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Italian ryegrass subjected to doses of nitrogen, phosphorus and potassium in plintossolo

Azevém italiano submetido a doses de nitrogênio, fósforo e potássio em plintossolo

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ABSTRACT

The objective of this study was to evaluate the combination of nitrogen (N), phosphorus (P), and potassium (K) doses associated with the maximum total dry matter production of Italian ryegrass (*Lolium multiflorum* Lam). The experiment was conducted in pots in a greenhouse at the Federal University of Pampa, Campus Itaqui – RS, Brazil. A total of 20 treatments were tested, resulting from the combination of four N doses (0, 75, 125, and 175% of the recommended N rate) and five doses of P and K (0, 50, 100, 150, and 200% of the recommended rates). The experimental design was completely randomized in a 4 x 5 factorial arrangement with four replicates. Two, five, six, and five cuts were made referring to doses of N, 0, 75, 125, and 175%, respectively, as the plant reached 20 cm in height to obtain total dry matter (DM) production. Data were subjected to analysis of variance ($P < 0.05$) using the F test with adjusted regressions. The model with the highest significance level between linear and quadratic regressions was selected. Dry matter production (kg ha^{-1}) exhibited a quadratic response to increasing N doses across all P and K levels, with higher production between levels 75 and 125% of N. The highest yield was obtained with 125% of the recommended N dose combined with 150% of the recommended P and K doses, with a mean DM production of 625 kg ha^{-1}.

KEYWORDS: Dry matter production. *Lolium multiflorum* Lam. Nitrogen fertilization. Pasture.

RESUMO

O objetivo deste estudo foi avaliar a combinação de doses de nitrogênio (N), fósforo (P) e potássio (K) associadas à máxima produção total de matéria seca do azevém anual (*Lolium multiflorum* Lam). O experimento foi conduzido em vasos em estufa da Universidade Federal do Pampa, Campus Itaqui – RS, Brasil. Foram testados 20 tratamentos, resultantes da combinação de quatro doses de N (0, 75, 125 e 175% da recomendação de N) e cinco doses de P e K (0, 50, 100, 150 e 200% da dose recomendada). O delineamento experimental utilizado foi o inteiramente casualizado, em arranjo fatorial 4 x 5, com quatro repetições. Foram feitos dois, cinco, seis e cinco cortes referentes às doses de N, 0, 75, 120 e 175%, respectivamente, à medida que a planta atingia 20 cm de altura para obtenção da produção total de matéria seca (MS). Os dados foram submetidos à análise de variância ($P < 0,05$) utilizando o teste F com regressões ajustadas. Foi escolhido o modelo com maior grau de significância entre a regressão linear e quadrática. A produção de matéria seca (kg ha^{-1}) apresentou efeito quadrático com o aumento das doses de N aplicadas, em todos os níveis de P e K utilizadas, com maiores produções entre os níveis 75 e 125% de N. O maior rendimento foi obtido com 125% da dose recomendada de N combinada com 150% das doses recomendadas para P e K, com uma produção média de MS de 625 kg ha^{-1}.

PALAVRAS-CHAVE: Produção de matéria seca. *Lolium multiflorum* Lam. Fertilização nitrogenada. Pastagem.

INTRODUCTION

Animal production in natural pastures under a humid subtropical climate, as observed in southern Brazil, relies on warm season species that exhibit reduced growth rates and a decrease in quality in the cool season period. This period of limited forage availability due to cold temperatures limits livestock production rates, affecting the profitability of the production system. In this context, using forages from temperate climates has been one of the main strategies used to overcome forage scarcity in autumn-winter (EMADODIN et al. 2021).

Italian ryegrass (*Lolium multiflorum* Lam.) is one of the most widely used temperate grasses worldwide for pasture, hay, and silage production (YAVUZ et al. 2017, GAYER et al. 2019, DORNELLES et al. 2022). It is characterized by high forage yield, a prolonged vegetative cycle, disease resistance, good regrowth potential, high nutritional value, high production of seeds, natural reseeding capacity, and low implementation cost (CARVALHO et al. 2010). Since it thrives in mild to warm climatic conditions, with peak production at temperatures between 20 and 25 °C, it is a great forage option to complement the vegetative cycle of natural pastures to minimize the effects of forage deficit during winter in subtropical climates (HAVILAH 2017).

