Australian Journal of Crop Science AJCS

AJCS 17(5):453-462 (2023) ISSN:1835-2707
doi: 10.21475/ajcs.23.17.05.p3843

The efficiency of liquid source nitrogen for foliar absorption in oat

Luana Henrichsen, Natiane Carolina Ferrari Basso, José Antonio Gonzalez da Silva, Ivan Ricardo Carvalho, Christiane de Fátima Colet, Denize da Rosa Fraga, Odenis Alessi, Gerusa Massuquini Conceição, Deivid Araújo Magano, Cibele Luisa Peter, Juliana Aozane da Rosa, Márcia Sostmeyer Jung, Cristhian Milbradt Babeski, Maria Eduarda Steidl

Regional University of the Northwest of the State of Rio Grande do Sul, Ijuí, Rio Grande do Sul, Brazil

Abstract

The objective of the study is to estimate the technical, economic and stability of nitrogen use efficiency in oats intercropped with soybean and corn in conventional management using urea and nutrient spraying for foliar absorption, considering the expression of biomass and grain yields in different cropping systems, subsidizing the validation of this technology. The study was carried out in Augusto Pestana, RS, Brazil, in a soybean/oat and corn/oat system. In each system, two experiments were carried out, one to quantify biomass yield and another to estimate grain yield, totally four experiments. In all experiments the design was randomized blocks with four replications in a 2x4 factorial, for 2 nitrogen sources (liquid and solid) with 4 doses (0, 30, 60 and 120 kg ha^{-1}), respectively. The solid source (urea) with 45% of nitrogen for root absorption and the liquid source (N-Top®) with 28% of the nutrient for foliar absorption were applied at the phenological stage of the fourth expanded oat leaf. The analyzed variables were biomass and grain productivity, obtained by cutting the three central rows of each plot at the physiological and harvest maturity stages, respectively. The efficiency of using nitrogen from a liquid source via foliar absorption in oats promotes similar results when using urea. Regardless of the nitrogen source, doses of 45 and 75 kg ha^{-1} are more efficient in soybean/oat and corn/oat systems, respectively. Although the technical efficiency of liquid source nitrogen is proven, the high cost does not allow recommendation on a commercial scale.

Keywords: *Avena sativa* L; Stability; Productivity; Mathematical modeling; Sustainable Agriculture.

Abbreviations: GY_grain yield; BP_Biomass productivity; IY_Intermediate year; FY_Favorable year; UY_Unfavorable year; Wi_Stability coefficient; MS_mean square; L_Liquid; S_Solid; N_{MET}_Maximum technical efficiency of nitrogen; N_{MEE}_Maximum economic efficiency of nitrogen; N_{MEES}_Maximum nitrogen stability efficiency.

Introduction

White oat (*Avena sativa* L.) is a winter cereal grown for grain and forage production, being recognized worldwide for its functional properties and benefits to agriculture (Coelho et al., 2020; Silva et al., 2020). In Brazil, the cereal cultivation area should exceed 500 thousand hectares in 2022, with a production of more than one million tons of grains (CONAB, 2022). This scenario reinforces the importance of the crop for agribusiness and leads to the need to develop agricultural practices capable of guaranteeing the good performance of the species (Kraisig et al., 2020; Rosa et al., 2021a).

Among the agricultural practices in oat cultivation, nitrogen supply is essential to guarantee the productive potential (Barbosa et al., 2020; Reginatto et al., 2021). This nutrient is part of the composition of important biomolecules such as ATP, NADH, NADPH, chlorophyll, proteins and several enzymes, influencing plant growth more than any other nutrient (Arenhardt et al., 2017; Pereira et al., 2018). Therefore, it is the element most absorbed by oats, a condition that requires exogenous supply due to the insufficient amount made available by the soil in the crop cycle (Mamann et al., 2020; Muratore et al., 2021). The rest of the nitrogen used to meet the desired yield expectation is commonly performed by the application of urea (45% N), a solid source that, in contact with the soil, makes the nutrient available for absorption by the roots (Fageria et al., 2009; Coelho et al., 2020). It is noteworthy that the adjusted time for this management practice is 30 to 60 days after plant emergence or in the phenological condition of three to four expanded leaves, a moment that characterizes the tillering and differentiation of the oat spikelet primordia (Mantai et al., 2016; Kraisig et al., 2020).

