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Oat productivity by root and foliar nitrogen uptake in cropping systems

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Abstract

Urea is the standard source of nitrogen for plants, yet it is very unstable, causing losses and environmental pollution. The objective of this study is to validate the technology of spraying liquid source N-Top® of nitrogen for foliar uptake, considering the main oat crops systems in southern Brazil under different agricultural year conditions. The study was developed in 2016, 2017, and 2018, in the city of Augusto Pestana, RS, Brazil, in system soybean/oat and maize/oat. In each system, two experiments were conducted, one for quantifying the biomass rate and the other for the estimation of grain yield. In the four experiments, the design of the randomized block was used with four repetitions in factorial 2×4, for 2 nitrogen sources (liquid and urea) with 4 doses of the nutrient (0, 30, 60, and 120 kg ha^{-1}), respectively. The urea source with 45% of nitrogen for root absorption and the liquid with 28% (N-Top®), via foliar absorption, were applied at the phenological stage of the fourth expanded leaf. In corn/oat system, increasing the dose of nitrogen from urea and liquid sources promotes linear behavior in the expression of grain yield, with similar values of angular coefficient. In the soybean/oat system in the average of the agricultural years, the dose of 78 kg ha^{-1} of nitrogen, promotes grain yield around 3000 kg ha^{-1}, regardless of the nutrient source. N-top® liquid source nitrogen validation is confirmed, however the acquisition cost may make the recommendation unfeasible.

Keywords: *Avena sativa* L.; modeling; N-top®; environmental quality; C/N ratio, technology; urea.
Abbreviations: FY_year favorable; UY_year unfavorable; BY_biomass yield; GY_grain yield; NS_nitrogen source; ND_nitrogen dose.

Introduction

Oats (*Avena sativa* L.) is a species that stands out in the southern region of Brazil with numerous benefits in crop rotation systems, animal feed, and human nutrition (Dornelles et al., 2018; Sgarbossa et al., 2020). Nitrogen (N) is an essential macronutrient for plants with great influence on productivity, therefore limit growth and development especially for grass species such as oats, which do not fix nitrogen by symbiotic bacteria, exogenous supply of the nutrient is essential (Mantai et al., 2016; Liu et al., 2018). The most widely used source of N fertilizer is urea, a solid product of white color and spherical shape with dimensions ranging from 1.2 to 4.0 mm (Urquiaga and Malavolta, 2002; Theago et al., 2014). Its advantages are the high concentration of N (45%), rapid availability, high solubility, and compatibility with numerous fertilizers and plant protection products (Prando et al., 2013; Santos et al., 2020).
The efficiency of nitrogen uptake by urea is dependent on meteorological conditions and soil moisture during fertilizer application. (Silva et al., 2016; Mantai, et al., 2021a). The high mobility dynamics of the nitrogen in the soil leads to easy losses by leaching due to rainfall after application, and volatilization by reduced soil moisture and high temperatures (Miransari 2011; Scopel and Borsoi, 2017). These conditions generate decreased efficiency, leading to lower productivity and environmental contamination (Galloway et al., 2013; Wang and Lu, 2020).
These conditions reinforce the essential need to balance the productivity of the species, profitability, care for the environment, and human health by employing more sustainable management of nitrogen (Ying et al., 2017; Trautmann et al., 2021). For this, studies focused on other forms of nutrient supply can help reduce losses and, consequently, the negative effects arising from the use of nitrogen in crops.
As nitrogen is an easily mobile element in the cellular tissue, it could be easily absorbed and translocated in the leaves, principally thru the water, by promoting the cooling of the leaves and facilitating the opening of the stomata for the entry of the nutrient. Some studies with urea dissolved in water showed evidence of this possibility, however, they do not bring conclusive results (Júnior et al., 2015; House and House, 2017). Currently, a new line of products with a high concentration of nitrogen is being recommended in oat cultivation fields, a technology called N-Top®, with perspectives of guaranteeing productivity with greater

efficiency in the management of the nutrient. The objective of this study is to validate the technology of spraying liquid source N-Top® of nitrogen for foliar uptake, considering the main oat crops systems in southern Brazil under different agricultural year conditions.

