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TILLERING CAPACITY AND NITROGEN FERTILIZATION IN WHITE OAT

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ABSTRACT - Nitrogen fertilization enhances the tillering capacity of white oats and a greater number of fertile tillers is directly related to the increase in grains per area, which is related to grain yield. The objectives of this work were to evaluate the tillering capacity and the linear relationships between characters of white oat cultivars, associated with the use of nitrogen fertilization. The experiment was carried out in Santa Maria - RS, in a randomized block design, with the main plot comprising five white oat cultivars and the subplot comprising four doses of nitrogen applied as a top dressing when the crop had 3 developed leaves (0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1}, and 150 kg ha^{-1}). Six hundred plants were sampled when the crop was at the full tillering stage and the characters were assessed: plant height (cm), height of first leaf insertion (cm), number of fully expanded leaves, number of tillers, stem diameter (cm), and dry matter phytomass (g). Nitrogen had a positive effect on the number of tillers, with the most effective doses being between 101.67 and 122.14 kg ha-1. The 122.14 kg ha^{-1} dose is recommended in order to achieve maximum technical efficiency for the production of tillers in the white oat crop, with emphasis on the URS Altiva cultivar, which had the highest number of tillers. The number of tillers and plant height have a positive linear relationship with dry matter phytomass and can be used for indirect selection.
Keywords: *Avena sativa* L., nitrogen doses, morphological characters, path analysis, indirect selection.

CAPACIDADE DE AFILHAMENTO E ADUBAÇÃO NITROGENADA EM CULTIVARES DE AVEIA BRANCA

RESUMO - A adubação nitrogenada potencializa a capacidade de afilhamento na cultura da aveia branca e um maior número de afilhos férteis apresenta relação direta com o aumento de grãos por área, estando relacionado com a produtividade de grãos. Os objetivos deste trabalho foram avaliar a capacidade de afilhamento e as relações lineares entre caracteres de cultivares de aveia branca, associado ao uso de adubação nitrogenada. O experimento foi conduzido em Santa Maria - RS, experimental de blocos ao acaso, com parcela principal de cinco cultivares de aveia branca e a subparcela com quatro doses de nitrogênio aplicadas em cobertura quando a cultura apresentava de 3 folhas desenvolvidas (0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1} e 150 kg ha^{-1}), quando a cultura encontrava-se no estádio de afilhamento pleno foram amostradas 600 plantas e avaliados os caracteres: altura de planta (cm), altura de inserção da primeira folha (cm), número de folhas completamente expandidas, número de afilhos, diâmetro do colmo (cm) e fitomassa da matéria seca (g). O nitrogênio teve efeito positivo para a emissão de afilhos, com doses mais eficazes entre 101,67 e 122,14 kg ha^{-1}, sendo indicado aquela a dose de 122,14 kg ha^{-1}, a fim de alcançar a máxima eficiência técnica para a produção de afilhos na cultura da aveia branca, com destaque para a cultivar URS Altiva, que apresentou maior número de afilhos. O número de afilhos e altura de planta têm relação linear positiva com a fitomassa de matéria seca e podem ser caracteres utilizados na seleção indireta.
Palavras-chave: *Avena sativa* L., doses de nitrogênio, caracteres morfológicos, análise de trilha, seleção indireta.

INTRODUCTION

White oats (*Avena sativa* L.) are one of the most widely grown cereals in temperate regions, including southern Brazil during the cold season, due to their wide agricultural suitability. Through its grain production, the cereal provides a source of food for human and animal consumption, as well as being used as a ground cover and as fodder for animal grazing. The inclusion of the crop in the production system improves the biological, chemical, and physical properties of the soil (LI et al., 2021), making it an excellent alternative for diversifying the production system in a profitable and sustainable way.

The Brazilian cultivated area of white oats was 503,400 ha in the 2020/21 harvest and is estimated at 542,400 ha for the 2021/22 harvest, with a projected growth of 7.7% compared to the previous harvest. Grain production was 1,143.2 thousand tons in the 2020/21 harvest and is estimated at 1,267 thousand tons for the 2021/22 harvest, an increase of 10.8% over the previous harvest (CONAB, 2022), with the state of Rio Grande do Sul standing out in Brazil production scenario.

