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Strategies for split nitrogen topdressing in potato

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Abstract

This work evaluated the effects of splitting nitrogen topdressing applications on potato under field conditions. The experiment was carried out in the municipality of Ibiraiaras, Rio Grande do Sul (RS), Brazil, within a commercial production area during the 2023/1 season. Using a split-plot design with three treatments and four replicates, YaraBela 27-00-00 was applied. The first application occurred 34 days after planting (DAP), at hilling; subsequent applications were at 53, 68, and 83 DAP. Treatment 1 applied 75 kg·ha^{-1} at the first application, 75 kg·ha^{-1} at the second, and 100 kg·ha^{-1} at the third. Treatment 2 applied 75 kg·ha^{-1}, 50 kg·ha^{-1}, 50 kg·ha^{-1}, and 75 kg·ha^{-1} at the first, second, third, and fourth applications, respectively. Treatment 3 served as the control (producer's standard), with two applications only: 100 kg·ha^{-1} at the second and 150 kg·ha^{-1} at the third application. At crop maturity, tuber mass, number, and yield were assessed for two size classes (> 45 mm and < 45 mm), as well as total yield. Splitting did not affect tuber number. However, three applications increased average tuber mass in both size classes and significantly increased the yield of tubers < 45 mm. Under the evaluated edaphoclimatic conditions, dividing nitrogen into three topdressing applications is a favorable strategy for potato cultivation.

Keywords: ammonium-N; nitrate-N; nitrogen nutrition; *Solanum tuberosum*; tuber.

Resumo

Estratégias de parcelamento da adubação nitrogenada na cultura da batata

O objetivo deste trabalho foi avaliar os efeitos da aplicação de nitrogênio em cobertura em diferentes parcelamentos no cultivo da batata, em condições de campo. O experimento foi realizado no município de Ibiraiaras, RS, em meio a uma área de produção comercial na safra 2023/1. Conduzido na forma de parcelas subdivididas, contou com três tratamentos e quatro repetições com aplicação de YaraBela 27-00-00. A primeira aplicação foi efetuada aos 34 dias após o plantio, correspondendo à fase de amontoa. As aplicações seguintes foram aos 53, 68 e 83 dias após o plantio. O Tratamento 1 contou com a aplicação na dose de 75 kg·ha^{-1} na primeira fase de aplicação, 75 kg·ha^{-1} na segunda fase de aplicação e 100 kg·ha^{-1} na terceira fase de aplicação. O Tratamento 2 contou com a dose de 75 kg·ha^{-1} na primeira fase de aplicação, 50 kg·ha^{-1} na segunda fase de aplicação, 50 kg·ha^{-1} na terceira fase de aplicação e 75 kg·ha^{-1} na quarta fase de aplicação. O Tratamento 3 correspondeu ao controle, mantendo-se o padrão do produtor e contando com apenas duas aplicações na dose de 100 kg·ha^{-1} na segunda fase de aplicação e 150 kg·ha^{-1} na terceira fase de aplicação. Ao final do ciclo da cultura, foram avaliados os parâmetros de massa, número e produtividade dos tubérculos classificados em duas categorias: acima de 45 mm e abaixo de 45 mm, além da produtividade total. Os resultados demonstraram que o parcelamento não afetou o número de tubérculos produzidos. Entretanto, o parcelamento em três aplicações proporcionou maior massa média de tubérculos acima e abaixo de 45 mm, refletindo em um aumento significativo da produtividade de tubérculos abaixo de 45 mm. Assim, nas condições edafoclimáticas avaliadas, o parcelamento do nitrogênio em três aplicações é uma estratégia favorável para a cultura da batata.

Palavras-chave: nitrogênio nítrico; nitrogênio amoniacal; nutrição; *Solanum tuberosum*; tubérculo.