Results and Discussion

Classification of agricultural year

In Figure 1, it is shown the meteorological conditions during the oat crop cycle, indicating the time of N-fertilizer application in the years of 2016, 2017, and 2018. In 2016 the conditions were milder temperatures with adequate rainfall distribution throughout the crop cycle, these conditions facilitate the use of nitrogen and more expressive values of grain yield (Table 1), classifying the year 2016 as favorable to the crop (FY). The year 2017 (Figure 1), was characterized by a period of restricted rainfall at the beginning of the development cycle and air temperatures range from 30° C to below zero, along with the formation of frost in the same week. From the middle of the cycle onwards very high temperatures and rainfall concentration near the grain harvest (Figure 1). The observed restrictions hinder the adequate use of nitrogen and at the same time generated reduced grain yield, year classified as unfavorable (UY) to the cultivation of oats (Table 1). In the year 2018 (Figure 1), the moment of application of N-fertilizer occurred with reduced soil moisture and higher temperatures, which may have contributed to the loss of the nutrient by volatilization, reducing the nitrogen uptake efficiency by the oats. Frost formation was observed at the beginning of elongation, 60 days after emergence, with periods without rain for almost 30 days at mid-cycle, and from there with adequate rainfall distribution until the end of the cycle. The productivity obtained combined with the meteorological information contributed to 2018 being classified as an unfavorable year (UY) for cultivation (Table 1).

Within all economic activities, agriculture is the most dependent on weather conditions (Chies and Yokoo 2012; Marolli et al., 2017). The development of oats is strongly affected by high air temperature and soil moisture restriction, causing a significant reduction in productivity (Sánchez-Martín et al., 2016). It is noteworthy that mild temperatures, of 22 and 25 ° C, are considered optimal for the cultivation of oats, in the periods from emergence to blossoming, and from blossoming to maturity, respectively (Mantai et al., 2017). Although nitrogen is the most important element, its uptake can be compromised by water restriction, affecting the production components (Correa Filho et al., 2017). The development of oats is strongly influenced by high air temperature and soil moisture restriction, causing significant reflections on the reduction of productivity (Sánchez-Martín et al., 2016). For this reason, well-distributed rainfall volumes and lower intensity enable the best results on oat grain yields (Scremin et al., 2020).

Biomass rate and productivity averages

In the present study, the variance analysis showed a three-way interaction between year, source, and dosage of nitrogen (not presented), showing the need for means analysis and regression by decomposing this interaction into simple effects. In Table 2, for the soybean/oat system, an increase in biomass rate is observed as the nutrient doses increase, regardless of the source and year of cultivation. The increase in biomass rate is maximized by the most favorable conditions of crop years, showing the strong relationship between nitrogen and weather conditions. In 2016 (favorable year), the point of 60 kg ha^{-1} shows a biomass rate of 109 kg ha^{-1} per day with maximum grain yield, similar to the highest dose of the nutrient. In 2017 (unfavorable year), even with the biomass rate of 81.7 kg ha^{-1} per day and greater contribution of 120 kg ha^{-1} of nitrogen, the results presented are lower when compared to the absence of nitrogen in the favorable year to the crop, proving the difficulty of absorption and transformation of the element into biomass. Furthermore, there were no changes in grain yield, the main product of economic profit from the use of fertilizer, whether from liquid or solid sources. These results corroborate the technical and economical unfeasibility of the use of nitrogen by the expectation of higher yields from fertilization, generating large losses of the nutrient and environmental pollution. In 2018 (unfavorable year) the use of 30 kg ha^{-1} dose shows biomass rate increment of 70.1 and 76.5 kg ha^{-1} per day, for the liquid and solid sources, respectively, reaching maximum grain yield, similar to the points of 60 and 120 kg ha^{-1} of nitrogen. In a general, comparing the sources of nitrogen, independent of the agricultural year, the use of the urea source and N-Top® showed no difference in the productivity of the grains, supporting the technical viability in the crop system soybeans/oats, implementing alternative management to urea, by the spraying application of nitrogen via foliar absorption in oats.