The best use of the nutrient depends on the conditions of milder air temperature and adequate soil moisture, without the occurrence of rain soon after application of the input (Scremin et al., 2020; Reginatto et al., 2021). However, these ideal conditions hardly happen at the most suitable stage for the management of topdressing fertilization, a condition that compromises the efficiency of the nutrient use by the plant, reducing the expression of productivity indicators, in addition to raising production costs and generating environmental pollution (Mamann et al., 2020; Mantai et al., 2021). When analyzing the fate of nitrogen lost to the environment, about one-third is denitrified into N2, one-third is taken to groundwater as nitrates, and one-third is released as N2O, the gas responsible for destroying the ozone layer (Good & Beatty, 2011; Lebedev et al., 2021). Therefore, it is estimated that more than 60% of the nitrogen applied in the form of urea is lost to the environment (Suherman, 2010; Beig et al., 2020). The high demand for chemical fertilizers in agriculture has received increasing attention demanding the development of innovative techniques to balance the entrance of inputs into cropping systems with greater sustainability (Li et al., 2020; Trautmann et al., 2022).

In order to reduce nitrogen losses by urea and maximize the efficiency of nutrient absorption by plants, there are indications that supplying the nutrient by foliar absorption with a liquid source can bring promising results (Mortate et al., 2018; Vasundhara & Chabra, 2021). Nitrogen is a mobile element as it is easily absorbed and translocated within plant tissue (Bredemeier & Mundstock, 2000; Karthika et al., 2018). In addition, the liquid source can cause foliar cooling, a condition that would lead to the opening of stomata and, consequently, facilitate nutrient absorption, regardless of soil moisture condition (Alshaal & El-Ramady, 2017; Wang et al., 2022).

The increasing concern for the environment due to the excessive application of nitrogen fertilizers clearly shows the need to implement more efficient techniques for the use of nitrogen in the oat cultivation system. The definition of the maximum technical and economic efficiency for the use of nitrogen from a liquid source in oats can help to validate the use of this technology (Silva et al., 2016; Omara et al., 2019). The technical efficiency of nitrogen use involves the definition of the maximum absorption point of the nutrient to the biological expression of the production and the economic efficiency, also includes monetary aspects for the cost of the product obtained and input supplied (Mantai et al., 2015; Assis et al., 2018). In addition, there is the possibility of detecting the dose of stability, regardless of the condition of the agricultural year, by biometric models that measure this characteristic (Krüger et al., 2016; Silva et al., 2016). The objective of the study is to estimate the technical, economic and stability of nitrogen use efficiency in oats intercropped with soybean and corn in conventional management using urea and nutrient spraying for foliar absorption, considering the expression of biomass and grain yields in different cropping systems, subsidizing the validation of this technology.

Results and discussion

Influence of the studied factors

In the analysis of variance in Table 1, the main effects of year and nitrogen dose changed the expression of grain and biomass yield, whether liquid or solid nitrogen source. The interaction effects were also confirmed in all conditions analyzed, enabling the use of models that estimate stability. Furthermore, it highlights the need to estimate the technical and economic efficiency of nitrogen use in each crop year condition.

Maximum expression of biomass and grain yield with stability

In Table 2, in the soybean/oat system, the liquid source shows the lowest use of the input with an expressive mean value "a" at the dose of 45 kg ha^{-1} of nitrogen. Even between the lowest values of ecovalence and mean square with no significance of the regression model, configuring a stable dose. In the solid source, this same condition was observed, indicating that there is similarity of the lowest stability dose in the liquid and solid nitrogen source on grain yield in the soybean/oat system. Also in Table 2, in the corn/oat system, the lowest nitrogen dose with a significant value for grain yield was obtained at the dose of 75 kg ha^{-1}, regardless of the nutrient source. The ecovalence and mean square values together with the absence of significance of the regression model, confirm a stable dose adjusted to the corn/oats system.

In Table 3, in the soybean/oat system, the liquid source shows the lowest use of the input with an expressive mean value "a" at the dose of 60 kg ha^{-1} of nitrogen. Although it presents a higher mean square magnitude (MS) than the dose of 45 kg ha^{-1}, the point 60 kg ha^{-1} of nitrogen is among the lowest values of ecovalence together with the non-significance of the regression parameter, confirming point of stability. This same scenario was also observed with the use of solid source in this cultivation system. In the corn/oat system (Table 3), regardless of the nitrogen source (liquid and solid), the lowest input dose with the highest expression of biomass productivity was obtained with 90 kg ha^{-1}. In this scenario, the lowest ecovalence values and the non-significance of the stability parameter confirm it as a stability dose. It is noteworthy that in Tables 2 and 3, the point of greatest stability was identified that configures doses that promote greater expression of biomass productivity and "a" grain with the lowest use of the input.

