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Dose and form of nitrogen supply in the relationship dynamics of wheat ear components with yield in cropping systems

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ABSTRACT. Nitrogen management distinctly influences the expression and magnitude of relationships between wheat ear components and grain yield. We sought to determine the variables linked to wheat ear that are more responsive to changes in the dose and form of nitrogen supply and to determine the direct and indirect effects on grain yield by single and fractional nitrogen supply in soybean/wheat and corn/wheat succession systems. The study was conducted in 2018 and 2019 in a randomized block experimental design with four replications, in a 3 x 3 factorial, for N-fertilizer doses (30, 60, 120 kg ha-1) and forms of supply [single dose (100 %) in phenological stage V_3 (third expanded leaf); fractionated dose (70% and 30%) at the V_3/V_6 phenological stage (third and sixth expanded leaf) and; fractionated dose (70% and 30%) at phenological stage V_3/R_1 (expanded third leaf and beginning of grain filling)], respectively, in the soybean/wheat and corn/wheat succession systems. The increase in the nitrogen doses promotes productivity due to the greater contribution of grain mass and ear length in the V_3 stage and ear grain mass in V_3/V_6 and $V_3/R_{1,}$ in a soybean/wheat system. In the corn/wheat system, the increase in nitrogen promotes productivity, with a greater contribution of grain mass in the ear, regardless of the form of supply. Nitrogen supply in single dose ($V_{3)}$ and fractionated in theV_3/V_6 gave similar productivity, with a reduction in $V_3/R_{1.}$ The grain mass of the ear showed greater contribution of alteration by the form of single and fractioned nitrogen supply, regardless of the dose and succession system. The grain mass of the ear shows a high correlation with yield, regardless of the dose and form of nitrogen supply in the soybean/wheat system, with a positive indirect effect by the ear mass. In the corn/wheat system, ear grain mass shows a high correlation with yield, when nitrogen is supplied in a single dose at 30 and 60 kg ha^{-1}, with a positive indirect effect due to ear length.

Key words: *Triticum aestivum*; N-dose; N-fraction; Correlation and Path Analysis; C/N

INTRODUCTION

Wheat (*Triticum aestivum*) is the second most produced cereal in the world and is one of the main sources of animal and human food (De Mamann et al., 2017; Al-Ateeq et al., 2021). High wheat yields depend on efficient cultivars, favorable soil and climate conditions for cultivation, and management technologies (Brezolin et al., 2017; Linina and Ruza, 2018). Among the management technologies, nitrogen fertilization is highlighted because nitrogen is directly linked to the processes of elaboration of grain yield components and is the nutrient most required and absorbed by plants (Zörb et al., 2018; De Mamann et al., 2019). The most used source of nitrogen in agriculture is urea, a soluble fertilizer that contains 45% nitrogen in its composition, with broadcast application on the soil (Theago et al., 2014; Santos et al., 2020). The efficiency of nitrogen use by the urea source is affected by the type of residual cover and weather conditions during cultivation (Costa et al., 2017; Mantai et al., 2021). Under unfavorable conditions, nutrient losses by volatilization or leaching are imminent, limiting the expression of yield components and causing environmental pollution (Brezolin et al., 2016; De Mamann et al. 2019). An alternative to reduce losses and damage to the ecosystem by nitrogen occurs with the management of the nutrient in fractioned doses, applied at different stages of wheat development, favoring the use of the nutrient and enhancing grain yield. (Ferrari et al., 2016; Costa et al. 2018).

Wheat grain yield is directly and indirectly influenced by several ear components such as ear mass, number and ear grain mass, suffering variations due to individual or combined modifications of these components (Silva et al., 2005; Vesohoski et al., 2011). On the other hand, ear components are strongly influenced by variation in the dose and timing of nitrogen supply (Braz et al. 2006; Silva et al. 2015). The adjustment of the dose and form of nitrogen supply highlights the need to know the dynamics of wheat in the elaboration of yield components. In addition, the association of grain yield with ear components represents a strategy that can optimize the ways of using the nutrient, promoting a more sustainable production system (Teixeira Filho et al. 2010; Silva et al., 2015). Knowing the magnitudes of correlations of yield characters under different doses and forms of nitrogen supply allows for a better understanding of the specific relationships determined by phenotypic differences in the crop (Vesohoski et al., 2011; Batista et al., 2020).

Relative contribution, correlation, and path analyzes have been used in several species to clarify cause-and-effect relationships from different perspectives (Mantai et al., 2016). The analysis of relative contribution allows identifying the characters that most contribute to the total variability within a given set of variables (Alves and Kist, 2010; Grigolo et al., 2018). Correlation and trail methods allow us to assess and understand the causes involved in associations between characters and decompose the existing correlation into direct and indirect effects, through a main variable and explanatory variables (Cargnelutti Filho et al., 2010; Zuffo et al., 2018).

The study aims to determine the variables linked to wheat ear that are more responsive to changes in the dose and form of nitrogen supply and to determine the direct and indirect effects on grain yield by single and fractional nitrogen supply in succession systems of high and low N-residual release.