In Table 3, for the maize/oat system, it is possible to observe that the biomass rate increased as nitrogen doses increased, regardless of the source and year of assessment, especially in the system with lower N-residual contribution. In 2016 (favorable year) the favorable growing conditions allowed reaching, regardless of the source, around 121 kg ha^{-1} per day of biomass, furthermore, with the maximum grain yield of 3858 kg ha^{-1} in the highest dose of the nutrient using the N-Top® source and maximum grain yield with 60 kg ha^{-1} in the use of urea reaching 3130 kg ha^{-1} of grain yield, similar to the highest dose of nitrogen. These results show a linear trend by the effect of the foliar source (N-Top®) and in reaching stability with the solid source, urea, giving indications of a change in the efficiency behavior. In 2017 (unfavorable year) the increase in the biomass rate showed more expressive results in the highest dose of the nutrient, also confirming the highest grain yield by the N-Top® source, with 1995 kg ha^{-1}. When using urea, although the highest biomass rate is at the highest dose, the highest grain yield is already obtained with the dose of 60 kg ha^{-1} of nitrogen. Therefore, whether it is a favorable or unfavorable year, there is a linear increase trend by N-Top® and a confirmed trend of stability when using urea. In 2018 (unfavorable year), regardless of the nitrogen uptake pathway, the dose of 120 kg ha^{-1} corroborates to the highest biomass rate, with the maximum grain yield at 60 kg ha^{-1} with the N-Top® source and 30 kg ha^{-1} with urea. Generally, when comparing the sources of nitrogen in a favorable year of cultivation (2016), the similarity of grain yield was observed between the sources of the nutrient, a result that makes the liquid source of N-Top® viable for the nutrient management.

Regression analysis for nitrogen technical efficiency

In Table 4, for the soybean/oat system in the favorable year (2016) of cultivation, linear and quadratic behavior with

Table 1. Temperature and rainfall during the oat crop cycle with the average grain yield and the classification of agricultural years.

Month	Temperature (°C)			Rainfall (mm)		Grain Yield (kg ha^{-1})	Classification
	Min	Max	Average	25 years*	Occurred		
2016							
June	7.3	21.2	14.2	163	11.75	3201 a	FY
July	8.03	21.2	14.6	135	83.50		
August	9.41	22.5	15.9	138	160.0		
September	8.4	23.8	16.1	167	62.25		
October	13.4	26.7	20.03	156	273.75		
Total				908	591.25		
2017							
June	11.9	25.2	18.6	163	2.8	1964 b	UY
July	8.3	24.1	16.2	135	12.75		
August	11.4	23.8	35.1	138	119.75		
September	15.4	27.1	21.2	167	165.5		
October	14.1	26.5	20.3	156	261.7		
Total				908	562.5		
2018							
June	7.4	17.9	12.6	163	104.8	2256 b	UY
July	8.2	18.1	13.1	135	72.2		
August	7.1	17.7	12.4	138	105.8		
September	12.8	22.7	17.7	167	178.0		
October	12.8	22.8	17.8	156	51.0		
Total				908	211.8		

Data obtained from the weather station located at the Regional Institute of Rural Development /IRDeR/UNIJUÍ in 2016, 2017, and 2018. FY= favorable year; UY= unfavorable year; Min = minimum temperature; Max = maximum temperature; *Average pluviometry rainfall in the months of June to October of the last 25 years. Grain productivity averages followed by the same letters in the column constitute a statistically homogeneous group by Skott & Knott test at 5% probability of error.