In addition to its fundamental role in satisfying food demand during the cool season, Italian ryegrass is extremely important for environmental and economic sustainability in integrated agricultural production. Due to its reseeding ability and regrowth potential when well managed, it can as soil cover, contributing to the increase in carbon stock, improvements in fertility and stability of soil aggregates, in addition to helping to control weeds (BARBOSA et al. 2009). However, despite its good quality, forage production depends on the management practices, with the availability of water and nutrients being the main limitations (ABRAHA et al. 2015). Among the essential nutrients, nitrogen (N), phosphorus (P), and potassium (K) are the primary determinants of DM production, and key modulators of forage productivity (MEDEIROS & NABINGER 2001). The N promotes leaf elongation and profile density, while P is essential for root development and plays a crucial role in grass tillering. Regarding K, it plays a vital role in physiological and metabolic functions, including of photosynthetic enzymes and the translocation of assimilates (TAIZ et al. 2017).

Although the importance of these nutrients in the physiological processes of forage plants is evident, the high cost of fertilizers can lead to a reduction in their use, resulting in a decline in pasture quality and production (PEREIRA et al. 2022). Furthermore, fertilization recommendations are often generalized for forage species, highlighting the need for studies to determine the optimal fertilizer doses and using them rationally (DOMICIANO et al. 2020). In this context, this study aimed to evaluate the combination of nitrogen, phosphorus, and potassium doses associated with the maximum dry matter production of Italian ryegrass in a Plintossolo.

MATERIALS AND METHODS

The experiment was carried out in pots inside a greenhouse at the experimental area of the Federal University of Pampa, Itaqui Campus – RS, at latitude 29° 9′ 21.37″ S and longitude 56° 33′ 9.97″ W. The municipality of Itaqui is located on the western region of the state of Rio Grande do Sul, featuring a subtropical climate with no defined dry season (Cfa), according to the Köppen climate classification.

The experimental design was completely randomized in a 4 x 5 factorial scheme and four replications, consisting of four levels of nitrogen (N) and five levels of phosphorus (P) and potassium (K), totaling 80 pots. The four doses of N consisted of the application of 0%; 75%; 125% and 175% times the recommended dose of N. The five doses of P and K were 0%; 50%; 100%; 150%; and 200% the recommended P and K doses. Level 1, which corresponds to the recommended fertilization, was considered a dose of 200 mg dm^{-3} of P and 300 mg dm^{-3} of N and K. The other levels were established based on level 1 (standard) in percentages (0%, 75%, 125%, and 175%, N) and (0%, 50%, 100%, 150% and 200%, P and K) of that considered for N, P and K according to Table 1, following the CQFS-RS/SC, 2004, guidelines.

The soil used as substrate was collected from a 0 to 20 cm depth and is classified as Plintossolo Argilúvico Distrófico (SANTOS et al. 2018). The soil was previously dried, loosened, sieved, and placed in 8-liter conical pots with an upper diameter of 25 cm, a lower diameter of 17 cm, and a height of 24 cm. The soil chemical properties are described in Table 2, according to the methodology outlined in the fertilization and calculation manual for the states of Rio Grande do Sul and Santa Catarina (ROLAS 2004). The ryegrass cultivar used was Barjumbo, and five seeds were sown in each pot at a depth of 1 cm, with one plant remaining after thinning.

Table 1. Applied NPK doses in Italian Ryegrass and their percentage relative to the normally recommended dose.

Treatments	N	P	K	% N	% PK
	mg dm^{-3}				
T1	0	0	0	0	0
T2	0	100	150	0	50
T3	0	200	300	0	100
T4	0	300	450	0	150
T5	0	400	600	0	200
T6	225	0	0	75	0
T7	225	100	150	75	50
T8	225	200	300	75	100
T9	225	300	450	75	150
T10	225	400	600	75	200
T11	375	0	0	125	0
T12	375	100	150	125	50
T13	375	200	300	125	100
T14	375	300	450	125	150
T15	375	400	600	125	200
T16	525	0	0	175	0
T17	525	100	150	175	50
T18	525	200	300	175	100
T19	525	300	450	175	150
T20	525	400	600	175	200

*Recommended dose: 300 mg kg-1 of N, 200 mg kg-1 of P, and 300 mg kg-1 of K.