The agronomic performance of white oats is directly related to the availability of nitrogen to the plants throughout the development cycle. The use of nitrogen fertilizer significantly increases crop yield (ALLWOOD et

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al., 2021), increasing grain yield, phytomass and grain protein content (MANTAI et al., 2021). Nitrogen is important in the early vegetative stages of white oats and can promote tillering capacity and interfere with physiological processes and morphological changes in plant growth and development (MARSHALL et al., 2013).

However, cultivars respond differently to nitrogen levels, so it is necessary to develop specific management strategies for each cultivar (YAN et al., 2017). Since in Brazil, some white oat cultivars are intended for specific purposes, such as the use of cover crops, use as forage and some for the main purpose of grain production. In this context, proper nitrogen management is important in order to achieve the maximum production potential of each cultivar in a sustainable way. Therefore, evaluating the biometric characteristics of plants at the beginning of their development and checking their linear relationships helps to position cultivars and select white oat genotypes with greater initial growth.

One way of assessing the linear relationships between characters is by using Pearson linear correlation coefficient, which is suitable for measuring the degree of correlation between two characters (FERREIRA, 2009). However, when there are more than two traits under study, path analysis is appropriate as it provides information on the interrelationships between the traits. In path analysis, the correlation coefficients are broken down into direct and indirect effects, which makes it possible to measure the influence of one variable on another, independently of the others (CRUZ, 2006). Evaluating the response of white oat cultivars to tillering ability and its association with plant characteristics is a gap for cultivars intended for grain production. The objective of this study was to evaluate the tillering capacity and estimate the linear relationships between characters of white oat cultivars associated with the use of nitrogen fertilization.

MATERIAL AND METHODS

The experiment was carried out in an experimental area located at the Universidade Federal de Santa Maria (UFSM), in the city of Santa Maria (under geographical coordinates of latitude 29º 71' S, longitude 53º 70' O and altitude of 90 m), situated in the central region of the state of Rio Grande do Sul. According to the Köppen classification, the predominant climate in the region is *Cfa*, humid subtropical with hot summers and no defined dry season (ALVARES et al., 2013). The soil in the experimental area is managed under a no-tillage system and is classified as Argissolo Vermelho Distrófico Arnico (SANTOS et al., 2018).

According to the chemical analysis of the soil, the experimental area had: 1.5% organic matter; pH in H_2O = 5.3; H + Al = 3.9 cmolc dm^{-3}; P (Melich) = 22.1 mg dm^{-3}; K^+ = 0.184 cmolc dm^{-3}; Ca^{+2} = 3.1 cmol$_c$ dm^{-3}; and Mg^{+2} = 0.8 cmolc dm^{-3}.

The experimental design adopted was randomized blocks, in a 5 x 4 factorial scheme, with three replications. The treatments consisted of a combination of five cultivars of white oats, randomized in the main plots (URS Altiva, URS Brava, URS Charrua, URS Corona, and URS Taura) and four doses of nitrogen in top dressing, randomized in the subplots (0, 50, 100 and 150 kg ha^{-1} of N). The experimental units consisted of nine sowing rows, spaced 0.20 m apart and 7 m long, with a total area of 12.6 m^2. The useful area of each subplot was 2.52 m^2, with the plants collected for evaluation in the 3 central rows of the experimental units.

Sowing was carried out on May 11, 2019, following the period determined by the agricultural zoning of climatic risk, for cultivars in groups 1, 2, and 3, in Santa Maria (RS), with corn as the preceding crop. Using a winter experimental plot seeder, a density of 300 viable seeds m^{-2} was sown.

The base fertilizer deposited in the sowing furrow was 15 kg ha^{-1} of nitrogen, 60 kg ha^{-1} of phosphorus, and 60 kg ha^{-1} of potassium, mixed in the 05-20-20 formulation. Top-dressing nitrogen fertilization was carried out with the application of urea (45% N), when the plants reached the stage of 3-4 open leaves, the ideal time for top-dressing nitrogen fertilization. The other crop treatments, such as fungicide, herbicide, and insecticide applications, were carried out in accordance with the technical indications for growing wheat in the state of Rio Grande do Sul.