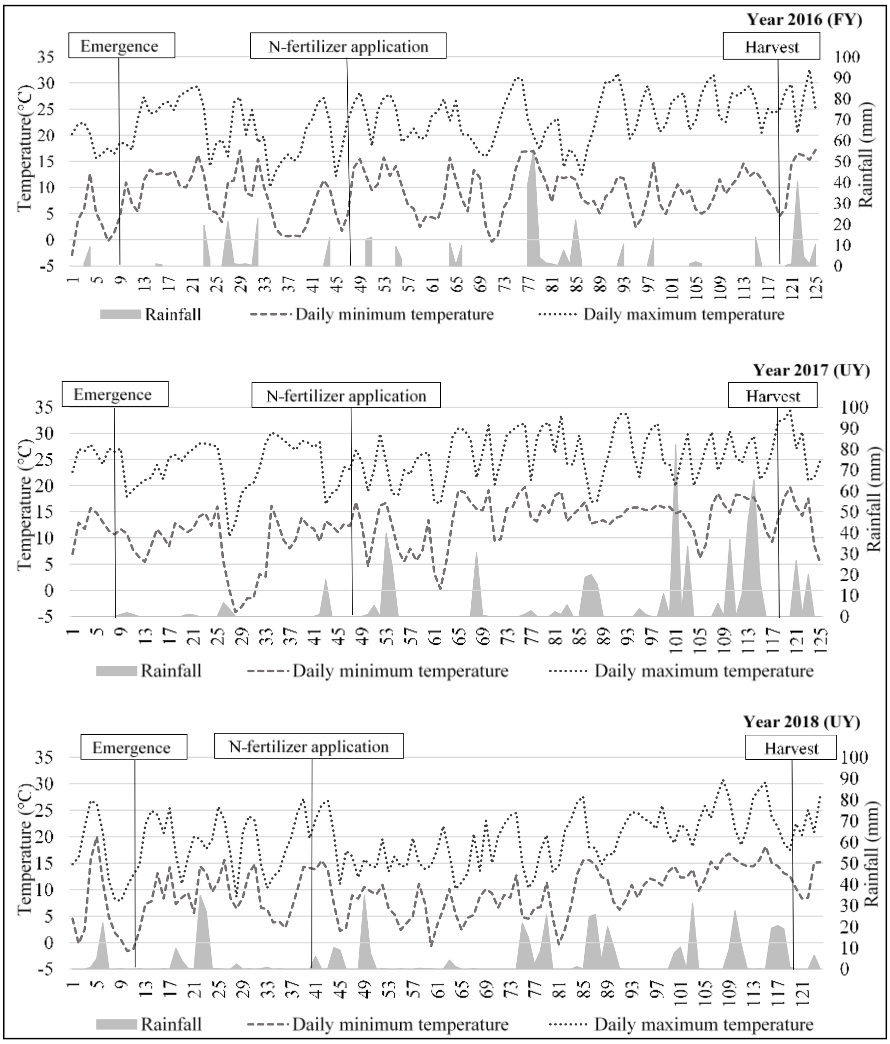

Fig 1. Rainfall data, minimum and maximum daily temperature during the oat crop cycle in the years 2016, 2017, and 2018. Data obtained from the weather station located at the Regional Institute for Rural Development IRDeR/UNIJUÍ. Sowing 2016 – 13/06; Sowing 2017 – 21/06; Sowing 2018 – 17/06. FY=favorable year; UY=unfavorable year.

Table 2. Estimation parameter of biomass rate ($b_i x$) and mean values of grain yield by liquid and solid nitrogen source in soybean/oat system.

Nitrogen source (NS)	Nitrogen Dose (ND, kg ha^{-1})	Equation BY=a ± b_ix	R^2 (%)	GY_{DN} (kg ha^{-1})	GY_{FN}
2016 (FY)					
Liquid/foliar (N-Top®)	0	1705 + 84.7*x*	99	2808 c	3479 A
	30	2065 + 95.6*x*	99	3394 b	
	60	2651 + 109.8*x*	99	3988 a	
	120	2620 + 114.3*x*	99	3728 a	
Solid/soil (Urea)	0	1954 + 88.4*x*	98	2853 c	3360 A
	30	2253 + 98.7*x*	98	3253 b	
	60	2701 + 107.7*x*	98	3715 a	
	120	2537 + 109.0*x*	99	3619 a	
2017 (UY)					
Liquid/foliar (N-Top®)	0	2169 + 72.2*x*	90	2117 a	2342 A
	30	1915 + 72.1*x*	91	2247 a	
	60	2172 + 77.5*x*	92	2646 a	
	120	2167 + 81.7*x*	90	2359 a	
Solid/soil (Urea)	0	1841 + 64.0*x*	96	2163 a	2348 A
	30	1871 + 70.4*x*	92	2518 a	
	60	1745 + 69.9*x*	92	2386 a	
	120	1921 + 77.6*x*	91	2325 a	
2018 (UY)					
Liquid/foliar (N-Top®)	0	1121 + 66.0*x*	94	2117 b	2485 A
	30	1107 + 70.1*x*	96	2646 a	
	60	1357 + 75.9*x*	97	2747 a	
	120	1478 + 82.7*x*	96	2431 a	
Solid/soil (Urea)	0	1187 + 69.0	95	2163 b	2360 A
	30	1520 + 76.5*x*	97	2518 a	
	60	1493 +82.6*x*	91	2586 a	
	120	1691 +86.0*x*	94	2175 b	

GY=grain yield; BY=biomass yield; FY=favorable year; UY=unfavorable year; R^2=coefficient of determination; bix = parameter of the slope of the line that indicates the productivity rate of biomass produced in kg ha^{-1} per day; GY_{DN}=average grain yield based on nitrogen doses; GY_{FN}=average of grain yield based on nitrogen sources; Averages followed by the same lower case letters constitute statistically homogeneous group by nitrogen dose by Skott & Knott test at 5% error probability; Averages followed by the same upper case letters constitute statistically homogeneous group by Skott & Knott test at 5% error probability.

Table 3. Estimation parameter of biomass rate ($b_i x$) and mean values of grain yield by liquid and solid nitrogen source in maize/oats system.