A calculation was performed to increase base saturation (V%) from 41 to 70%. Phosphate and potassium fertilizers were applied in a single dose. The doses of N were divided into three applications, with 50% applied at sowing and the remaining 50% distributed after the cuts (25% of the dose after the first cut and 25% of the dose after the second cut), both in the form of solution.

Table 2. Characterization of the Plintossolo Argilúvico Distrófico, before treatment application, Itaqui - RS.

pH_{H2O}	Ca	Mg	Al	H+Al	MO	S	P-Melich	K
	--------------------cmol$_c$ kg^{-1}----------------				%	-----------mg dm^{-3}-----------		
5.1	3.03	0.96	0.5	7.7	1.7	4.6	3	24

Ca: calcium; Mg: magnesium; Al: aluminum; H+Al: potential acidity; MO: organic matter; S: sulfur; P-melich: phosphorus extractor using the Melich method; K: potassium.

The cuts were made when the average plant height reached 20 cm, from the 10th to the 150th day after emergence (DAE). Thus, two, five, six, and five cuts corresponding to the N doses (0, 75, 125 and 175%) were made, leaving the plants with a residual height of 10 cm. The samples were placed in paper bags, weighed on a semi-analytical precision balance, and then dried in a forced air circulation oven at 55 °C for 72 hours. After drying, the samples were weighed again to determine the DM. Total DM production values (kg DM ha^{-1}) were determined by summing the cuts from the four replications of the same treatment per pot area, calculated as 0.5104 m^2.

Data was analyzed by ANOVA, and when significant effects were detected by the F test at a 5% probability level, regression equations were fitted. The significance of the linear and quadratic regression components was tested, and the model with the highest level of significance was selected.

RESULTS AND DISCUSSION

Total DM production showed a quadratic effect (P < 0.05) with increasing of N doses, regardless of the applied doses of P and K. There was no significant interaction between N doses and P and K doses (P > 0.05), and, therefore, regression analysis was performed for each level of P and K tested, using the quadratic response. However, the total average DM production for the 0% P and K dose was 72.36; 78.08; 97.08; and 50.09 kg ha^{-1} for increasing doses of 0, 75, 125, and 175 kg of N ha^{-1}, respectively. It is evident that the absence of P and K significantly affected the increase in DM, as even with 125% of the recommended N dose, only an average of 97.08 kg ha^{-1} was obtained (Figure 1). Thus, it is evident that the absence of a single essential element for plant development reduces MS production (MAGNUCKA et al. 2023). Furthermore, the production of diploid cultivars is greater than that of tetraploid cultivars in hydromorphic soils, a characteristics of the soil used in the present study (DORNELLES et al. 2022).

With the application of 50% of the recommended dose of P and K, the average DM was 72.25; 518.51; 501.61, and 490.79 kg ha^{-1} for increasing levels of 0, 75, 125 and 175kg of N ha^{-1}, obtaining an average of 395.79 kg ha^{-1} (Figure 2). The DM production of cold-season forage grasses is influenced, among other factors, by the adequate management of nitrogen fertilization, where greater biomass production is achieved with increased N doses (MEDEIROS & NABINGER 2001, QUATRIN et al. 2015).