To evaluate the response of the development of plant morphological characters to different doses of nitrogen, a sample of 10 random plants was collected in each subplot, when they reached the full tillering stage, totaling 600 plants sampled for evaluation. The characters measured were plant height (PH, cm), measuring the height from the neck of the stem to the apex of the last leaf; height of insertion of the first leaf (HIFL, cm), measuring the height from the neck of the stem to the collar, number of fully expanded leaves on the whole plant (NLWP), diameter of the stem (DS, cm), measured close to the ground using a caliper, number of tillers (NT), and dry mass of the plants (DMP, g), determined by drying them in an oven for 168 h at a temperature of 60°C and then weighing them on a precision scale.

The variables evaluated were subjected to analysis of variance and, if a significant effect was obtained, further statistical analysis was carried out using the Scott-Knott test to discriminate between the effects of the cultivars and polynomial regression for the effect of the N doses. The matrix of Pearson linear correlation coefficients (r) was estimated between the characters PH, HIFL, NLWP, DS, NT, and DMP and the significance of the coefficients was verified using Student t-test.

Multicollinearity was diagnosed using the matrix of Pearson linear correlation coefficients (r) between PH, HIFL, NLWP, DS, and NT. The criteria established by Montgomery and Peck (1982) were used to interpret the diagnosis of multicollinearity. A correlation matrix with a condition number (CN) of less than 100 is classified as having weak multicollinearity, moderate to strong when $100 \leq CN \leq 1,000$ and severe when CN > 1,000. Finally, a cause and effect analysis was carried out on the main variable (DMP) as a function of the explanatory variables (PH, HIFL, NLWP, DS, and NT). The analyses were carried out using the Microsoft Office Excel® application and the Genes software (CRUZ, 2016), adopting a 5% probability of error in the statistical analyses. Sigma Plot 14.5 software was used for the graphical representations.

RESULTS AND DISCUSSION

The analysis of variance showed a significant effect of the cultivar factor and N dose separately, with no significant interaction observed. For the variables PH, HIFL, NLWP, DS, NT, and DMP, there were significant differences (Table 1).

TABLE 1 - Mean squares from the analysis of variance (ANOVA) of the white oat characters evaluated.

FV	DF	PH	HIFL	NLWP	DS	NT	DMP
Blocks	2	360.827	132.738	51.361	0.881	0.186	0.022
Cultivar	4	72.316*	19.876*	9.101*	0.894*	1.674*	0.084*
Error 1	8	100.607	32.196	13.201	0.146	0.168	0.033
Dose of N	3	322.308*	91.049*	29.177*	0.873*	2.973*	0.376*
Cultivar*Dose of N	12	7.665^{ns}	2.259^{ns}	1.075^{ns}	0.064^{ns}	0.206^{ns}	0.020^{ns}
Error 2	30	98.828	33.238	0.686	0.058	0.074	0.019
Average	-	48.08	13.91	6.50	3.81	1.44	0.82
CV(%) Cultivar	-	6.60	12.90	17.66	10.03	28.34	22.06
CV(%) Dose of N	-	6.54	13.10	12.73	6.34	18.87	16.80

FV = variation factor, DF = degrees of freedom, CV = coefficient of variation (%), PH = plant height (cm), HIFL = height of insertion of the first leaf (cm), NLWP = number of fully expanded leaves on the whole plant, DS = diameter of the stem (cm), NT = number of tillers and DMP = dry mass of the plants (g), *significant at 5% probability of error by the test F, ns = not significant by the test F.

It is observed that in terms of PH, the cultivars URS Altiva (45.22 cm) and URS Taura (45.77 cm) had lower plant heights compared to the other cultivars. As for HIFL, the cultivars URS Taura and URS Corona showed lower insertion height of the first leaf compared to the other cultivars (Table 2). In terms of NLWP and NT, the URS Altiva cultivar had the highest number of total leaves per plant (7.87 leaves) and the highest number of tillers (2.09 tillers) compared to the other cultivars. Finally, with regard to the DMP variable, the cultivars URS Charrua (0.92 g) and URS Altiva (0.91 g) had higher dry matter phytomass values per plant compared to the other cultivars.

TABLE 2 - Means of agronomic characters evaluated in five white oat cultivars.