Nitrogen Source (NS)	Nitrogen Doses (ND, kg ha^{-1})	Equation BY=a ± b_ix	R^2 (%)	GY_{DN} (kg ha^{-1})	GY_{FN}
2016 (AF)					
Liquid/foliar (N-Top®)	0	2263 + 75.4*x*	97	2220 d	3096 A
	30	2866 + 92.7*x*	98	2981 c	
	60	2744 + 92.3*x*	99	3326 b	
	120	3305 + 121.4*x*	96	3858 a	
Solid/soil (Urea)	0	2657 + 75.6*x*	92	2088 b	2866 B
	30	2987 + 90.7*x*	93	2720 b	
	60	3236 + 98.2*x*	94	3130 a	
	120	3913 + 121.5*x*	89	3528 a	
2017 (AD)					
Liquid/foliar (N-Top®)	0	1083 + 44*x*	95	1100 b	1523 A
	30	1306 + 52.9*x*	93	1410 b	
	60	1167 + 55.8*x*	91	1588 b	
	120	1960 + 77.5*x*	93	1995 a	
Solid/soil (Urea)	0	1346 + 49.0*x*	90	1177 b	1638 A
	30	1518 + 58.5*x*	86	1458 b	
	60	2013 + 70.2*x*	94	1866 a	
	120	2400 + 81.7*x*	97	2054 a	
2018 (AD)					
Liquid/foliar (N-Top®)	0	1258 + 51.2*x*	99	1385 c	2114 A
	30	1549 + 63.7*x*	95	1986 b	
	60	1148 + 66.2*x*	95	2563 a	
	120	2432 + 103.5*x*	89	2522 a	
Solid/soil (Urea)	0	1479 + 51.9*x*	95	1334 b	2064 A
	30	2021 + 69.1*x*	95	2148 a	
	60	2003 + 74.4*x*	92	2302 a	
	120	3076 + 105.5*x*	94	2472 a	

GY=grain yield; BY=biomass yiled; FY=favorable year; UY=unfavorable year; R^2=coefficient of determination; bix = parameter of the slope of the line that indicates the productivity rate of biomass produced in kg ha^{-1} per day; GY_{DN}=average grain yield based on nitrogen doses; GY_{FN}=average of grain yield based on nitrogen sources; Averages followed by the same lower case letters constitute statistically homogeneous group by nitrogen dose by Skott & Knott test at 5% error probability; Averages followed by the same upper case letters constitute statistically homogeneous group by Skott & Knott test at 5% error probability.

Table 4. Regression analysis in the definition of technical efficiency of nitrogen from liquid and solid sources, and estimation of grain yield in soybean/oat system.

Nitrogen source	SV	QM_{GY}	Equation $GY = b_0 \pm b_1 x \pm b_2 x^2$	$P (b_iX^n)$	R^2	MTE_N kg ha^{-1}	GY_E
2016 (FY)							
Liquid/foliar (N-Top®)	L	1698182*	$3094 + 7.34x$	*	86	82	-
	Q	1338743*	$2768 + 29.8x - 0.18x^2$	*	97		4000
	Error	45014					
Solid/soil (Urea)	L	1226908*	$3032 + 6.24x$	*	86	94	-
	Q	564344*	$2820 + 20.8x - 0.11x^2$	*	97		3803
	Error	49891					
2017 (UY)							
Liquid/foliar (N-Top®)	L	153683^{ns}	$2226 + 2.2x$	ns	75	-	-
	Q	325634*	$2065 + 13.3x - 0.08x^2$	*	88	83	2617
	Error	56299					
Solid/soil (Urea)	L	37359^{ns}	$2291 + 1.0x$	ns	94	-	-
	Q	221161*	$2158 + 10.2x - 0.07x^2$	*	98	72	2529
	Error	33265					
2018 (UY)							
Liquid/foliar (N-Top®)	L	100526^{ns}	$2137 + 19.3x$	ns	86	-	-
	Q	809390*	$2137 + 19.3x - 0.14x^2$	*	97	68	2802
	Error	54439					
Solid/soil (Urea)	L	8101^{ns}	$2387 - 0.5x$	ns	81	-	-
	Q	584066*	$2172 + 14.3x - 0.11x^2$	*	98	65	2636
	Error	65731					

SV=source of variation; GY=grain yield (kg ha^{-1}); QM=mean square; L=linear; Q=quadratic; R^2=coefficient of determination; P (b_ix^n) =probability of the slope parameter; MTE_N=maximum technical efficiency of nitrogen; GY_E=grain yield estimated by the use of optimal doses; FY=favorable year; UY=unfavorable year; *Significance at 5% probability of error by t-test; ^{ns} Not significant at 5% probability of error.