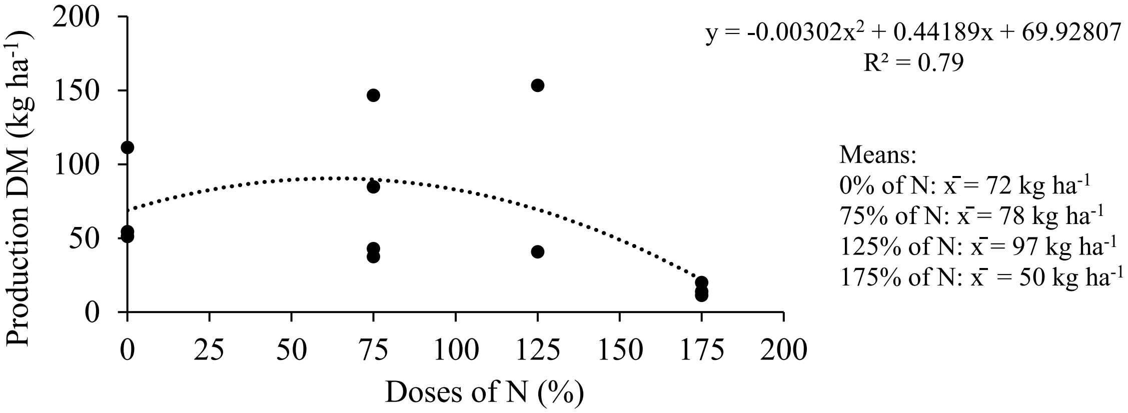

Figure 1. Total dry matter production, in Italian Ryegrass, of ryegrass subjected to doses of nitrogen with application of 0% of the recommended dose of phosphorus and potassium.

However, the low DM productions observed in this study are attributed to the law of the minimum, where LIEBIG (1840) proved that the absence of one or more essential nutrients inhibits the growth and development of plants. In addition, the soil used as a substrate has low organic matter content, resulting in a positive response to increasing N doses up to a certain point (SILVA et al. 2024). At the doses above 125%, which was identified as the maximum technical efficiency dose, further nutrient absorption did not translate into increased DM yield, indicating a condition of "luxury consumption".

Using 100% of the recommended dose of P and K, the average DM was 68.82; 452.0; 561.18; and 405.32 kg ha^{-1} for doses of 0, 75, 125, and 175 kg of N ha^{-1}, respectively (Figure 3). Similar results were evident with the application of 150% of the recommended dose of P and K, yielding average DM of 65.98; 557.55; 625.34, and 521.68 kg ha^{-1} for doses of 0, 75, 125, and 175 kg of N ha^{-1}, respectively (Figure 4). The application of 200% of the recommended doses for P and K resulted in average DM yields of 121.52; 601.73; 573.37 and 485.55 kg ha^{-1} for the same N levels mentioned above (Figure 5). Different levels of N, P, and K applied to cool-season forage grasses showed the best results when the highest doses of all three nutrients were combined (LERMI et al. 2023).

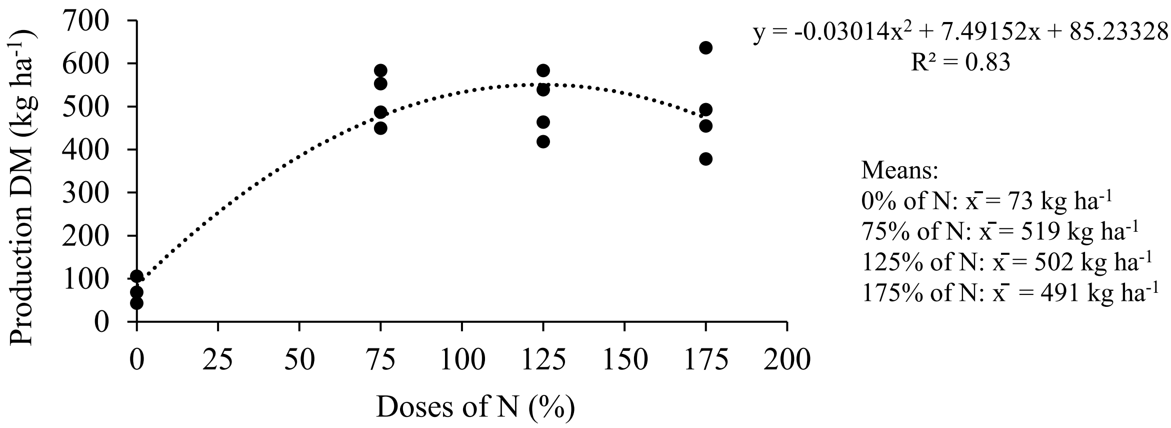

Figure 2. Total dry matter production in Italian Ryegrass subjected to nitrogen doses with application of 50% of the recommended dose of phosphorus and potassium.