MATERIAL AND METHODS

The experiment was conducted in the agricultural years of 2018 and 2019, in the municipality of Augusto Pestana, RS, Brazil (28° 26' 30'' latitude S and 54° 00' 58'' longitude W). The soil is classified as a typical dystroferric red latosol and the climate of the region, according to the Köeppen classification, is the Cfa type, with hot summer without a dry season. Ten days before sowing, soil analysis was performed and identified, over the years, the following chemical characteristics: i) corn/wheat system (pH= 6.5, P= 34.4 mg dm^{-3}, K= 262 mg dm^{-3}, MO= 3.5%, Al= 0.0 $cmol_c$ dm^{-3}, Ca= 6.6 $cmol_c$ dm^{-3} and Mg= 3.4 $cmol_c$ dm^{-3}) and; ii) soybeans/wheat system (pH= 6.2, P= 33.9 mg dm^{-3}, K= 200 mg dm^{-3}, MO= 3.4%, Al= 0.0 $cmol_c$ dm^{-3}, Ca= 6.5 $cmol_c$ dm^{-3} and Mg= 2.5 $cmol_c$ dm^{-3}).

The experimental design was a randomized block design with four replications, in a 3 x 3 factorial scheme for nitrogen rates (30, 60, 120 kg ha^{-1}) and supply forms [single dose, with 100% nitrogen applied at phenological stage V_3 (third expanded sheet); fractionated dose, with 70% and 30% nitrogen applied in the phenological stages V_3 (expanded third leaf) and V_6 (expanded sixth leaf), respectively; and fractionated dose, with 70% and 30% nitrogen applied in the phenological stages V_3 (expanded third leaf) and R_1 (beginning of grain filling), respectively] (Costa, 2013).

The sowing was performed with a seeder-fertilizer to compose plots with five rows five meters in length and spaced by 0.20 meters, forming the experimental unit of 5 m^2. At sowing, 30 kg and 15 kg ha^{-1} of P_2O_5 and K_2O were applied, respectively, based on the P and K contents in the soil for an expected grain yield of 3 t ha^{-1} and N in the base with 10 kg ha^{-1} in the form of urea, with the remainder to cover the doses proposed in the study. The seeds were submitted to a germination and vigor test in the laboratory, in order to correct the desired density of 400 viable seeds m^{-2}. Applications of tebuconazole fungicide at a dose of 0.75 L ha^{-1} and weed control with metsulfuron-methyl herbicide at a dose of 4 g ha^{-1} were carried out. The wheat cultivar BRS Guamirim was used, small, early cycle, resistant to lodging, commercial class "bread" type and with high production potential, representing the standard biotype desired by wheat growers in southern Brazil (Alessi et al., 2021).

The harvest of the experiment, to estimate the grain yield, was done manually by cutting the three central lines of each plot, stage close to the harvest point (125 days), with grain moisture of approximately 15%. The plots were tracked with a stationary harvester and sent to the laboratory to correct the grain moisture to 13%, after which the weighing and estimation of grain yield (PG, kg ha^{-1}) were carried out. In the analysis of the ear components, a random collection of 20 ears of wheat per experimental unit was performed, which were sent to the laboratory for decomposition of the inflorescence components. Ear mass (ME, g), ear grain mass (MGE, g), ear grain number (NGE, n), ear length (CE, cm) and ear harvest index (ICE, g g^{-1}) were measured given by the ratio of the ear grain mass to the ear mass (Costa, 2013).

After verifying the assumptions of homogeneity and normality of the variables, analysis of variance of the main effects and interaction of doses and forms of nitrogen supply was performed (not shown). By the Singh method, the relative contribution analysis of nitrogen doses on wheat ear components in different forms of nutrient supply was performed, as well as the relative contribution analysis of single and fractional nitrogen supply on ear components of wheat in different doses of the nutrient. Singh's method is based on the $S_{.j}$ statistic, where:

$$D_{ii'}^2 = \delta'\psi^{-1}\delta = \sum_{j=1}^{n}\sum_{j'=1}^{n}\omega_{jj'}d_j d_{j'} \quad \text{(Eq. 1)}$$

in which: $D_{ii'}^2$ is the Mahalanobis distance between treatments i and i', ψ is the matrix of residual variances and covariances, $\delta' = [\, d_1 \;\; d_2 \; ... \;\; d_n]$, where $d_j = Y_{ij} - Y_{i'j}$ the mean of the i-th dose in relation to the j-th character and ω is the element of the j-th row and j-th column of the inverse of the matrix of residual variances and covariances. The total of distances involving all pairs of treatments is given by:

$$\sum_{i<}\sum_{i'} D_{ii'}^2 = \sum_m D_m^2 = \sum_{j=1} S_{.j} \quad \text{(Eq. 2)}$$

The percentage values of $S_{.j}$ indicate the measure of the relative importance of the variable j.