Nitrogen is a nutrient easily subject to losses due to runoff after rains, volatilization and leaching, resulting in productivity instability. This is a scenario that shows great variations in the efficiency of nutrient use in the elaboration of productivity and oats (Barbosa et al., 2020; Rosa et al., 2021 b). Although the Technical Indication recommends the optimal dose from the succession system, soil organic matter content and productivity expectation (INDICAÇÕES TÉCNICAS, 2021) this expectation is generally not achieved due to environmental variations during the cycles of cultivation, which are generally not the most favorable to nitrogen management (Siqueira Neto et al., 2010; Silva et al., 2015 a). Nitrogen is applied at the beginning of oat development, around 30 to 60 days after plant emergence, when different scenarios for nutrient management take place (Arenhardt et al., 2015; Reginatto et al., 2021). This scenario shows the need to understand the relationship between nitrogen management and environmental conditions, which generates the possibility of involving models that measure stability by changes in the agricultural year (Silva et al., 2016). Wricke's (1965) model that calculates echovalence considers the dose to be more stable when the lowest values of the parameter W_i are observed. The traditional method considers the most stable dose to be the one with the lowest variance between environments, represented by the lowest mean square (MS) value (Wrike et al., 1965; Arenhardt et al., 2015). The regression model by Eberhart and Russell (1966) takes into account an environmental index and uses the parameter S^2_{ij} as an indicator of stability (Eberhart & Russell, 1966; Silva et al., 2015 b). Studies addressing the use of stability models were also developed in wheat to identify the best time for nitrogen application in favorable and unfavorable years for cultivation (Arenhardt et al., 2015). Studies seeking to define the stable dose of nitrogen were also carried out by Silva et al. (2016), showing greater stability against agricultural scenarios with a dose of 60 kg ha^{-1} of nitrogen. This result is in line with those obtained in this study in the analysis of biomass productivity in soybean/oat systems.

Technical, economic efficiency and stability of nitrogen use

In Table 4, in the soybean/oat system, the favorable year of cultivation (2016) shows the technical efficiency of nitrogen use by liquid and solid sources with doses of 82 and 94 kg ha^{-1}, respectively. In this condition, the liquid source shows less use of the input with a higher productivity value than the solid source. However, the economic efficiency of the commercial product makes its recommendation unfeasible, which generates an estimated yield of 2768 kg ha^{-1} without the use of the input, reducing by more than 1200 kg ha^{-1} of grains compared to the technical efficiency. In this configuration, the solid source stands out, considering the price of the product and the input, there is a reduction from 94 to 54 kg ha^{-1} of nitrogen due to economic efficiency, with an expected yield of 3622 kg ha^{-1}. Therefore, a reduction of 40 kg of nitrogen per hectare and productivity close to that obtained by technical efficiency does not consider marketing prices. In addition, the inclusion in the model of the nitrogen dose with stability (Table 2), that is, regardless of the condition of the crop year, promotes greater reduction in nitrogen use, ensuring satisfactory productivity.

Also in Table 4, in the unfavorable (2017) and intermediate (2018) year for oat cultivation, the technical feasibility of using a liquid source by foliar absorption is confirmed, with similar productivities between the sources in the two years of cultivation. However, conditions of unfavorable or intermediate year for cultivation, show that the recommendation for the expectation of productivity by the fertilization manual is not confirmed. Thus, the dose of nitrogen by economic efficiency brings a scenario of strong reduction in the use of the nutrient with yields relatively close to that obtained by technical efficiency. However, if the stability dose is used, there is a productivity similar to the technical efficiency and with a nitrogen reduction greater than 20 kg ha^{-1} of nitrogen. This condition raises the hypothesis of the amount of nitrogen that would be directed to the environment generating environmental pollution when considering the expectation of productivity in a more restrictive scenario of cultivation.

In Table 4, in the corn oat system, the sources of liquid and solid nitrogen showed linear behavior in favorable (2016) and unfavorable (2017) years for oat cultivation. In a favorable year, the intercept value and superior angular coefficient show superior absolute values compared to the solid source, generating an indication of a possible better response in nitrogen absorption and transformation into grains. On the other hand, in the unfavorable year, both intercept and slope values show similarity. These facts confirm again that the liquid nitrogen source for foliar absorption shows similar results to the urea source for nitrogen release by root absorption. In this scenario, the use of a dose of stability that does not depend on the condition of the agricultural year shows a superiority of the absolute values of the liquid source over the solid source in a favorable year. On the other hand, in 2017, a trend of better response by solid source. The year 2018, of intermediate agricultural condition, shows quadratic behavior on the expression of productivity in liquid and solid sources of nitrogen (Table 4). However, the use of solid source only is justified by the high commercialized value of nitrogen from liquid source. Although the technical efficiency shows an optimal dose with 96 kg ha^{-1} of the nutrient, the recommendation for technical efficiency and stability promotes a reduction of 34 and 21 kg ha^{-1} of nitrogen by the dose of maximum economic efficiency and stability, respectively. Although economic efficiency does not make it possible to recommend the liquid source, advances in research can provide a greater percentage of nitrogen in the formulation with a reduction in the cost of the product, enabling its use. Anyway, the results obtained show the technical feasibility of using a source by foliar absorption, whether solid or liquid, with a great possibility of reducing the use of fertilizer in the perspective of greater sustainability in nitrogen management when considering the recommendation by dose of economic efficiency and stability.