The highest DM values were obtained in treatments with higher levels of phosphate and potassium fertilization. However, a similar level of production can be observed from 50% of the recommended dose of fertilizer for P and K. The interaction between these nutrients is a key factor, as plants may exhibit different behaviors, leading to variations in biomass production (RAGÁLYI et al. 2025). This result can likely be explained by the fact that P is an essential component of several important compounds in plant cells, such as phosphate sugars and intermediates of respiration and photosynthesis. In contrast, K plays a crucial role in the activation of enzymes involved in plant respiration and photosynthesis, which may directly contribute to biomass accumulation (DUNKER et al. 2023).

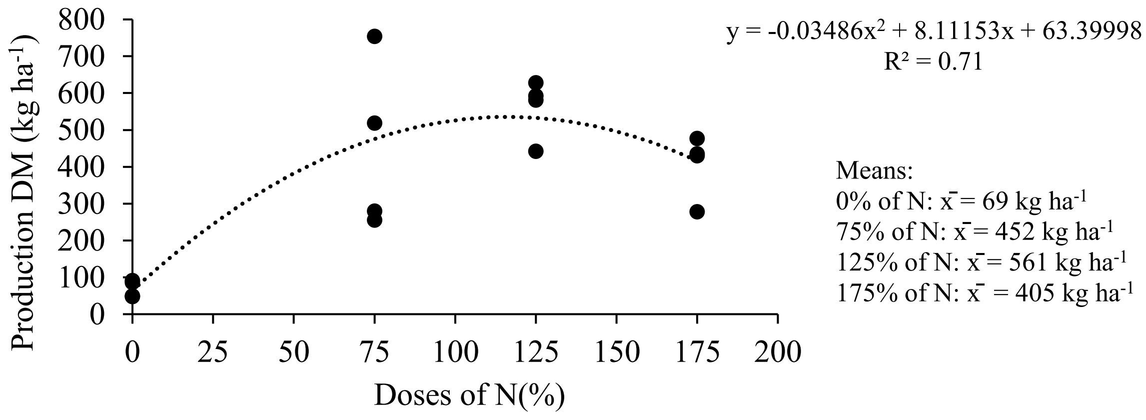

Figure 3. Total dry matter production in Italian Ryegrass subjected to nitrogen doses with application of 100% of the recommended dose of phosphorus and potassium.

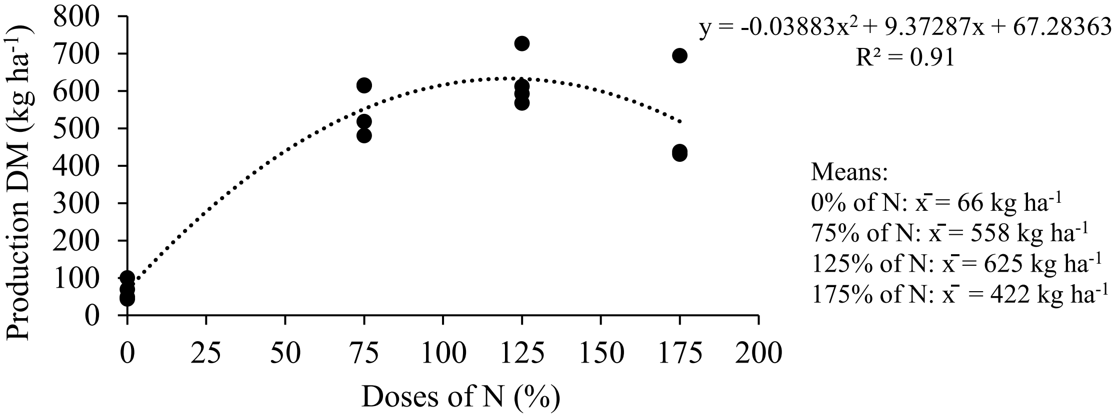

Figure 4. Total dry matter production in Italian Ryegrass subjected to nitrogen doses with application of 150% of the recommended dose of phosphorus and potassium.