The magnitude and direction of correlations between grain yield and wheat ear components were determined. The hypotheses were tested at a 5% probability of error level using the t test, considering $n-2$ degrees of freedom and following the model

$$t = \frac{r}{\left[\frac{\sqrt{(1-r_2)}}{n-2}\right]} \quad \text{(Eq. 3)}$$

where r is the correlation coefficient between the characters X and Y, and n in the degrees of freedom in the levels of treatments considered. In the correlation analysis, the joint effect of the sources of variation in agricultural years and cultivars was considered, as the inclusion of sources of variation in the correlation model is an effective way of knowing with greater reliability the strength of these relationships (Krüger et al., 2011). Path analysis was performed to detect direct and indirect effects of the variables on grain yield in terms of rates and forms of nitrogen supply per cropping system. Considering Y (grain productivity) as the main variable resulting from the joint action of other variables (components of the ear), the following model is obtained:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon \quad \text{(Eq. 4)}$$

in which $X_1, X_2, \dots, X_n$ are explanatory variables and Y the main (or dependent) variable.

Considering,

$$y = \frac{Y - \bar{Y}}{\hat{\sigma}_y} \quad \text{(Eq. 5)}$$

$$x = \frac{X_i - \bar{X}_i}{\hat{\sigma}_{xi}} \quad \text{(Eq. 6)}$$

$$u = \frac{\varepsilon}{\hat{\sigma}_\varepsilon} \quad \text{(Eq. 7)}$$

$$p = \frac{\hat{\sigma}_\varepsilon}{\hat{\sigma}_y} \quad \text{(Eq. 8)}$$

$$p_{oi} = \frac{b_{oi}\hat{\sigma}_{xi}}{\hat{\sigma}_y} \quad \text{(Eq. 9)}$$

there is,

$$y = p_1x_1 + p_2x_2 + \cdots + p_nx_n + p_\varepsilon u \quad \text{(Eq. 10)}$$

Using this model, the direct and indirect effects of the explanatory variables on the main variable were estimated. The path coefficients were estimated from the system of equations $X'X\hat{\beta} = X'Y$, being

$$X'Y = \begin{bmatrix} r_{1y} \\ r_{2y} \\ \vdots \\ r_{ny} \end{bmatrix} \quad X'X = \begin{bmatrix} 1 & r_{12} & \cdots & r_{1n} \\ r_{12} & 1 & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{1n} & r_{2n} & \cdots & 1 \end{bmatrix} \quad e \quad \hat{\beta} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} \quad \text{(Eq. 11)}$$

so,

$$r_{ij} = p_i + \sum_{j \neq 1}^{n} p_j r_{ij} \quad \text{(Eq. 12)}$$

in which r_{ij} is the correlation between the main variable (y) and the i-th explanatory variable, p_i is the measure of the direct effect of variable i on the main variable and $p_j r_{ij}$ is the measure of the indirect effect of the variable i, via variable j, over the main variable.

The coefficient of determination of the path diagram is given by:

$$R^2 = p_2r_{1y} + p_2r_{2y} + \cdots + p_nr_{ny} \quad \text{(Eq. 13)}$$

and the residual effect is estimated by:

$$\hat{p}_\varepsilon = \sqrt{1 - R^2} \quad \text{(Eq. 14)}$$

For all determinations, the free computer program GENES (Cruz, 2013) was used.

RESULTS AND DISCUSSION

In Table 1, for the soybean/wheat system, the average values for grain yield show that the increase in the nitrogen dose provides an increase in yield. This behavior is not observed in most ear components, where the highest means are observed in the lowest nitrogen dose. On the other hand, for the corn/wheat succession system, it is observed an increase in the average grain yield and a tendency to increase the averages of the ear components with the increase in the nitrogen dose. These results show that the type of plant residue with high (corn) and low (soybean) C/N ratio alters the expression of ear components by nitrogen fertilization. For the system with the lowest C/N ratio (soybean/wheat), the greater availability of residual-N ensured sufficient nutrient availability to enhance the expression of ear components, even with less chemical fertilization. The expressive increase in yield at the highest dose may be linked to the stimulus for greater production of tillers, a component also directly linked to wheat yield. In the system with residual-N restriction imposed by the higher C/N ratio (corn/wheat), the greater expression of ear components is difficult by less nutrient availability, making the results of the use of fertilizer-N more visible.

Table 1. Average and relative contribution of wheat ear yield and components by nitrogen rates with different forms of supply.