Table 5. Regression analysis in the definition of technical efficiency of nitrogen from liquid and solid sources and estimation of grain yield in maize/oat system.

Nitrogen Source	SV	QM_{GY}	Equation $GY = b_0 \pm b_1 x \pm b_2 x^2$	$P (b_iX^n)$	R^2	MTE_N kg ha^{-1}	GY_E
2016 (FY)							
Liquid/foliar (N-Top®)	L	5252562*	$2418 + 12.9x$	*	92	-	-
	Q	356113*	$2250 + 24.5 - 0.09x^2$	ns	99	-	-
	Error	34297					
Solid/soil (Urea)	L	4185390*	$2261 + 11.5x$	*	91	-	-
	Q	347842^{ns}	$2095 + 23x - 0.09x^2$	ns	99	-	-
	Error	218541					
2017 (UY)							
Liquid/foliar (N-Top®)	L	1657350*	$1143 + 7.2x$	*	98	-	-
	Q	11677*	$1112 + 9.3x - 0.01x^2$	ns	99	-	-
	Error	90126					
Solid/soil (Urea)	L	1711756*	$1252 + 7.3x$	*	91	-	-
	Q	131347^{ns}	$1149 + 14.4x - 0.05x^2$	ns	98	-	-
	Error	98533					
2018 (UY)							
Liquid/foliar (N-Top®)	L	2638219*	$1634 + 9.1x$	*	82	94	-
	Q	978891*	$1355 + 28.4x - 0.15x^2$	*	98		2699
	Error	39935					
Solid/soil (Urea)	L	2193629*	$1626 + 8.3x$	*	81	96	-
	Q	731745*	$1384 + 25x - 0.13x^2$	*	95		2586
	Error	33174					

SV=source of variation; GY=grain yield (kg ha^{-1}); QM=mean square; L=linear; Q=quadratic; R^2=coefficient of determination; P (b_ix^n) =probability of the slope parameter; MTE_N=maximum technical efficiency of nitrogen; GY_E=grain yield estimated by the use of optimal doses; FY=favorable year; UY=unfavorable year; *Significance at 5% probability of error by t-test; ^{ns} Not significant at 5% probability of error.

significant angular coefficients were obtained. The agronomic efficiency by the linear equation shows that by every kilo of nitrogen supplied returns are 7.34 and 6.24 kg ha^{-1} of grains with the liquid and solid source, respectively. Indicating greater efficiency of the ratio input supplied and the product obtained by the liquid source. This fact is confirmed with a polynomial equation of second degree in the estimation of technical efficiency with the optimal dose of 82 kg ha^{-1}, estimating 4000 kg ha^{-1} of grain by the liquid source, compared to the optimal dose of 94 kg ha^{-1} of nitrogen in an expectation of 3800 kg ha^{-1} of grain, by solid fertilizer source. Therefore, showing a reduction of nitrogen use by more than 10 kg and higher productivity by almost 200 kg ha^{-1} of grain.

In the unfavorable year of cultivation (2017) is confirmed quadratic behavior that leads to a point of stability, enabling the estimation of technical efficiency, with 83 kg ha^{-1} of the input in the liquid source, calculating 2617 kg ha^{-1} of grain yield, and 72 kg ha^{-1} of the solid source, with an estimate of 2529 kg ha^{-1} of grain yield. In this crop condition, it is perceived reduction of nitrogen use around 11 kg with the solid source with similarity of productivity, leading to the higher efficiency of urea use. In the unfavorable year of 2018, the liquid source shows technical efficiency of 68 kg ha-1 of nitrogen with estimated productivity of 2802 kg ha-1 and the solid source with 65 kg ha^{-1} of nitrogen with the expectation of 2636 kg ha^{-1} of grains. The similarity of the technical efficiency was verified, however, leading to a greater contribution in grain yield with the use of the liquid source.