In an analysis seeking to measure the effects of doses in different nitrogen sources on total biomass productivity, Table 5 presents the functions that describe the expression behavior of this variable in the different conditions provided with the nutrient. Thus, in soybean/oat system, regardless of crop year condition and nitrogen source, the expression of biomass productivity shows an increasing linear behavior with increasing doses. In this scenario, the angular coefficient values in the liquid source are higher in favorable and intermediate years for cultivation, contrary condition in unfavorable years. The inclusion of the stability dose by the variations of agricultural year in the soybean/oat system (60 kg ha^{-1}) shows the reflexes that confirm the efficiency of use of the liquid source similar or superior by the absolute values in comparison with the solid standard source (urea). A similar scenario observed in the corn/oat system in the different years of study stands out, confirming the high mobility of nitrogen in the leaf tissue and its transformation capacity in the formation of different molecules linked to the routes that elaborate productivity.

Nitrogen is the most abundant mineral nutrient in nature, about 78% present in the atmosphere. It is the element most required by plants, directly affecting the growth and development of agricultural species in the world (Zhao & Shen, 2018; Anas et al., 2020). Large amounts of nitrogen fertilizers are used in agriculture to supply the nutrient deficiency in the soil and ensure the proper performance of cultivated plants (Qureshi et al., 2018; Qiao et al., 2019). However, the sharp increase in the use of nitrogen fertilizers has generated adverse effects on human health and the environment due to eutrophication of surface waters, excess nitrate in groundwater and increased greenhouse gas emissions (Ren et al., 2022). These results are associated, among other factors, with the losses of nitrogen fertilizers, since less than 50% of the nitrogen applied to the soil is used by plants, with the remainder being lost to the environment by nitrate leaching, ammonia volatilization and N_2, N_2O emission (Bredemeier & Mundstock, 2000; Hammad et al., 2017). The elements listed show the importance of observing the factors related to the soil and the atmosphere to guarantee the efficiency of nitrogen use, a necessary condition to avoid nutrient losses and reduce the costs with fertilization and reduction of environmental pollution (Hammad et al., 2017; Marolli et al., 2018).

From the perspective of improving nitrogen efficiency, some studies mentioned the possibility of using the nutrient by the leaves due to the high mobility of the nutrient in the cellular tissue, a condition that could potentiate technologies of application by the leaves to greater efficiency of use (Fernández & Brown, 2013; Avellan et al., 2021). It is noteworthy that nitrogen from a liquid source

Table 1. Summary of analysis of variance of main and interaction effects of crop years and nitrogen rates, from solid and liquid sources in oat in different cropping systems.

Variation source	DF	Mean square (GY, kg ha^{-1})		Mean square (BB, kg ha^{-1})	
		Liquid source	Solid Source	Liquid source	Solid source
Soybean/oat system					
Block	3	218576	157471	806843	577066
Year (Y)	2	15417685*	13503986*	121172337*	110406166*
Dose (D)	8	743168*	345660*	4539860*	2821302*
YxD	16	96349*	99699*	516861*	198604*
Error	78	31685	43596	106228	113621
Total	107				
General Average		2836	2735	7855	7714
CV (%)		16.2	17.6	14.1	14.3
Corn/oat system					
Block	3	475636	36179	1532086	627662
Year (Y)	2	24326860*	14792004*	124106220*	61508697*
Dose (D)	8	2095937*	1838278*	16276191*	17302189*
YxD	16	95102*	50725*	314517*	264829*
Error	78	34364	94297	143544	339135
Total	107				
General Average		2340	2281	6902	6971
CV (%)		17.9	13.4	15.4	18.3

DF – Degrees of freedom; GY – Grain yield; BP – Biomass productivity; CV – Coefficient of variation; * – Significant at 5% error probability.

Table 2. Average and estimation of stability parameters by the Wricke (Wi), Traditional (MS) and regression methods of nitrogen rates on grain yield.