Characters	Average Nitrogen doses (kg ha^{-1})			Relative contribution (Singh, %) Single and Fractionated Dose		
	30	60	120	V_3	V_3/V_6	V_3/R_1
(2018+2019) soybean/wheat system						
PG	2698	3033	3836	10.36	0.59	3.38
ME	1.44	1.32	1.43	6.89	34.82	18.97
MGE	1.09	0.98	1.04	14.04	39.17	54.18
NGE	28.60	27.09	28.07	7.05	0.94	0.27
CE	7.02	7.08	7.02	34.87	6.03	8.91
ICE	0.75	0.74	0.72	26.80	18.45	14.28
corn/wheat system						
PG	2162	2634	3265	5.11	2.75	2.37
ME	1.27	1.30	1.35	44.60	7.23	35.75
MGE	0.90	0.95	0.97	32.53	45.77	1.90
NGE	26.42	26.95	26.88	4.23	1.58	26.08
CE	6.64	6.64	6.69	7.50	27.18	7.70
ICE	0.71	0.72	0.72	6.02	15.50	26.19

V_3 = collar formed on the 3rd sheet of the main culm, V_6= collar formed on the 6th sheet of the main culm and R_1= ear differentiation; PG= grain yield (kg ha^{-1}); ME= ear mass (g); MGE= grain mass per ear (g); NGE= number of grains per ear (n); CE= ear length (cm); ICE= ear harvest index (MGE/ME). Single dose (100 %) in phenological stage V_3 (third expanded leaf); fractionated dose (70% and 30%) at the V_3/V_6 phenological stage (third and sixth expanded leaf), and fractionated dose (70% and 30%) at phenological stage V_3/R_1 (expanded third leaf and beginning of grain filling).

In the analysis of the contribution in the soybean/wheat system (Table 1), the variables ear grain mass, ear length and ear harvest index showed greater change by nitrogen doses in a single supply at stage V_3. On the other hand, when nitrogen was supplied in a fractional form, the greatest contribution by the doses was in the variables ear mass, ear grain mass and ear harvest index, either in V_3/V_6 or in V_3/R_1. Regardless of the form of supply, the ear grain mass and harvest index show a strong modification contribution. The supply at stage V_3 shows that increasing the dose promotes greater change in ear length, which indirectly ensures a greater possibility of spikelet formation and inflorescence mass, influencing the final grain yield.

In the corn/wheat system (Table 1), a high change is also observed in the variables ear mass and ear grain mass by nitrogen doses given in a single dose at phenological stage V_3. In the V_3/V_6 fractionation, the ear grain mass continues to show a high contribution, along with the ear length and ear harvest index. In the fractionation in V_3/R_1, the increase in the nitrogen dose changes more significantly the ear mass, number of ear grains and the ear harvest index.

Fertilization in V_3/R_1 fractionation shows that nitrogen no longer influences grain mass, a component directly linked to grain yield. On the other hand, there is an increase in the contribution of nitrogen on the ear harvest index with fractional fertilization in the later condition, the opposite condition when compared to the soybean/wheat system.

In Table 2, the mean values of grain yield and wheat ear components show a tendency to reduction in most variables with nitrogen fractionation, regardless of the cropping system. This result indicates that the fractionation of the dose of the nutrient at stages close to grain filling does not contribute to the maximization of components linked to yield.

Table 2. Average values and relative contribution of yield and ear components by the forms of nitrogen supply for each dose of the nitrogen.

Characters	Average Forms of Nitrogen Supply			Relative Contribution (Singh, %) Nitrogen Dose (kg, ha^{-1})		
	V_3	V_3/V_6	V_3/R_1	30	60	120
(2018+2019) soybeans/wheat system						
PG	3278	3226	3065	21.53	23.69	10.0
ME	1.45	1.39	1.35	14.96	24.69	15.1
MGE	1.06	1.05	1.01	35.90	39.25	38.8
NGE	27.88	27.92	27.96	0.80	1.72	9.0
CE	7.25	6.72	7.15	0.42	5.83	14.6
ICE	0.72	0.75	0.74	26.39	4.81	12.5
corn/wheat system						
PG	2752	2762	2546	31.05	55.88	70.47
ME	1.35	1.28	1.28	19.31	9.32	7.17
MGE	0.97	0.92	0.94	34.14	14.92	10.54
NGE	27.29	27.22	25.74	0.31	10.03	5.10
CE	6.98	6.48	6.51	2.36	4.05	0.96
ICE	0.72	0.72	0.73	12.82	5.80	5.76

V_3 = collar formed on the 3rd sheet of the main culm, V_6= collar formed on the 6th sheet of the main culm e R_1= ear differentiation; PG= grain yield (kg ha^{-1}); ME= ear mass (g); MGE= grain mass per ear (g); NGE= number of grains per ear (n); CE= ear length (cm); ICE= ear harvest index (MGE/ME). Single dose (100 %) in phenological stage V_3 (third expanded leaf); fractionated dose (70% and 30%) at the V_3/V_6 phenological stage (third and sixth expanded leaf), and fractionated dose (70% and 30%) at phenological stage V_3/R_1 (expanded third leaf and beginning of grain filling).

In the analysis of the relative contribution by the form of supply in the soybean/wheat system (Table 2), the variables grain yield, ear mass, grain mass per ear and ear harvest index shows the greatest changes in the lowest dose of nitrogen. At the dose of 60 kg ha^{-1} of the nutrient, the contribution of changing the variables by the form of supply on grain yield, ear mass and ear grain mass is followed. At the highest nitrogen dose, all variables show considerable changes due to the form of supply, with great emphasis on the ear grain mass, whether in high, medium and reduced doses of fertilizer.