Resumen

Estrategias para instalar fertilización con nitrógeno en el cultivo de papa

El objetivo de este trabajo fue evaluar los efectos de la aplicación de fertilizantes nitrogenados en diferentes etapas del cultivo de papa, en condiciones de campo. El experimento se realizó en el municipio de Ibiraiaras, RS, en plena zona de producción comercial durante la cosecha 2023/1. Realizado en forma de parcelas subdivididas, contó con tres tratamientos y cuatro repeticiones, y la aplicación de YaraBela 27-00-00. La primera aplicación se realizó a los 34 días después de la siembra, correspondiente en la fase de aporque. Las siguientes aplicaciones se realizaron a los 53, 68 y 83 días después de la siembra. El tratamiento 1 incluyó una aplicación a una dosis de 75 kg·ha^{-1} en la primera fase, otra a la misma dosis en la segunda fase y una última a 100 kg·ha^{-1} en la tercera fase. El tratamiento 2 tuvo una dosis de 75 kg·ha^{-1} en la primera fase de aplicación, 50 kg·ha^{-1} en la segunda fase y en la tercera fase de aplicación y 75 kg·ha^{-1} en la cuarta. El tratamiento 3 correspondió al testigo, manteniendo el estándar del productor, con solo dos aplicaciones: una de 100 kg·ha-1 en la segunda fase y otra de 150 kg·ha^{-1} en la tercera. Al final del ciclo del cultivo se evaluaron los parámetros de masa, número y productividad de los tubérculos clasificados en dos categorías: superiores a 45 mm y inferiores a 45 mm, además de la productividad total. Los resultados demostraron que la división no afectó la cantidad de tubérculos producidos. Sin embargo, la división en tres aplicaciones proporcionó una mayor masa media de tubérculos superior e inferior 45 mm, lo que resultó en un aumento significativo de la productividad inferior 45 mm. En consecuencia, en función de las condiciones edafoclimáticas evaluadas, la estrategia más favorable para el cultivo de papas es la división del nitrógeno en tres aplicaciones.

Palabras clave: nitrógeno nítrico; nitrógeno amoniacal; nutrición; *Solanum tuberosum*; tubérculo.

Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world, playing a strategic role in global food security (FAO, 2025). The pursuit of high productivity has increased production costs, necessitating the generation of information to aid decision-making, especially regarding the nutrition of this crop (Gomes, 2019).

Potatoes have high nitrogen (N) requirements, a macronutrient that plays a decisive role in vegetative growth, yield, and tuber quality (Koch *et al.*, 2020). Due to its high demand, nitrogen fertilization represents a significant portion of production costs and is directly associated with potential losses due to leaching, volatilization, and gaseous emissions, making it a central issue in crop sustainability (Mahmud *et al.*, 2021).

For the states of Santa Catarina and Rio Grande do Sul, nitrogen indications are based on the organic matter (OM) content present in the soil. Based on productivity expectations greater than 20 t·ha^{-1}, for soils with OM less than or equal to 2.5 % w/v, it is recommended to use 160 kg·ha^{-1} for OM contents varying from 2.6 – 5.0 % w/v, 140 kg·ha^{-1} is indicated and, with OM contents greater than 5.0 % w/v, doses equal to or less than 120 kg·ha-1 (Sociedade Brasileira de Ciência do Solo - SBCS, 2016). However, in Brazil, the recommendations for nitrogen fertilization for potato vary between 60 – 250 kg·ha^{-1} of N (Fernandes *et al.*, 2015).

Synchronizing soil N availability with the crop's demand curve is one of the greatest management challenges. Potatoes require the most nitrogen during the tuber growth period. Approximately 58 – 70 % of the N required throughout the production period is absorbed during this developmental phase (Koch *et al.*, 2020). Therefore, split application at different phenological stages has been studied as a strategy to maximize nutrient use efficiency, mitigate environmental losses, and increase yield stability (Clément *et al.*, 2021; Davenport *et* *al.*, 2005; Joern, Vitosh, 1995; Khakbazan *et al.*, 2024).