In Table 5, for the maize/oats system in the year favorable to cultivation (2016), linear behavior with the significance of the angular coefficient was obtained, ensuring only estimation of agronomic efficiency. The linear equation shows that each kilo of nitrogen supplied returns in 12.9 and 11.5 kg ha^{-1} of grains with the liquid and solid source, respectively, indicating greater efficiency by the liquid source, which also departs from an intercept point greater than 200 kg ha^{-1}. In the unfavorable year, 2017, agronomic efficiency of 7.2 and 7.3 kg ha^{-1} grain is observed with the liquid and solid source, respectively, showing similar efficiency. In the year 2018, unfavorable to cultivation, linear and quadratic behavior with the significance of the angular coefficient were obtained. In this regard, the technical efficiency with the liquid source was 94 kg ha^{-1} of nitrogen with estimated productivity of 2699 kg ha^{-1}. In the solid source, the technical efficiency was obtained with 96 kg ha^{-1} of nitrogen with 2586 kg ha^{-1} of grain, showing greater contribution in grain yield with the liquid source.

The results presented in Table 5 show increased usage of the nitrogen input by the maize/oat condition, which was expected due to the high carbon/nitrogen ratio of the maize straw, making less N-residual available to the system during the crop cycle. The results presented prove the theory that the high N mobility in the cellular tissue makes the use of fertilization via spraying on the leaves feasible. However, one of the decisive issues of product recommendation is the ease of acquisition and its purchase cost. In this research, the liquid source of nitrogen is the commercial product N-Top® which is easily available on the market, with a density of 1.3 g ml^{-1} and 28% nitrogen, representing 364 grams of nitrogen per liter. The cost of the liter of the product is around BRL 20.00, which corresponds to BRL 65.00 per kilo of the nutrient. On the other hand, considering urea with 45% nitrogen and the value of the ton at BRL 1585.00, this represents a value of BRL 3.52 per kilogram of nitrogen. Thus, considering the soybean/oat system, in an expectation of 3000 kg ha^{-1} of grains, the recommendation indicates the supply of 60 kg ha^{-1} of nitrogen. In this perspective, the cost of using liquid source nitrogen is BRL 3900.00 per hectare and that of the solid source is BRL 211.20 per hectare. Therefore, although the technical viability is confirmed, the high cost of the liquid source makes its recommendation for foliar application unfeasible.

Foliar N uptake may be an alternative to the application of solid urea for root uptake, offering advantages such as the use of smaller quantities of the nutrient and rapid assimilation compared with soil N applications (Gutiérrez-Gamboa et al., 2017). Likewise, the constant search for more sustainable nitrogen management alternatives is essential to reduce negative impacts on the environment and human health, contributing to goals 2 (Zero hunger and sustainable agriculture), 3 (Health and well-being), 12 (Responsible consumption and production) and 13 (Actions against global climate change) of the 17 goals for sustainable development (Wang and Lu, 2020).

In oats cultivation, increasing the dosage and correct timing of nitrogen application combined to favorable growing conditions promotes better use of the nutrient, which favors increased biomass yield and grain yield (Silva et al., 2016; Arenhardt et al., 2017). The use of nitrogen is necessary from exogenous form, due to the low amount released by the soil during cultivation (Hawerroth et al., 2013; Ma et al., 2017). Research on nutrient management techniques shows that nitrogen is the main element for plant growth and development, but in inadequate conditions of temperature and soil moisture, the element is easily lost, either by leaching or volatilization (Silva et al., 2016). Mantai et al. (2015) analyzing white oat cultivars, verified the ideal nitrogen doses adjusted at 66 and 76 kg ha^{-1} with an approximate grain yield estimation of 3874 and 4360 kg ha^{-1}, respectively. Mantai et al. (2021b) confirmed that nitrogen increases grain, straw, and total protein, with agronomic efficiencies of 7.8, 19.7, and 3.3 kg ha^{-1} and 0.10 g kg^{-1}. These same authors found the maximum technical efficiency of nitrogen utilization to elaborate grain yield with variations between 82 and 104 kg ha^{-1}, results that are strongly influenced by environmental conditions of agricultural year and period of nutrient application.

Materials and Methods

Plant materials and field experiment

The study was conducted during the years 2016, 2017, and 2018, in the city of Augusto Pestana, RS, Brazil (latitude 28° 26' 30'' S and longitude 54° 00' 58'' W). The soil of the experimental area is classified as Typical Dystrophic Red Latosol, with a deep, well-drained profile and dark red coloration. The climate of the region, according to the Köppen classification, is Cfa (humid subtropical), with well-distributed rainfall during the year, and annual rainfall of around 1600 mm, reaching the greater rainfall in the winter (Alvares et al., 2013). Ten days before sowing, soil analysis was performed showing the following chemical characteristics: pH= 6,2; P=33,9 mg dm^{-3}; K= 200 mg dm^{-3}; MO= 3,0 %; Al= 0 cmolc dm^{-3}; Ca = 6,5 cmolc dm^{-3} and Mg=2,5 cmolc dm^{-3}.