In the corn/wheat system (Table 2), the contribution of changing variables by the form of nitrogen supply shows, at a reduced dose, a greater effect on grain yield, ear mass, ear grain mass and ear harvest index. The number of grains in the ear, which is a direct component of productivity, does not show responses in this condition due to the form of supply. At the dose of 60 kg ha^{-1} of nitrogen, the vast majority of variables show considerable contribution values, with the exception of ear length and harvest index that were little changed. At the highest dose of nitrogen, there is a concentration of contribution of the nitrogen supply to grain yield and only the ear grain mass indicates a more considerable contribution in relation to the others. These results raise the hypothesis that the form of nitrogen supply in corn/wheat system has less effect on ear components and maximizes the action on tiller production, leading to a concentration of effects on grain yield, especially with the increase in the dose of the nutrient.

The number and mass of ear grains and the number of fertile tillers per plant or per area are components directly linked to yield, with a significant contribution of tiller in changing the final grain yield (Valério et al., 2009; Silva et al., 2015). Silva et al. (2005) observed in the wheat crop that the ear mass and the number of grains per ear have a greater sensitivity to change in face of genetic and environmental effects, with direct effects on productivity. The productive potential of cereals is influenced by the efficiency of absorption, remobilization and use of nitrogen, so that grain productivity is significantly increased by the proper management of the nutrient (Beche et al., 2014; Silva et al., 2016). In oat culture, panicle mass is the most effective in showing change, either because of the variability of cultivars or management that interferes with productivity (Kurek et al., 2002; Marolli et al., 2017). Mantai et al. (2020a) used relative contribution analysis and observed that in oat culture panicle mass, panicle spikelet number and panicle grain mass have a greater contribution in promoting changes by increasing nitrogen. The analysis of the relative contribution has been a technique used to provide support in the identification of variables that are more altered on genetic and environmental effects, mainly by modifying management techniques (Mantai et al., 2016; Grigolo et al., 2018).

The use of techniques that verify the direct and indirect influence of inflorescence components by cause-and-effect relationships of the nitrogen action represent a strategy for selecting genotypes or managements that optimize the use of the nutrient. In this perspective, in Tables 3 and 4 the correlations and path analysis are presented, seeking a real understanding of the cause and effect of wheat ear components on grain yield in nitrogen management.

In Table 3, in the correlation and path analysis in the soybean/wheat system, a high correlation between ear mass and grain yield is observed in a single and fractioned nitrogen dose at different levels of the nutrient. This correlation shows the participation of the direct effect via grain yield and the indirect effect through the grain mass and number of grains in the ear. The ear grain mass also shows a high correlation with yield under all conditions. Likewise, the direct effect with productivity is shown to be enhanced, along with ear mass and number of grains per ear. The number of grains per ear also has a strong correlation with grain yield, with the exception of the phenological stage V_3/R_1, at the dose of 60 and 120 kg ha^{-1} of nitrogen. In these doses of fertilizer, the maximum expression of the number of grains that influences productivity has possibly already been reached, canceling out the effects of this correlation. The existing dynamics of positive and negative effects on this relationship stand out, being potentialized, mainly through the direct way of grain yield. There is also relevance in the indirect effect via ear mass and grain mass per ear. In the correlation between ear length and grain yield, there is no effective relationship under different nitrogen management conditions. Overall, there is a prominent direct effect of grain yield and an indirect effect of ear mass, grain mass per ear, and ear grain number. The harvest index also shows effectiveness compared to ear length, a relationship indirectly linked to ear mass, ear grain mass and ear grain number.

Table 3. Correlation and path analysis from the stages of nitrogen application at different fertilizer doses on wheat in a soybean/wheat system.