Nitrogen Source	Dose	Average	Ecovalence (Wi)	Mean square (MS)	Regression** S^2d	Regression** R^2
	Soybean/oat system					
Liquid (N-Top®)	0	2347 d	35.4	15115	-4142^{ns}	98
	15	2554 c	16.8	18168	-3379^{ns}	99
	30	2762 b	14.0	153970	30571^{ns}	94
	45	2944 a	1.5	23292	-2098^{ns}	99
	60	3127 a	4.9	7702	-5995^{ns}	99
	75	3055 a	5.6	9895	-5447^{ns}	99
	90	2983 a	6.3	12278	-4851^{ns}	99
	105	2911 b	7.1	15264	-4150^{ns}	99
	120	2840 b	8.0	18294	-3347^{ns}	99
Solid (Urea)	0	2393 b	22.9	93	-10875^{ns}	99
	15	2556 b	16.9	6871	-9181^{ns}	99
	30	2719 b	13.0	30536	-3265^{ns}	99
	45	2829 a	2.0	16299	-6824^{ns}	99
	60	2940 a	2.1	6495	-9275^{ns}	99
	75	2881 a	3.9	700	-10897^{ns}	99
	90	2823 a	7.3	5622	-9493^{ns}	99
	105	2765 a	12.4	23344	-5063^{ns}	99
	120	2707 a	19.0	53492	-2473^{ns}	99
	Corn/oat system					
Liquid (N-Top®)	0	1568 f	36.3	66101	7934^{ns}	97
	15	1847 e	11.7	27666	-1674^{ns}	99
	30	2126 d	0.7	5808	-7139^{ns}	99
	45	2309 c	2.4	37638	818^{ns}	99
	60	2492 b	14.7	215358	45248*	96
	75	2567 a	6.2	69016	8662^{ns}	98
	90	2642 a	3.7	3724	-7660^{ns}	99
	105	2717 a	7.2	19599	-3691^{ns}	99
	120	2792 a	16.6	117077	20678^{ns}	98
Solid (Urea)	0	1533 e	34.2	66893	-6859^{ns}	96
	15	1821 d	9.2	5114	-22295^{ns}	99
	30	2108 c	20.4	160821	16631^{ns}	94
	45	2270 b	4.9	38735	-13890^{ns}	98
	60	2432 b	0.01	69	-23556^{ns}	99
	75	2495 a	1.1	2055	-23060^{ns}	99
	90	2559 a	4.2	6688	-21902^{ns}	99
	105	2622 a	9.3	14175	-20030^{ns}	99
	120	2684 a	16.4	24395	-17475^{ns}	99

Wi - Stability coefficient obtained by the method of Wricke (1965); MS - Mean square; S^2d - Regression deviations; R^2 - Coefficient of determination, obtained by the method of Eberhart & Russell (1966); * significant and ^{ns} not significant, respectively, by the adaptability and stability model of Eberhart & Russell (1966); **Regression by the Eberhart & Russell (1966) adaptability and stability model.

Table 3. Average and estimation of stability parameters by the Wricke (Wi), Traditional (MS) and regression methods of nitrogen rates on biomass productivity.

Nitrogen Source	Dose	Average	Ecovalence (Wi)	Mean square (MS)	Regression S^2d	R^2
	Soybean/oat system					
Liquid (N-Top®)	0	6841 d	31.3	34885	-378335*	99
	15	7110 c	18.9	3602	-35656*	99
	30	7378 c	5.3	4464	-25440^{ns}	99
	45	7749 b	4.0	1248	-26244^{ns}	99
	60	8119 a	6.0	19074	-21788^{ns}	99
	75	8222 a	6.7	2307	-25980^{ns}	99
	90	8324 a	6.6	1905	-26080^{ns}	99
	105	8426 a	6.7	17798	-22107^{ns}	99
	120	8529 a	7.0	50357	-33967*	99
Solid (Urea)	0	6821 b	34.6	4355	-37316*	99
	15	7150 b	14.6	108	-28378^{ns}	99
	30	7478 b	3.2	2119	-27875^{ns}	99
	45	7668 b	2.2	63888	-12433^{ns}	99
	60	7858 a	4.3	212009	-24597^{ns}	99
	75	7960 a	7.5	43209	-17602^{ns}	99
	90	8062 a	4.8	1985	-27908^{ns}	99
	105	8163 a	6.4	88201	-6354^{ns}	99
	120	8265 a	22.1	301577	46988^{ns}	98
	Corn/oat system					
Liquid (N-Top®)	0	5196 c	31.5	87373	-14042^{ns}	99
	15	5702 c	11.4	239527	23995^{ns}	98
	30	6207 c	9.3	466697	80788^{ns}	98
	45	6456 b	5.1	205015	15367^{ns}	99
	60	6705 b	4.1	49690	-23463^{ns}	99
	75	7209 b	2.5	6535	-34252^{ns}	99
	90	7712 a	4.7	147617	1018^{ns}	99
	105	8216 a	10.6	472739	82298^{ns}	98
	120	8719 a	20.3	982569	209756^{ns}	96
Solid (Urea)	0	5102 d	13.3	481372	35559^{ns}	96
	15	5672 c	1.5	63993	-68785^{ns}	99
	30	6242 c	2.2	34897	-76059^{ns}	99
	45	6586 b	3.2	125480	-53413^{ns}	99
	60	6931 b	18.9	802506	115842^{ns}	94
	75	7379 b	2.6	113202	-56483^{ns}	99
	90	7828 a	1.1	49711	-72356^{ns}	99
	105	8276 a	14.4	612042	68226^{ns}	95
	120	8724 a	42.4	1798802	364916^{ns}	88