The low availability of P in the soil can compromise the establishment and development of forages, as well as reduce tiller production, number of leaves and total DM as results of low nutrient absorption (ROZANE et al. 2008). The increase in the applied dose and nutrient absorption causes high DM production in black oat (CARVALHO et al. 2010), equivalent to the results found in this work. Application of 150% of P and K doses was more efficient in DM production when N was supplied to the soil ($p < 0.05$). This is mainly attributed to the high DM production observed at this dose, as it continued to show increased production even with higher N doses, indicating better nutrient interaction. Higher DM yields were also observed when 200% of P and K doses were applied, however, when deciding on application doses, other factors must be considered, such as operational, economic, and environmental aspects, to ensure better technical efficiency.

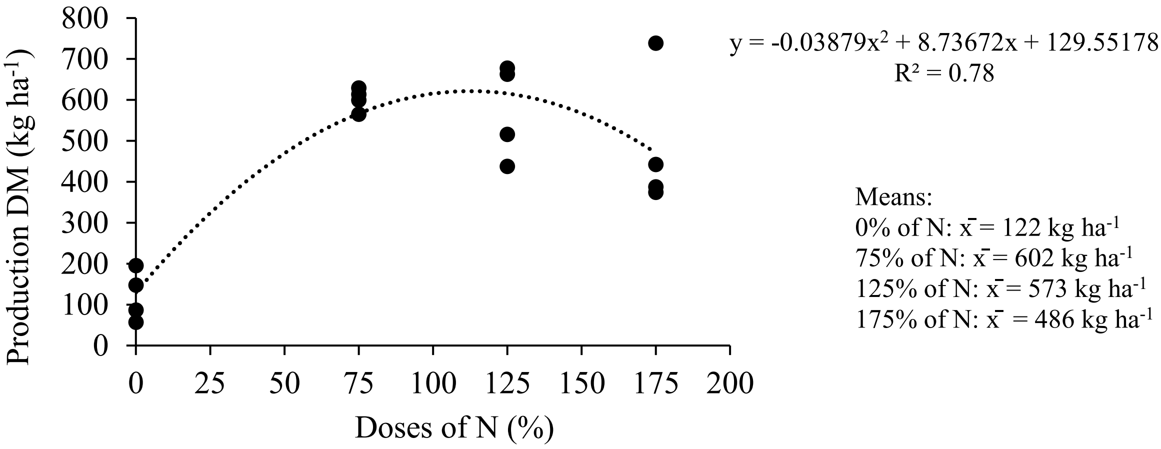

Figure 5. Total dry matter production in Italian Ryegrass subjected to nitrogen doses with application of 200% of the recommended dose of phosphorus and potassium.

This positive response of the crop can be explained by the interaction between the applied nutrients and the characteristics of the soil used, a Plitossolo Argilúvico Distrófico. This soil type has low natural fertility, high acidity, and low base saturation, which limits the availability of nutrients such as phosphorus due to fixation by iron and aluminum oxides. Therefore, even with high nitrogen doses, dry matter production is only optimized when phosphorus and potassium are simultaneously corrected. The combined and increased application of these nutrients helps overcome the chemical limitations of the soil, promoting a more favorable environment for root development, efficient nutrient uptake, and shoot growth. Therefore, the results highlight the importance of considering edaphic constraints when planning fertilization strategies, especially in soils with restrictive characteristics such as Plintossolos.

CONCLUSION

Phosphorus and potassium limitation reduced the effect of nitrogen on dry matter production in pots. On the other hand, N supply stimulated nutrient uptake. In soils with low organic matter content, the response to N was positive up to 125% of the recommended dose, above that, there was excessive absorption, with no productive gain. The highest dry matter production occurred with 125% N and 150% P and K in Plintossolo with tetraploid Italian ryegrass cultivars. However, larger scale studies with different ryegrass cultivars are needed to directly assess the limit between technical efficiency and production costs.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis**, EM, PJP and EBA**; software and validation**, MTB, LBM and LSD;** investigation**, MTB, PJP and EM**; resources and data curation**, LBM, PJP and EBA**; writing-original draft preparation**, MTB, EBD and EBA**; writing-review and editing**, LRS, LBM, LSD and EBD**; visualization**, EBA**; supervision, **PJP and EBA**; project administration, **EM, PJP and EBA**.. All authors have read and agreed to the published version of the manuscript.

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INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable for studies not involving humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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