Variables		30 kg ha^{-1} of N			60 kg ha^{-1} of N			120 kg ha^{-1} of N		
		V_3	V_3/V_6	V_3/R_1	V_3	V_3/V_6	V_3/R_1	V_3	V_3/V_6	V_3/R_1
r (ME X PG)		0.87*	0.75*	0.94*	0.98*	0.92*	0.67^{ns}	0.90*	0.98*	0.92*
	D: PG	0.35	-0.09	0.72	0.25	0.22	0.17	0.25	0.34	0.22
	ID:MGE	0.33	-0.06	0.52	0.23	0.40	0.29	0.20	0.24	0.30
ME	ID:NGE	-0.17	0.43	-0.27	0.23	0.17	-0.22	0.20	0.41	-0.10
	ID: CE	-0.02	0.48	0.02	0.09	0.02	0.18	0.07	0.03	0.46
	ID: ICE	0.38	-0.01	-0.08	0.19	0.10	0.25	0.19	-0.04	0.04
r (MGE X PG)		0.91*	0.81*	0.92*	0.99*	0.90*	0.85*	0.96*	0.97*	0.94*
	D: PG	0.23	-0.07	0.55	0.23	0.42	0.31	0.21	0.24	0.30
	ID: ME	0.34	-0.09	0.72	0.25	0.22	0.16	0.24	0.34	0.22
MGE	ID:NGE	-0.25	0.45	-0.29	0.23	0.17	-0.25	0.20	0.41	-0.11
	ID: CE	-0.02	0.52	0.02	0.09	0.02	0.25	0.10	0.03	0.48
	ID: ICE	0.61	0.00	-0.08	0.19	0.07	0.38	0.22	-0.05	0.04
r (NGE X PG)		0.78*	0.90*	0.77*	0.98*	0.89*	0.47^{ns}	0.95*	0.98*	0.76*
	D: PG	-0.18	0.47	-0.31	0.24	0.18	-0.40	0.20	0.41	-0.18
	ID: ME	0.34	-0.08	0.67	0.24	0.22	0.10	0.25	0.34	0.12
NGE	ID:MGE	0.31	-0.06	0.45	0.22	0.40	0.21	0.20	0.25	0.18
	ID: CE	-0.02	0.57	0.03	0.09	0.02	0.26	0.10	0.03	0.45
	ID: ICE	0.33	0.00	-0.07	0.19	0.07	0.32	0.20	-0.05	0.05
r (CE X PG)		0.28^{ns}	0.93*	0.64^{ns}	0.93*	0.76*	0.84*	0.68^{ns}	0.83*	0.91*
	D: PG	-0.61	0.62	0.03	0.09	0.02	0.32	0.17	0.03	0.53
	ID: ME	0.18	-0.08	0.55	0.23	0.18	0.10	0.09	0.29	0.19
CE	ID:MGE	0.14	-0.06	0.40	0.21	0.33	0.24	0.12	0.20	0.27
	ID:NGE	-0.09	0.45	-0.28	0.22	0.15	-0.32	0.12	0.34	-0.15
	ID: ICE	0.10	0.00	-0.06	0.18	0.08	0.50	0.18	-0.04	0.07
r (ICE X PG)		0.92*	-0.04^{ns}	0.83*	0.99*	-0.55^{ns}	0.92*	0.94*	0.80*	0.69^{ns}
	D: PG	0.46	0.02	-0.09	0.19	-0.17	0.53	0.23	-0.05	0.06
	ID: ME	0.30	0.04	0.67	0.24	-0.13	0.11	0.20	0.28	0.13
ICE	ID:MGE	0.31	0.01	0.50	0.23	-0.16	0.22	0.19	0.21	0.22
	ID:NGE	-0.14	-0.07	-0.27	0.24	-0.08	-0.24	0.19	0.35	-0.14
	ID: CE	-0.01	-0.04	0.02	0.09	-0.01	0.30	0.13	0.02	0.42
R^2		0.86	0.85	0.87	0.99	0.84	0.96	0.96	0.96	0.91
K		0.05	0.03	0.05	0.05	0.05	0.04	0.05	0.05	0.05

N= nitrogen; V_3= collar formed on the 3rd sheet of the main culm; V_6= collar formed on the 6th sheet of the main culm; R_1= ear differentiation; PG= grain yield (kg ha^{-1}); ME= ear mass (g); MGE= grain mass per ear (g); NGE= number of grains per ear (n); CE= ear length (cm); ICE= ear harvest index (g g^{-1}); r= correlation value; D= direct contribution; ID= indirect contribution; R^2= determination coefficient; K= linearization coefficient; *= significant at 5% probability of error by the test t; ^{ns}= not significant. Single dose (100 %) in phenological stage V_3 (third expanded leaf); fractionated dose (70% and 30%) at the V_3/V_6 phenological stage (third and sixth expanded leaf), and fractionated dose (70% and 30%) at phenological stage V_3/R_1 (expanded third leaf and beginning of grain filling).

In Table 4, from the correlation and trail analysis in the corn/wheat system, in the vast majority of associations, a lack of correlation with grain yield was detected, very different result from those observed for soybean residue (Table 3). The correlation of ear mass and grain yield was detected only at the highest dose of fertilizer in the fractionated condition V_3/V_6. In this result, there is a high direct effect of grain yield, followed by a positive indirect effect of the ear mass and number of grains. In the correlation between ear grain mass and yield, a significant and positive association was only observed in stage V_3 at the dose of 30 and 60 kg ha^{-1} of nitrogen, with an indirect contribution on ear length. This condition reinforces the need for fertilization in a single way (V_3) in a reduced or intermediate dose of N-fertilizer. At the highest dose, the positive correlation between ear grain mass and grain yield was detected only in the V_3/V_6 condition. The strong direct contribution via grain yield and indirect by the ear mass stands out. In the correlation between the number of grains in the ear and grain yield, this relationship was significant only at the highest dose, when in phenological stage V_3. This condition expresses a high positive direct effect via grain yield. In the correlation of ear length with grain yield, under the condition of 30 kg ha^{-1} of nitrogen, a high negative correlation was detected, indicating that the increase in ear length promotes a reduction in grain yield at stages V_3 and V_3/R_1. Under both conditions, the direct negative effect of grain yield was decisive on the magnitude of these correlations. It is noteworthy that at the dose of 60 kg ha^{-1} of nitrogen, at stage V_3, the negative correlation between ear length and grain yield was also detected, with a high negative indirect effect via ear grain mass, and negative direct for productivity. These results reinforce the care taken in the development of new cultivars with high ear length, which can promote a reduction in grain yield, especially under lower N-fertilizer conditions. In the correlation between ear harvest index and grain yield, a significant correlation was detected at stages V_3 and V_3/V_6, at a dose of 60 kg ha^{-1} of the nutrient.