Wi - Stability coefficient obtained by the method of Wricke (1965); MS - Mean square; S^2d - Regression deviations; R_2 - Coefficient of determination, obtained by the method of Eberhart & Russell (1966); * significant and ^{ns} not significant, respectively, by the adaptability and stability model of Eberhart & Russell (1966).

Table 4. Oat grain yield estimation by the technical, economic and stability of nitrogen from liquid and solid sources.

SS	NS	Equation $GY = b_0 \pm b_1x \pm b_2x^2$	R^2 (%)	N_{MET} (kg ha^{-1})	GY	N_{MEE} (kg ha^{-1})	GY	N_{MEES} (kg ha^{-1})	GY
Soybean/oat	2016 (FY)								
	L	$3094 + 7.34^{*}x$	86	-	-	-	-	-	-
		$2768 + 29.8x - 0.18^{*}x^2$	97	82	4000	0	2768	-	-
	S	$3032 + 6.24^{*}x$	86	-	-	-	-	-	-
		$2820 + 20.8x - 0.11^{*}x^2$	97	94	3803	54	3622	45	3532
	2017 (UY)								
	L	$2226 + 2.2^{ns}x$	85	-	-	-	-	-	-
		$2065 + 13.3x - 0.08^{*}x^2$	88	83	2617	0	2065	45	2501
	S	$2291 + 1.0^{ns}x$	94	-	-	-	-	-	-
		$2158 + 10.2x - 0.07^{*}x^2$	98	72	2529	0	2158	45	2445
	2018 (IY)								
	L	$2137 + 19.3^{ns}x$	86	-	-	-	-	-	-

		$2137 + 19.3x - 0.14^{*}x^2$	97	68	2802	0	2137	45	2722
	S	$2387 - 0.5^{ns}x$	81	-	-	-	-	-	-
		$2172 + 14.3x - 0.11^{*}x^2$	98	65	2636	25	2461	45	2592
Corn/oat	2016 (FY)								
	L	$2418 + 12.9^{*}x$	92	-	-	-	-	75	3385
		$2250 + 24.5x - 0.09^{ns}x^2$	99	-	-	-	-	-	-
	S	$2261 + 11.5^{*}x$	91	-	-	-	-	75	3123
		$2095 + 23x - 0.09^{ns}x^2$	99	-	-	-	-	-	-
	2017 (UY)								
	L	$1143 + 7.2^{*}x$	98	-	-	-	-	75	1683
		$1112 + 9.3x - 0.01^{ns}x^2$	99	-	-	-	-	-	-
	S	$1252 + 7.3^{*}x$	91	-	-	-	-	75	1799
		$1149 + 14.4x - 0.05^{ns}x^2$	98	-	-	-	-	-	-
	2018 (IY)								
	L	$1634 + 9.1^{*}x$	72	-	-	-	-	-	-
		$1355 + 28.4x - 0.15^{*}x^2$	98	94	2699	0	1355	75	2641
	S	$1626 + 8.3^{*}x$	71	-	-	-	-	-	-
		$1384 + 25x - 0.13^{*}x^2$	95	96	2586	62	2434	75	2527

SS – Succession system; NS – Nitrogen source; L – Liquid; S – Solid; PG – Grain yield (kg ha^{-1}); R² - Coefficient of determination; N_{MET} – Maximum technical efficiency of nitrogen; N_{MEE} – Maximum economic efficiency of nitrogen; N_{MEES} – Maximum nitrogen stability efficiency; IY – Intermediate year; FY – Favorable year; UY – Unfavorable year.

Table 5. Oat biomass yield estimation by the technical, economic and stability efficiency of nitrogen from liquid and solid sources.