Cultivars	PH	HIFL	NLWP	DS	NT	DMP
URS Altiva	45.22 b*	14.07 a	7.87 a	3.95 a	2.09 a	0.91 a
URS Brava	49.12 a	14.72 a	6.27 b	3.35 b	1.37 b	0.75 b
URS Charrua	50.81 a	15.52 a	6.80 b	4.05 a	1.38 b	0.92 a
URS Corona	49.51 a	12.88 b	5.79 b	3.84 a	1.13 b	0.80 b
URS Taura	45.77 b	12.39 b	5.80 b	3.89 a	1.27 b	0.76 b
CV(%)	6.97	14.01	15.64	11.64	22.05	17.98

*Means followed by the same letter in the column do not differ from each other using the Scott-Knott test, at a 5% probability of error, CV = coefficient of variation (%). PH = plant height (cm), HIFL = height of insertion of the first leaf (cm), NLWP = number of fully expanded leaves on the whole plant, DS = diameter of the stem (cm), NT = number of tillers and DMP = dry mass of the plants (g).

Cultivars can differ in their ability to produce tillers, cycle and seed production potential (COSTA et al., 2013). According to Kavalco et al. (2014), the number of tillers is highly influenced by genotypic characteristics and environmental conditions. In addition, the same authors point out that selecting plants with a higher number of tillers will result in more productive genotypes. The biomass productivity of white oats is associated with the response of cultivars, management technologies, climate, and soil conditions (MAROLLI et al., 2018). This highlights the importance of positioning white oat cultivars, as the production of dry matter phytomass varies according to the growing region, cultivar, and management used (COELHO et al., 2020).

The oscillations in the responses of the variables PH, HIFL, NLWP, DS, NT, and DMP of white oats to the different doses of nitrogen applied are shown in Figure 1. The treatments with the highest nitrogen availability showed the highest values for the variables measured, with an increasing response for the variables PH, HIFL, NLWP, DS, NT, and DMP as the dose of nitrogen used increased, until the point of maximum technical efficiency (MTE) was reached.

The maximum technical efficiencies were identified with the nitrogen fertilizer dose of 122.43 kg ha^{-1} (51.13 cm) for PH; 114.75 kg ha^{-1} (15.73 cm) for HIFL, 136.25 kg ha^{-1} (8.22 leaves) for NLWP, 107.00 kg ha^{-1} (4.04 cm) for DS, 122.14 kg ha^{-1} (1.86 tillers) for NT, and 101.67 kg ha^{-1} (0.92 g) for DMP. The doses of maximum technical efficiency of nitrogen use obtained in this work are similar to those described by Kolmanič et al. (2022) and Mantai et al. (2021), with the optimum dose of N for oats ranging from 30 to 120 kg ha^{-1}, depending on the environment, cultivar, crop rotation system, and soil management. A similar result is described for another winter grass by Trautmann et al. (2022), where the wheat crop obtained MTE with 120 kg ha^{-1} of N applied in a single dose at phenological stage V3.

Nitrogen fertilization in oats results in morphological and physiological changes in plant growth (KOLMANIČ et al., 2022), stimulating vegetative growth, influencing biomass production and the nutritional quality of the leaves due to the higher protein content (OBOUR et al., 2018). The application of N to white oat crops is related to the tillering process, influencing the emission and survival of tillers (DEISS et al., 2014). Increasing tillering and tiller survival is an important aspect of increasing biomass (ZILIO et al., 2018) and grain yield in white oats (SEIDEL et al., 2022).