Table 4. Correlation and path analysis from the stages of nitrogen application at different fertilizer doses on wheat in a corn/wheat system.

Variables		30 kg ha^{-1} of N			60 kg ha^{-1} of N			120 kg ha^{-1} of N		
		V_3	V_3/V_6	V_3/R_1	V_3	V_3/V_6	V_3/R_1	V_3	V_3/V_6	V_3/R_1
r (ME X PG)		0.59^{ns}	0.26^{ns}	-0.12^{ns}	0.46^{ns}	0.03^{ns}	0.55^{ns}	-0.01^{ns}	0.84*	0.44^{ns}
	D: PG	0.35	-0.12	-0.10	-0.33	-0.37	0.21	-0.01	0.37	0.31
	ID: MGE	0.06	0.31	0.31	0.89	0.20	-0.72	-0.27	0.28	0.20
ME	ID: NGE	-0.07	-0.02	-0.01	-0.09	0.10	0.00	0.52	0.22	0.02
	ID: CE	0.22	-0.27	-0.27	0.04	-0.16	-0.09	-0.11	-0.01	0.03
	ID: ICE	0.00	-0.02	-0.02	-0.01	0.28	0.15	-0.03	-0.02	-0.13
r (MGE X PG)		0.88*	0.31^{ns}	0.41^{ns}	0.88*	0.60^{ns}	0.40^{ns}	-0.10^{ns}	0.93*	0.58^{ns}
	D: PG	0.10	0.12	0.45	0.05	0.25	-0.81	0.51	0.50	0.23
	ID: ME	0.19	0.18	-0.09	-0.17	-0.30	1.08	-0.27	0.30	0.28
MGE	ID: NGE	0.02	0.32	-0.06	-0.12	0.12	0.01	-0.20	0.03	-0.07
	ID: CE	0.66	-0.54	0.20	0.25	-0.21	-0.12	-0.22	-0.01	0.41
	ID: ICE	-0.10	0.23	-0.09	-0.03	0.72	0.24	-0.09	0.10	-0.27
r (NGE X PG)		-0.26^{ns}	0.56^{ns}	-0.10^{ns}	0.49^{ns}	0.35^{ns}	0.23^{ns}	0.81*	-0.45^{ns}	0.45^{ns}
	D: PG	-0.19	0.46	-0.16	-0.14	0.20	-0.05	0.67	-0.22	-0.25
	ID: ME	0.14	0.14	0.00	-0.20	-0.19	-0.02	0.10	0.01	-0.02
NGE	ID: MGE	-0.01	0.08	0.13	0.87	0.15	0.22	-0.18	-0.06	0.06
	ID: CE	-0.18	-0.25	0.00	0.01	-0.26	0.24	0.13	-0.08	0.87
	ID: ICE	0.00	0.11	-0.02	-0.02	0.43	-0.14	0.08	-0.05	-0.20
r (CE X PG)		-0.93*	-0.22^{ns}	-0.91*	-0.72*	0.40^{ns}	0.10^{ns}	-0.40^{ns}	-0.23^{ns}	0.61^{ns}
	D: PG	-0.60	-0.72	-0.91	-0.29	-0.29	0.31	-0.32	-0.09	0.96
	ID: ME	-0.13	0.10	-0.70	0.04	-0.21	-0.36	-0.03	0.06	0.01
CE	ID: MGE	-0.09	0.09	-0.05	-0.47	0.18	0.32	0.24	0.03	0.10
	ID: NGE	-0.06	0.16	-0.22	0.00	0.19	-0.04	-0.19	-0.18	-0.23
	ID: ICE	0.00	0.14	0.01	0.02	0.54	-0.13	-0.10	-0.03	-0.26
r (ICE X PG)		0.64^{ns}	0.35^{ns}	0.23^{ns}	0.74*	0.93*	0.11^{ns}	-0.43^{ns}	0.86*	0.50^{ns}
	D: PG	0.00	0.33	-0.12	-0.03	0.88	0.29	-0.12	0.10	-0.35
	ID: ME	-0.02	0.08	-0.02	-0.11	-0.12	0.64	-0.03	0.23	0.12
ICE	ID: MGE	0.08	0.08	0.21	0.84	0.21	-0.69	0.39	0.37	0.18
	ID: NGE	0.06	0.16	-0.02	-0.11	0.10	0.02	-0.36	0.11	-0.14
	ID: CE	0.52	-0.31	0.18	0.16	-0.18	-0.15	-0.27	0.03	0.72
R^2		0.90	0.73	0.70	0.89	0.91	0.60	0.72	0.86	0.78
K		0.10	0.05	0.31	0.11	0.05	0.01	0.31	0.27	0.05