SS	NS	Equation $BP = b_0 \pm b_1x \pm b_2x^2$	R^2 (%)	N_{MET} (kg ha^{-1})	BP	N_{MEE} (kg ha^{-1})	BP	N_{MEES} (kg ha^{-1})	BP
Soybean/oat	2016 (FY)								
	L	$8518 + 22.3^{*}x$	86	-	-	-	-	60	9856
		$8107 + 50.7x - 0.22^{ns}x^2$	97	-	-	-	-	-	-
	S	$8589 + 16{,}1^{*}x$	90	-	-	-	-	60	9555
		$8320 + 34.7x - 0.14^{ns}x^2$	99	-	-	-	-	-	-
	2017 (UY)								
	L	$5992 + 7.5^{*}x$	95	-	-	-	-	60	6442
		$5958 + 9.9x - 0.01^{ns}x^2$	96	-	-	-	-	-	-
	S	$5607 + 9.1^{*}x$	94	-	-	-	-	60	6153
		$5644 + 6.4x + 0.02^{ns}x^2$	95	-	-	-	-	-	-
	2018 (IY)								
	L	$6412 + 12.4^{*}x$	97	-	-	-	-	60	7156
		$6319 + 18.8x - 0.05^{ns}x^2$	99	-	-	-	-	-	-
	S	$6812 + 9{,}2^{*}x$	73	-	-	-	-	60	7364
		$6538 + 28.1x - 0.15^{ns}x^2$	99	-	-	-	-	-	-
Corn/oat	2016 (FY)								
	L	$7031 + 30.6^{*}x$	97	-	-	-	-	90	9785
		$6858 + 42.5x - 0.09^{ns}x^2$	98	-	-	-	-	-	-
	S	$6689 + 27.8^{*}x$	91	-	-	-	-	90	9191
		$6539 + 38.1 - 0.08^{ns}x^2$	99	-	-	-	-	-	-
	2017 (UY)								
	L	$3878 + 22.4^{*}x$	96	-	-	-	-	90	5894
		$4026 + 12.2x + 0.08^{ns}x^2$	98	-	-	-	-	-	-
	S	$4248 + 25.3^{*}x$	98	-	-	-	-	90	6225
		$4141 + 32.7x - 0.05^{ns}x^2$	99	-	-	-	-	-	-
	2018 (IY)								
	L	$4683 + 33.1^{*}x$	97	-	-	-	-	90	7662
		$4914 + 17.2x + 0.12^{ns}x^2$	99	-	-	-	-	-	-
	S	$4661 + 35.3^{*}x$	96	-	-	-	-	90	7838
		$4771 + 27.7x + 0.06^{ns}x^2$	97	-	-	-	-	-	-

SS – Succession system; NS – Nitrogen source; L – Liquid; S – Solid; BP – Biomass productivity (kg ha^{-1}); R² - Coefficient of determination; N_{MET} – Maximum technical efficiency of nitrogen; N_{MEE} – Maximum economic efficiency of nitrogen; N_{MEES} – Maximum nitrogen stability efficiency; IY – Intermediate year; FY – Favorable year; UY – Unfavorable year.

has water as a vehicle, which, in contact with the leaf, could favor leaf cooling and promote stomata opening, facilitating greater entry of the nutrient into plant metabolism. Therefore, a possibility to improve the use of the nutrient due to less dependence on soil conditions combined with the quick response of the plant, reducing the occurrence of losses by leaching and denitrification (Gooding & Davies, 1992; Lyu et al., 2022). In the study carried out here, the possibility of using nitrogen from a liquid source is confirmed, bringing results similar to those obtained by using the standard source (urea). However, scientific advances that reduce the production cost of this technology can advance a new line of nutrient management. In addition, new mechanisms to facilitate the entry of nitrogen by foliar absorption should be considered, such as the use of natural compounds to reduce the impact of leaf wax, the nano encapsulation of the nutrient facilitating entry by stomata, among others. In this context, new research related to the topic can collaborate to define more sustainable management of nitrogen use in agricultural crops and make it possible to understand the mechanisms of nutrient absorption by leaves in the development of productivity. The advances to be obtained raise a series of possibilities for action and strengthen this global trend towards more sustainable technologies in food production. Therefore, it brings to light the possibility of developing different researches to strengthen a new era of world agriculture, in line with the Sustainable Development Goals of the UN 2030 Agenda, with emphasis on goal 2, "Zero hunger and sustainable agriculture".

Materials and Methods

Study area and experimental design

The study was carried out in 2016, 2017 and 2018, in Augusto Pestana, RS, Brazil (28° 26' 30'' latitude S and 54° 00' 58'' longitude W). The soil of the experimental area is classified as Typical Dystroferric Red Latosol, with a deep, well-drained profile and dark red color. The climate of the region, according to the Köppen classification, is Cfa (humid subtropical), with well-distributed rainfall throughout the year, with volumes close to 1600 mm per year, with higher volumes of precipitation in winter. 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 $cmol_c$ dm^{-3}; Ca = 6.5 $cmol_c$ dm^{-3} and Mg=2.5 $cmol_c$ dm^{-3}). Sowing was carried out with a seeder-fertilizer in two cropping systems (soybean/oats and corn/oats) between the first and third week of June in the different years, using the white oat cultivar URS Guará, with a population density of 400 viable seeds m^{-2}. In each cropping system (soybean/oats, corn/oats), two experiments were carried out, one to quantify the biomass productivity (BP, kg ha^{-1}) and the other to estimate the grain yield (GY, kg ha^{-1}). Therefore, in the four experiments, the design was randomized blocks with four replications in a 2x4 factorial model, for 2 nitrogen sources (liquid and solid) with 4 doses of the nutrient (0, 30, 60 and 120 kg ha^{-1}), respectively. The experimental unit consisted of a plot of five lines of 5 meters in length and spaced at 0.20 meters, totaling 5 m².