Experimental design

The sowing was performed with a sowing machine in two cropping systems, soybean/oat, and maize/oat, between the first and third week of June of each year, using the white oat cultivar URS Guará, with a population density of 400 viable seeds m^{-2}. In each cropping system, two experiments were conducted, one to quantify the biomass yield (BY, kg ha^{-1}), measured by cuts performed every 30 days until physiological maturity, and the other to estimate the grain yield (GY, kg ha^{-1}). Therefore, in the four experiments, the design was randomized block design with four repetitions in a 2×4 factorial model, for two sources of nitrogen (liquid and solid) with four doses of the nutrient (0, 30, 60, and 120 kg ha^{-1}), respectively. The experimental site was composed of a plot of five rows 5 meters long and spaced at 0.20 meters apart, totaling an area of 5 m².

At the sowing, 45 and 30 kg ha^{-1} of P_2O_5 and K_2O were applied based on the soil P and K contents, calculated for the grain yield expectation of 3 t ha^{-1}, respectively, and 10 kg ha^{-1} of N, except in the experimental area. During the execution of the study, applications of tebuconazole fungicide named

FOLICUR® CE at a dosage of 0.75 L ha^{-1} were done. Weeds were controlled by applying metsulfuron-methyl herbicide named ALLY® at a dose of 2.4 g ha^{-1} and additional mechanical weeding whenever necessary.

Application of forms of nitrogen

The source of nitrogen for root uptake in the soil was urea (45% N) applied as topdressing, and for foliar uptake was the commercial product N-Top® (28% N) in liquid form with a density of 1.3g ml^{-1}, sprayed with a volume of water of 200 L ha^{-1}. In each of the nitrogen sources, the different doses indicated in the study were scaled and converted to the experimental area of $5m^2$. Foliar N application was performed with a knapsack sprayer at a constant pressure of 30 lb in^{-2}, using compressed CO_2, with conical spray tips, the duration of spraying was determined by the dose of the nutrient for each application. The treatments were performed, for root and foliar absorption sources, at the V_4 phenological stage considering the oat plant with four unfolded leaves.

Data measurement

In the trials to quantify the biomass yield (BY, kg ha^{-1}) throughout the development cycle of oats, the plants of the three central rows of each plot were cut at ground level. Next, the green biomass samples were placed in the forced air-drying kiln at a temperature of 65°C until reaching constant weight, then weighed on precision balance for the estimation of total dry matter, converted into kg ha^{-1}. The cuts of biomass were performed at 30, 60, 90, and 120 days after emergence, and in the last cut, the plants were already in the physiological maturity stage. In the experiments to estimate the grain yield (GY, kg ha^{-1}) it was performed the cut of the three central lines of each plot was in the stage of maturity, considering the harvest at grain humidity of around 22%. The plants were sorted in a stationary thresher, and the grains were directed to the laboratory for drying until the humidity to 13%, and subsequent calculation of productivity in kg ha^{-1}. The data of rainfall (Prec mm), minimum temperature (T_{min}, ºC), maximum temperature (T_{max} ºC), and average temperature (T_{avg} ºC) were obtained from an automatic weather station located approximately 400 meters to the experiment.

Statistical analysis

After meeting the assumptions of homogeneity and normality using Bartlett's test, analysis of variance was performed to detect the main effects and interaction between years and sources of nitrogen dose (not presented). Then, comparison test of means by Scott & Knott, in each point of nitrogen dose, and source of supply by agricultural year in the analysis of grain yield. The estimation of biomass yield (b_ix) in kg ha^{-1} day^{-1} was processed by linear function adjustment ($y= b_0 \pm b_ix$), in the function of the days of cut, and agronomic efficiency of the relationship between the dose supplied (x) by kilogram of the obtained product (b_ix), in the function of the nitrogen doses. Additionally, quadratic regression analysis ($y= b_0 \pm b_1x \pm b_2x^2$) to estimate the maximum nitrogen use technical efficiency ($MET = -[(b_1)/(2b_2)]$) on grain yield in comparison of the two nitrogen sources. The Genes program (Cruz 2006) was used for all analyses.

Conclusion

The technology of spraying liquid nitrogen for foliar uptake shows similar results to nitrogen applied in topdressing by urea source, regardless of the cropping system and crop year condition. Although the technical validation of liquid nitrogen is confirmed, the high cost of acquisition makes its use still impractical for recommendation on a commercial scale in oats crops.

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