However, the benefits of split N application vary with climate and soil conditions, with conflicting results in the literature regarding potato yield. Some studies demonstrate that splitting may not yield significant yield gains (Errebhi *et al.*, 1998; Vos, 1999; Zebarth *et al.*, 2004). On the other hand, excess N or poorly synchronized applications result in residual nitrate in the soil, increasing the risk of leaching into groundwater and emissions of nitrous oxide (N_2O), a potent greenhouse gas (Gao *et al.*, 2013; Ning *et al.*, 2023; Shcherbak; Millar; Robertson, 2014; Su *et al.*, 2024).

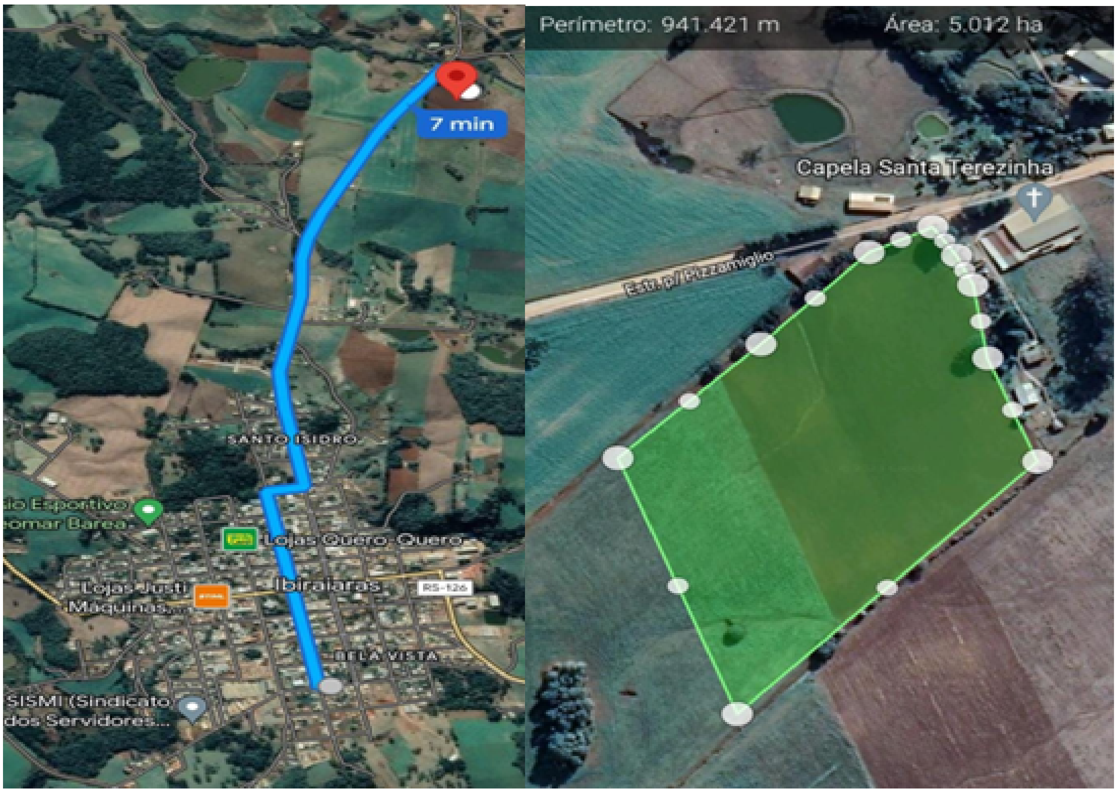
Therefore, given the ongoing change in potato production levels and the need to maximize nutrient use efficiency and reduce losses of environmentally harmful nitrogen compounds, experiments with nitrogen fertilization are still necessary. Although splitting nitrogen fertilization has shown benefits in terms of N use efficiency and productivity, results may vary depending on factors such as soil texture, precipitation regime, and management practices. Given the above, this work aimed to evaluate the effects of applying nitrogen as a top dressing in different divisions on potato cultivation under field conditions.

