DE	-0.0030
	Indirect way NGE	0.0009
	Indirect way PE	0.3782
	Full	0.3888
NGE	Direct about PROD	0.0028
	Indirect way AE	-0.0006
	Indirect way AP	0.0003
	Indirect way DE	0.0063
	Indirect way CE	0.0037
	Indirect way PE	0.5948
	Full	0.6072
PE	Direct about PROD	0.9897
	Indirect way AE	0.0004
	Indirect way AP	-0.0011
	Indirect way DE	0.0048
	Indirect way CE	0.0044
	Indirect way NGE	0.0017
	Full	0.9999
Coefficient of determination (R^2)		0.9999
Effect of residual variable		0.0071

r ≥ 0.6 or*r* ≤ -0.6, wherer*a*bove 0.6 is considered moderate to strong[25].Plant Height (AP), Height of the Spike (AE), Diameter of the Spike (DE), Length of Spike (CE), Number of Grains in Row (NGE), Weight of the Spike (PE),and Productivity (PROD).

When correlation values (*r*) and the direct effect are similar in magnitude and sign, the correlation explains well the association between the variables; if the r was positive and the direct effect is low and/or negative, the correlation that exists is due to indirect effects, indicating that the truncated selection in the auxiliary variable can provide satisfactory gains in the main variable. In this case, the best strategy is the simultaneous selection of variables, with emphasis also on those whose indirect effects are significant; when the value of *r*is low and/or negative and the direct effect was positive and high, the lack of correlation is caused by the indirect effects [26].

Under low P conditions (Table 3), the greatest direct effect on grain yield was from the weight of the (PE) (0.999), which also showed a high correlation (0.9897), indicating that the correlation explains well the association between the characters and, that the PE, can be used in the indirect selection for grain yield. Moreover, for all other characteristics studied, without exception, the indirect effect via PE was the component of the greatest contribution to their correlation, which confirms the importance of PE in the selection process aiming at increasing productivity under low P.

Mundim et al. [27] and Silva et al. [10] report that high values of correlations and right effect reveal a direct, cause-effect association between the attributes used in the analysis.

In the general context, the effects of the developments, through the analysis of the correlation coefficients of AP, DE, CE, NGE, and PE, were positive and showed significance. Only AE was negative about the PROD.

In high conditions P (Tabela 4), as occurred with Low P (Tabela 3), the weight of the spike (PE) showed high correlation and high direct effect with productivity (PROD), indicating a strong relationship between them. Also, similarly to what happened with Low P (Table 3), for all other characters, the indirect effect via PE was the component of the greatest contribution to their correlation with grain yield.

Both in low P and high P, all characteristics, except PE, there was a correlation of considerable magnitude and very similar, but with low direct effect with grain yield, and the PE character, as shown above, was the main responsible for this effect.

Thus, regardless of the P dose, the P doses applied at sowing were not able to promote significant changes in terms of the magnitude of the correlations between the explanatory variables and grain yield.

Table 4 - Estimation of the direct and indirect effects involving the main variable, grain yield in kg ha^{-1} (PROD), and the explanatory (AE, AP, DE, CE, NGE,and PE), for 10 maize genotypes, in high P.

Characters	Association effects	Estimate
AE	Direct about PROD	-0.0001
	Indirect way AP	-0.0035
	Indirect way DE	0.0004
	Indirect way CE	0.0035
	Indirect way NGE	-0.0003
	Indirect way PE	-0.4016
	Full	-0.4016
AP	Direct about PROD	-0.0041
	Indirect way AE	-0.0001
	Indirect way DE	0.0004
	Indirect way CE	0.0031
	Indirect way NGE	-0.0004
	Indirect way PE	-0.5502
	Full	-0.5512
DE	Direct about PROD	-0.0009

	Indirect way AE	0.0006
	Indirect way AP	0.0019
	Indirect way CE	0.0016
	Indirect way NGE	0.0006
	Indirect way PE	0.4426
	Full	0.4458
CE	Direct about PROD	-0.0064
	Indirect way AE	0.0001
	Indirect way AP	0.0019
	Indirect way DE	0.0002
	Indirect way NGE	0.0000
	Indirect way PE	0.2090
	Full	0.2047
NGE	Direct about PROD	0.0010
	Indirect way AE	0.0000
	Indirect way AP	0.0015
	Indirect way DE	-0.0005
	Indirect way CE	0.0001
	Indirect way PE	0.5617
	Full	0.5639
PE	Direct about PROD	0.9989
	Indirect way AE	0.0001
	Indirect way AP	0.0022
	Indirect way DE	-0.0004
	Indirect way CE	-0.0013
	Indirect way NGE	0.0006
	Full	1.0000
Coefficient of determination (R^2)		1.0000
Effect of residual variable		0.0000

$r \geq 0.6$ or $r \leq -0.6$, where *r*above 0.6 is considered moderate to strong [25]. Plant Height (AP), Height of the Spike (AE), Diameter of the Spike (DE), Length of Spike (CE), Number of Grains in Row (NGE), Weight of the Spike (PE), and Productivity (PROD).

IV. CONCLUSION

The variable ear weight showed the highest direct effect on grain yield in corn genotypes in the Cerrado-Amazon region, being the most indicated for indirect selection for grain yield.

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