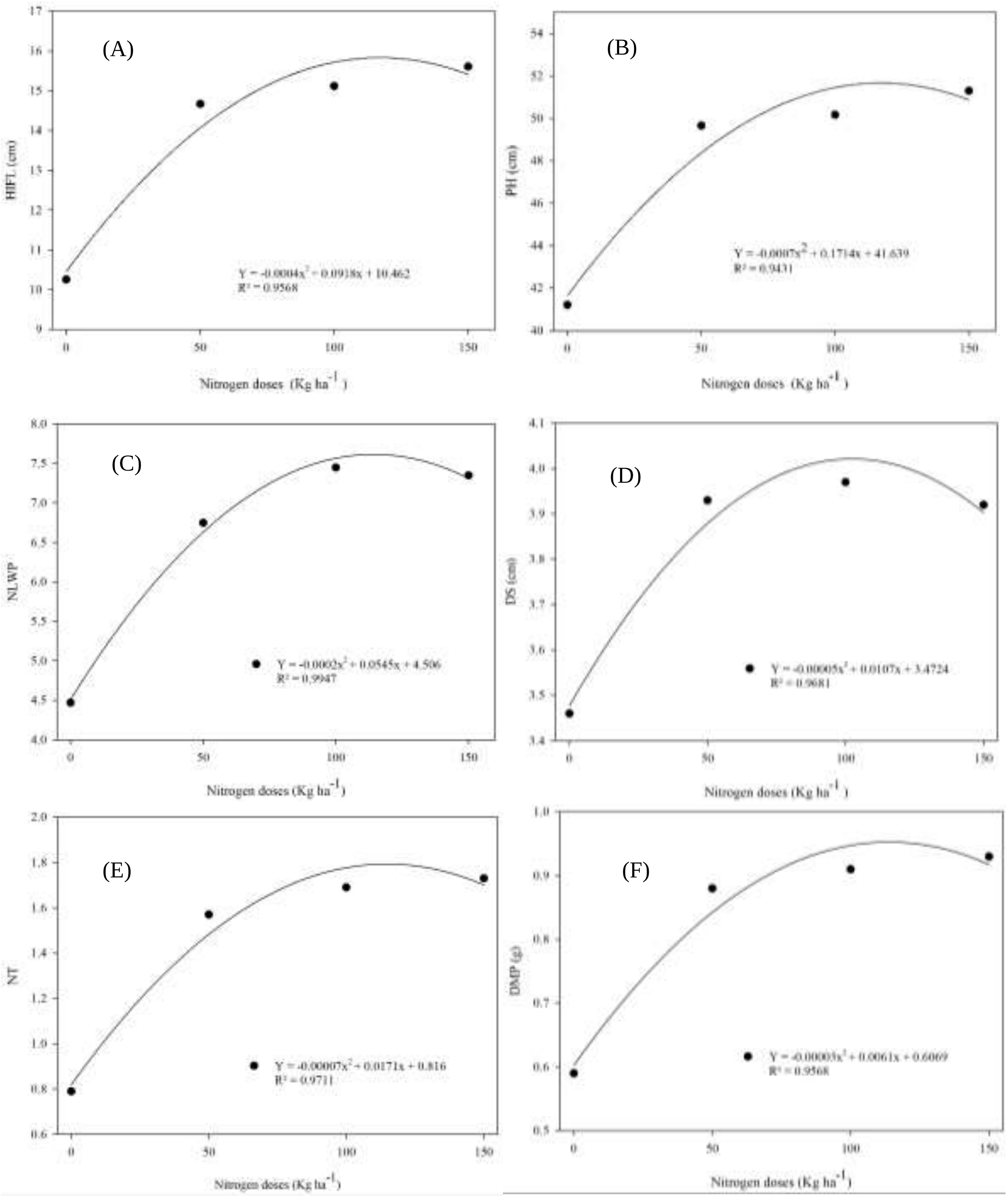

FIGURE 1 - Height of first leaf insertion (cm) (A), plant height (cm) (B), number of fully expanded leaves on the whole plant (C), stem diameter (cm) (D), number of tillers (E), and dry matter phytomass (g) (F), for white oat cultivars as a function of nitrogen doses (kg ha^{-1}).

In the same way as in other cereals, the height of plants in white oat cultivars is related to the availability of nitrogen in the growing environment, with an increase in height generally being observed due to the increase in nitrogen doses (HAWERROTH et al., 2014). However, high doses of nitrogen can make the plant more vulnerable to lodging. For white oats, there is a strong positive correlation (r = 0.88) between lodging and the dose of nitrogen (KOLMANIČ et al., 2022), as well as causing damage to the environment through leaching or volatilization of nitrates, leading to a decrease in the efficiency of nitrogen use and economic losses for farmers (COSTA et al., 2013).

Based on the 600 plants evaluated, Pearson linear correlation coefficients (r) between the white oat characters ranged from $0.4487 \leq r \leq 0.9083$ (Table 3), showing positive linear associations between the characters evaluated. Positive associations between white oat traits, using genotypic and phenotypic correlations, were also verified by Nirmalakumari et al. (2013).

TABLE 3 - Pearson linear correlation coefficient between characters measured in five white oat cultivars.

Characters	PH	HIFL	NLWP	DS	NT	DMP
PH	-	0.8604*	0.6302*	0.7394*	0.4487*	0.7006*
HIFL		-	0.7051*	0.5748*	0.5876*	0.7518*
NLWP			-	0.6297*	0.9083*	0.8140*
DS				-	0.5277*	0.6938*
NT					-	0.8022*
DMP						-

*Significant at 5% probability of error, respectively, by t-test. PH = plant height, HIFL = height of insertion of the first leaf, NLWP = number of fully expanded leaves on the whole plant, DS = diameter of the stem, NT = number of tillers and DMP = dry mass of the plants.