Materials and methods

Experimental location

The work was conducted in a commercial cultivation (coordinates: 28°21' S and 51°36' W) area in the municipality of Ibiraiaras, localized in the northeast region of Rio Grande do Sul State, Brazil (Figure 1), at a distance of 247 km from Porto Alegre (state capital), with an altitude of 795 m and a Cfa climate type according to Köppen classification (Alvares *et al.*, 2013). The soil was classified at the site as red oxisol. The area used for the experiment included the cultivation of soybeans in the 2020/2021 harvest in a direct planting system, onions in the 2021 harvest, and potatoes in the 2022 harvest in conventional cultivation. The experiment took place 3 km from the city of Ibiriaras, RS, in the middle of commercial farming of the Asterix® variety, with 5 ha of potatoes for fresh commercial purposes.

Figure 1 - Route and localization of the experiment field. Ibiraiaras, RS.



Source: authors (2025).

Soil fertility conditions before the installation of the experiment are compiled in Table 1.

Table 1 - Fertility parameters of the soil before the installation of the experiment and their interpretation regarding soybean crop requirements.

Parameter	Unit	Depth (cm)	
		0-20	20-40
pH	-	5.7	5.1
H+Al	$cmol_c \cdot dm^{-3}$	5.5	10.9
Clay	% w/v	48	51
CTC (pH 7.0)	$cmol_c \cdot dm^{-3}$	17.6	18.3
MO	% w/v	5.8	2.7
Al	$cmol_c \cdot dm^{-3}$	0.04	1.4
Ca	$cmol_c \cdot dm^{-3}$	8.9	5.0
Mg	$cmol_c \cdot dm^{-3}$	2.7	2.0
K	$mg \cdot dm^{-3}$	209.8	149.0
P	$mg \cdot dm^{-3}$	4.6	1.9
S	$mg \cdot dm^{-3}$	<4.1	10.3
Zn	$mg \cdot dm^{-3}$	19.8	14.4
Cu	$mg \cdot dm^{-3}$	5.1	2.3
Mn	$mg \cdot dm^{-3}$	7.0	18.1
B	$mg \cdot dm^{-3}$	1.0	0.7
Base Saturation	%	68.9	40.2

Source: authors (2025).

Experimental design and treatments

The experiment was conducted in the form of plots, subdivided into three distinct plots, varying the amounts of nitrogen supplied via coverage and the time of application. The experiment was implemented within an area of 5 ha with three treatments in plots of 72 m^2 (4.8 m x 15 m), divided into four replications containing 18 m^2 (2.4 m x 7.5 m) in each plot. Each treatment had six planting rows, where nitrogen applications were made using the commercial fertilizer YaraBela® from the first half of April to the second half of May de 2023. YaraBela® fertilizer contains 27 wt.% of N, 5 wt.% of Ca and 3.7 wt.% of S, coming from the sources calcium nitrate ($Ca(NO_3)_2$) and ammonium sulfate ($(NH_4)_2SO_4$). The total dose of commercial fertilizer used was the same in all treatments and those used by the farmer, e.g., 250 $kg \cdot ha^{-1}$.

Treatment T1 consisted of three application stages: the first and second applications of 75 $kg \cdot ha^{-1}$ and the third application of 100 $kg \cdot ha^{-1}$. In treatment T2, a first dose of 75 $kg \cdot ha^{-1}$ was applied, the second and third applications were 50 $kg \cdot ha^{-1}$, and the fourth was 75 $kg \cdot ha^{-1}$. The T3 treatment corresponded to the control, being the standard used by the producer, being an application of 100 $kg \cdot ha^{-1}$ in the second moment and a dose of 150 $kg \cdot ha^{-1}$ in the third moment of application. Nitrogen applications were carried out on April 3 (1st), April 22 (2nd), May 7 (3rd) and May 22, 2023 (4th).