N= nitrogen; V_3= collar formed on the 3rd sheet of the main culm; V_6= collar formed on the 6th sheet of the main culm; R_1= ear differentiation; PG= grain yield (kg ha^{-1}); ME= ear mass (g); MGE= grain mass per ear (g); NGE= number of grains per ear (n); CE= ear length (cm); ICE= ear harvest index (g g^{-1}); r= correlation value; D= direct contribution; ID= indirect contribution; R^2= determination coefficient; K= linearization coefficient; *= significant at 5% probability of error by the test t; ^{ns}= not significant. Single dose (100 %) in phenological stage V_3 (third expanded leaf); fractionated dose (70% and 30%) at the V_3/V_6 phenological stage (third and sixth expanded leaf), and fractionated dose (70% and 30%) at phenological stage V_3/R_1 (expanded third leaf and beginning of grain filling).

The fertilizer supply in V_3 showed a strong indirect contribution by the ear grain mass, and the direct effect of grain yield in V_3/V_6. In the nitrogen dose of 120 kg ha^{-1}, only the V_3/V_6 stage was observed a significant correlation, with a greater indirect effect by the ear grain mass. Such conditions show that the ear mass and the ear grain mass bring the greatest contributions in the magnitude of the correlations on the grain yield in the corn/wheat system. Allied to this, there are distinct changes in the dynamics of productivity relationships with ear components in different doses of nitrogen use due to the type of succession system (C/N ratio). Therefore, the reduced number of component relationships with yield suggests that the application of nitrogen in V_3 comprises the beginning of the floral primordium differentiation, the amounts provided at this stage in corn/wheat system, possibly also being used as an energy source by bacteria responsible for the decomposition of the straw. In addition, the doses of nitrogen in this condition may have been limiting, especially in fractionation, in which 30% of the doses applied in V_3 was removed, decisive period for the development of tillering and differentiation of the number of spikelets per ear.

The study of correlation between components linked to grain yield in different crops can favor the choice of genotypes and/or more adjusted managements. However, only the correlations are not able to inform the cause and effect relationships between the explanatory and the main variables, suggesting the decomposition of these relationships via path analysis (Costa, 2013; Mantai et al., 2016). Vesohoski et al. (2011) comment that indirect selection through the number of grains per ear, taking into account the mass of a thousand grains, is the best strategy to obtain wheat cultivars with high grain yield. Kavalco et al. (2014) identified through path analysis that the characters that most contributed to wheat grain yield were grain mass per ear, number of grains per ear, mass of a thousand grains and number of fertile tillers. Mantai et al. (2020b) through path analysis, observed that in oat cultivation, the increase in nitrogen fertilization in coverage promotes an increase in total protein and a reduction in fiber in the oat grains. In addition, they observed that the increase in grain protein by nitrogen fertilization implies a reduction in grain and industry productivity. Oliveira et al. (2021) conclude through path analysis that the number of grains per ear in wheat is the most efficient characteristic in selecting high-yielding cultivars under heat stress conditions. Teixeira Filho et al. (2010), identified that the timing of fertilizer-N application is one of the most controversial aspects in the management of nitrogen fertilization of grasses in a no-tillage system, since, in the first years of adoption of this system, there may be an initial shortage of nitrogen resulting from the immobilization caused by the microbial decomposition of the residues of the predecessor culture. According to Ferrari et al. (2016), the number of grains per ear is influenced by the forms of nitrogen supply, and has a strong correlation with grain yield. Therefore, the aim is to increase the number of grains on the ear in order to increase the final yield. Silva et al. (2015) found that the amount of nitrogen made available in the corn/wheat system brings significant results on grain yield, with the ear components being mainly altered by the mass of a thousand grains and the mass of grains per ear. Furthermore, the behavior of cultivars in terms of yield and nitrogen utilization components are dependent on the agricultural year under study (Megda et al., 2009). The distinct associations in the direct and indirect effects of the wheat inflorescence characters show the importance of analyzes regarding the doses and forms of nitrogen supply, enabling the choice of variables that provide indications for management that improve the expression of the final grain yield.

CONCLUSIONS

The increase in the nitrogen doses promotes productivity due to the greater contribution of grain mass and ear length in the V_3 stage and ear grain mass in V_3/V_6 and V_3/R_1, in the soybean/wheat system. In the corn/wheat system, the increase in nitrogen promotes productivity with a greater contribution of grain mass in the ear, regardless of the form of supply.

Nitrogen supply in a single dose (V_3) and fractionated at V_3/V_6 shows similarity in productivity, with a reduction in V_3/R_1. The grain mass of the ear shows greater contribution of alteration by the form of single and fractioned nitrogen supply, regardless of the dose and succession system.

The grain mass of the ear shows a high correlation with yield, regardless of the dose and form of nitrogen supply in the soybean/wheat system, with a positive indirect effect by the ear mass. In the corn/wheat system, ear grain mass shows a high correlation with yield, when nitrogen is supplied in a single dose at 30 and 60 kg ha^{-1}, with a positive indirect effect due to ear length.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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