The NLWP × NT correlation showed the highest degree of linear association (r = 0.9083), highlighting that the greater the number of tillers, the greater the number of leaves on the plant. Similar results were reported by Cargnelutti Filho et al. (2015), who evaluated the correlation between these characters in black oats and obtained correlations of 0.70 to 0.91. The NT x DMP correlation showed a strong degree of linear association (r = 0.8022) and the PH x DMP correlation a moderate degree of linear association (r = 0.7006). In this way, an increase in the number of tillers and plant height leads to an increase in dry mass production/plant.

Similar results were described by Ahmad et al. (2013), who observed that the fresh mass of white oats showed a positive linear correlation with plant height, number of leaves, and number of tillers. Nirmalakumari et al. (2013) observed a significant genotypic and phenotypic correlation between number of tillers and green mass in white oats. The correlations PH × NT (r = 0.4487), HIFL x NT (r = 0.5876), DS x NT (r = 0.5277), were positive, but with a lower magnitude. Therefore, it can be seen that the NT has low linear relationships with the other characteristics.

After carrying out the multicollinearity test between the variables, a condition number equal to 62.91 was obtained, showing the occurrence of collinearity classified as weak, according to the criteria of Montgomery & Peck (1982). Thus, the cause and effect analysis (Table 4) of DMP, as a function of the explanatory variables PH, HIFL, NLWP, DS, and NT, can be carried out properly, and it is possible to identify their direct and indirect effects on DMP. The NT had the greatest direct effect on DMP (0.5898), confirming the relationship observed earlier. PH also had a direct effect on DMP (0.1520), showing that the higher the number of tillers per plant and the greater the plant height, the greater the positive relationship with dry phytomass.

TABLE 4 - Direct and indirect effects of the analysis of cause and condition number of characters measured in five white oat cultivars, based on Pearson correlation matrix.

Effects	PH	HIFL	NLWP	DS	NT
Direct effect on DMP	0.1520	0.2364	-0.1139	0.2061	0.5898
Indirect effect via PH		0.1307	0.0958	0.1123	0.0682
Indirect effect via HIFL	0.2034		0.1667	0.1359	0.1389
Indirect effect via NLWP	-0.0718	-0.0803		-0.0717	-0.1034
Indirect effect via DS	0.1524	0.1185	0.1297		0.1087
Indirect effect via NT	0.2646	0.3465	0.5357	0.3112	
Total (Pearson correlation)	0.7006*	0.7518*	0.8140*	0.6938*	0.8022*
Coefficient of determination	0.8076				
Effect of residual variable	0.1924				
Condition index	62,91				

*Significant at 5% probability of error, respectively, by t-test t. PH = plant height, HIFL = height of insertion of the first leaf, NLWP = number of fully expanded leaves on the whole plant, DS = diameter of the stem, NT = number of tillers and DMP = dry mass of the plants.

The results observed are in line with those described by Gupta and Mehta (2019), who observed a strong positive correlation between the characters plant height, number of tillers per plant and dry matter production of white oats. Poonia et al. (2017) considered plant height, number of tillers and leaf length to be the main traits that have a direct effect on the dry mass productivity of white oats and are effective in developing genotypes with high yield potential.

In a study by Cargnelutti Filho et al. (2015), cause and effect analysis was applied to unfold the direct and indirect effects of plant morphological variables on the production of fresh and dry phytomass of black oats. The results observed by these authors indicated that the number of leaves per plant and plant height have a positive linear relationship with fresh and dry matter, used as variables for indirect selection, corroborating the results obtained in this study, where a direct effect of the number of leaves per plant and plant height on dry matter phytomass was observed, making it possible to use these characters for indirect selection of white oat cultivars.

CONCLUSIONS

Nitrogen had a positive effect on the number of tillers, with the most effective doses being between 101.67 and 122.14 kg ha^{-1}. The dose of 122.14 kg ha^{-1} is recommended in order to achieve maximum technical efficiency for the production of tillers in the white oat crop, with emphasis on the URS Altiva cultivar, which had the highest number of tillers.

The number of tillers and plant height of white oats have a positive linear relationship with dry matter phytomass and can be used for indirect selection.

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