Experiment conduction

The fertilizer used was Top Mix 04-14-08, at a dosage of 3,500 $kg \cdot ha^{-1}$, the fertilizing regime adopted by the farmer, and limestone was not added. Pests and diseases were controlled through weekly monitoring in the area, totaling 15 applications during the crop cycle, which lasted 115 days from planting to harvest, using fungicides and insecticides recommended for the crop (Brasil, 2025). Rainfall in the area was monitored using a manual acrylic rain gauge with a scale of up to 150 mm. Precipitation data, expressed in millmeters (mm), was collected, and the water volume was discarded after each rainfall event from March 3 to May 8, 2023. Irrigation followed the producer's standard and was carried out in accordance with precipitation monitoring and meteorological information, such as the weather forecast. The area had slightly sloped terrain, favoring mechanization and water drainage from excessive rainfall.

Experiment assessment

The evaluation of the experiment took place on July 18, 2023, during harvest, using equipment to start the Hennipman WH-11.2 potatoes. The plots were evaluated separately, discarding the two lateral border rows and analyzing all the tubers in the two central rows over a length of 3 m, totaling 4.8 m² (1.6 m x 3.0 m). The number, mass, and productivity of tubers were evaluated.

The tubers were first manually classified into two categories, adapted from Ceagesp (2015): caliber greater than and less than 45 mm. Then, tubers from each category were counted and weighed to determine the number and total mass of tubers in each category (>45 mm and <45 mm). Furthermore, total productivity was estimated by calculating the total mass produced in the useful area of the plots and each category.

Statistical analysis

The data obtained were analyzed for normality using the Shapiro-Wilk test and homoscedasticity using the Levene test at a significance level of 5 %. The comparison of means was performed using analysis of variance (ANOVA), followed by the Tukey test ($p \leq 0.05$). All statistical analyses were performed using SPSS 21.0 software (SPSS inc., Chicago, IL).

Results and discussion

The results regarding the number of tubers larger or smaller than 45 mm depending on the nitrogen splitting in the potato crop did not show significant statistical differences, as shown in Table 2.

Table 2 - Average number of tubers produced per square meter with a diameter of less than and greater than 45 mm relative to nitrogen splitting. Ibiraiaras, RS, 2023.

Nitrogen fertilizer installment	Tubers per square meter	
	> 45mm	< 45mm
Three applications (T1)	19.85 ^{ns}	12.87 ^{ns}
Four applications (T2)	22.99	11.25
Two applications (Control - T3)	20.70	11.30
CV (%)	8.06	10.48

Source: authors (2025).
^{ns}: not significant by the F test ($p \leq 0.05$). CV: coefficient of variation.

The lack of responses regarding the number of tubers can be attributed to the quantities applied in the planting furrow being sufficient to define this yield component. According to Fernandes (2016), the quantities of tubers would vary if the amount of N supplied was small, at levels of deficiency for the plants, thus affecting the number of tubers produced.

The results regarding the average mass as a function of nitrogen splitting in the potato crop demonstrated significant statistical differences, as shown in Table 3.

Table 3 - Average mass of tubers produced with a caliber smaller and larger than 45 mm regarding nitrogen splitting. Ibiraiaras, RS, 2023.

Nitrogen fertilizer installment	Average mass of tubers ($kg \cdot m^{-2}$)	
	> 45mm	< 45mm
Three applications (T1)	0.151 a	0.051 a
Four applications (T2)	0.138 b	0.044 ab
Two applications (Control - T3)	0.139 b	0.042 b
CV (%)	3.81	7.87

Source: authors (2025).
Means followed by different letters in the column differ from each other using the Tukey test ($p < 0.05$). CV: coefficient of variation.

Splitting N into three applications proved more efficient in increasing tuber mass. According to Coelho *et al.* (2010), split applications increase productivity. However, very late applications cause losses, resulting in the development of the vegetative part being too much and resulting in less starch storage in the tubers.

The results regarding total productivity and tubers larger or smaller than 45 mm depending on nitrogen splitting in the potato crop demonstrated significant statistical differences in those with a caliber smaller than 45 mm (Table 4).

Table 4 - Total productivity of tubers produced and productivity with caliber less than and greater than 45 relative to nitrogen splitting. Ibiraiaras, RS, 2023.

Nitrogen fertilizer installment	Productivity (kg·ha^{-1})		
	Total	> 45mm	< 45mm
Three applications (T1)	36395.83 ^{ns}	29812.50 ^{ns}	6583.33 a
Four applications (T2)	36631.94	31637.61	4958.34 b
Two applications (Control - T3)	33515.62	28770.83	4744.79 b
CV (%)	7.83	9.51	9.91

Means followed by different letters in the column differ from each other using the Tukey test ($p < 0.05$). CV: coefficient of variation. Source: authors (2023).

The productivity of tubers under 45 mm stood out in the split treatment in three applications due to obtaining more standardized tubers with a higher average mass. For Fernandes and Soratto (2012), divided applications of N increase the efficiency of the nutrient compared to application only in the planting furrow, considering an average efficiency of 60 % in its use. The results obtained show that the distribution of nitrogen is essential to get good productivity. Still, attention should be paid to the stage of crop development, as very late applications do not have an effect as they are not reallocated to the tubers.

It is worth noting that the nitrogen levels applied, combined with application at planting and topdressing, exceeded the recommended levels for the crop for soil organic matter levels (SBCS RS/SC, 2016). This, combined with rainfall, may have influenced crop yield. On the other hand, Akkamis and Caliskan (2023) tested N doses of up to 500 kg·ha^{-1} and observed that irrigation combined with the application of 300 kg·ha^{-1} of N resulted in higher tuber yield, indicating the importance of adequate water and nitrogen supply for optimal crop performance. However, the authors emphasize that excessive nitrogen levels can have detrimental effects on potato yield and quality.

Precipitation decisively influences nitrogen (N) availability to plants, modulating both mineralization and nitrification processes and leaching and denitrification losses. Under adequate moisture conditions, microbial activity favors mineralization and increases soil inorganic N availability (Xu *et al.*, 2023), while excessive rainfall can reduce crop N use efficiency by intensifying leaching losses (Fletcher *et al.*, 2022). Furthermore, increased precipitation also interacts with N deposition, modifying the structure of soil microbial communities and nutrient cycling (Liu *et al.*, 2024). Thus, both the amount and temporal pattern of rainfall determine soil nitrogen dynamics, with direct implications for plant productivity and sustainable agricultural management. In the present experiment, there was regular rainfall that totaled 360 mm in the period from March 3rd to May 8, including the two 30 mm irrigations carried out from May 22 to June 6, 2023. After planting, there was a rainfall of 40 mm, favoring the emergence of the crop. In the interval between nitrogen applications, 35 mm were recorded after the first coverage, 76 mm after the second, 105 mm after the third, and two irrigations of 30 mm each after the fourth application. According to Cantarella (2007), nitrate leaching is closely related to the amount of water percolating in the profile and cites that values found in Brazil vary from approximately 1.0 - 1.5 mm·mm^{-1} of rainfall. Therefore, considering the precipitation recorded during the experiment and the irrigation performed, it is estimated that if the nitrogen applied at the beginning of the cycle had not been absorbed, the leaching of this nutrient throughout the crop cycle could have reached a depth of up to 54 cm. At this depth, there would still be the possibility of absorption by the potato crop, as most of the roots are located at depths of up to 40 – 50 cm (Fernandes *et al.*, 2015).

Therefore, under these conditions, the nitrogen division into three applications remained until the end of the cycle, not justifying the division into four applications. Furthermore, it is assumed that, even in the face of significant volumes of rain and irrigation in specific periods, such as after the third application, totaling 165 mm, the nitrogen from this application would remain in a layer of soil up to 25 cm, where the roots could still absorb it.

Conclusion

Nitrogen fertilization carried out in installments in three top dressing applications, proved more efficient in producing tubers with a mass corresponding to sizes greater and less than 45 mm. In this way, the distribution of nitrogen in stages III (tuberization) and IV (tuber growth) of potato crops is favorable to its productive potential.

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