Crop management

At sowing, 45 e 30 kg ha^{-1} of P_2O_5 and K_2O were applied com based on the P and K contents in the soil for expected grain yield of 3 t ha^{-1}, respectively, and 10 kg ha^{-1} of N (except in the standard experimental unit). During the execution of the study, applications of tebuconazole fungicide called FOLICUR® CE were carried out at a dose of 0.75 L ha^{-1}. Weeds were controlled by the application of the metsulfuron-methyl herbicide called ALLY® at a dose of 2.4 g ha^{-1} and additional weeding whenever necessary.

The nitrogen source for root absorption in the soil was urea (45% N) applied in top dressing and for foliar absorption was the commercial product N-Top® (28% N) in liquid form with a density of 1.3 g ml^{-1}. The liquid source nitrogen used comes from a substance with a high concentration of organic compounds, mainly humic and fulvid acids. The urea was applied by broadcast and the N-Top® was sprayed with a volume of water of 200 L ha^{-1}. In each of the sources, the different doses of nitrogen indicated in the study were dimensioned, converted to the area of the experimental unit of $5m^2$. The application of nitrogen by foliar was carried out with a backpack sprayer at a constant pressure of 30 lb in^{-2}, by compressed CO^2, with "cone" jet tips, and the spraying time was scaled to apply the different doses of the nutrient. The application of the treatments in the sources of absorption by radicular and foliar was in the phenological stage V_4, considering the oat plant with four expanded leaves.

Traits measured

In the experiments aiming to quantify the biomass productivity (BP, kg ha^{-1}) the three central lines of each plot close to the ground were cut with the plants at the physiological maturity stage. Afterwards, the green biomass samples were sent to a forced air oven at a temperature of 65°C until reaching constant weight and weighed on a precision scale to estimate the total dry matter, converted into kg ha^{-1}. In the experiments to estimate grain yield (GY, kg ha^{-1}) the three central lines of each plot were cut at the stage of harvest maturity with grain moisture around 22%. Afterwards, the plants were threshed on a stationary threshing machine and the grains sent to the laboratory for moisture correction to 13%, and yield conversion to kg ha^{-1}.

Statistical analysis

When meeting the assumptions of homogeneity and normality via Bartlett's test, analysis of variance was performed to detect the main and interaction effects between year and nitrogen doses for each nutrient source in the expression of biomass and oat grain yield in different systems of cultivation. In the proposal to estimate the nitrogen doses from liquid and solid sources that promote greater stability with productivity, the points of 15, 45, 75, 90 and 105 were interpolated by regression, which together with the real points (nitrogen doses) made it possible to test nine levels of the nutrient. Afterwards, stability analysis was performed using the Traditional, Wricke and Eberhart & Russell models. Using the traditional method, it is possible to estimate stability, considering the effects of agricultural years on each nitrogen dose, with the one with the lowest mean square magnitude being stable. In this methodology, the general average and the averages of doses and environments (years) are calculated. The joint analysis of variance is reconstituted from the averages of doses in the various environments and the F tests are performed considering the model as fixed. The degrees of freedom, sum of squares and mean square of the residual are obtained from preliminary information. The ambient sums of squares are obtained by fixing the dose by: SQA/D = SQA + SQDA, where:

SQA = environment sum of squares (Years)

SQA = sum of squares of dose-environment interaction

SQA/D = sum of squares of the environment fixing the dose

SQA/D = $r\ [\sum Yij\ 2 - 1\ a\ (\sum jYiJ)^2]j$

where Yij is the average of the i-th dose evaluated in the j-th environment, a the number of environments and r the number of repetitions.

Wricke's (1965) model, also called Ecovalence (Wi), considers the dose to be more stable when the lowest values of Wi or Wi (%). Thus, the Wricke model was estimated based on the following equations:

$$W_i = \sum_{j-1}^{n} (DN)_{ij}^2$$

$$(DN)_{ij}=Y_{ij}-Y_i-Y_j-Y$$

Where:

Y_{ij} = average dose "i" in environment "j";

Y_i = average dose "i" in all environments;

Y_j = average of the environment "j" in all doses; and,

$Y = m_i$ – general average.

Eberhart & Russell's (1966) model is based on linear regression aggregated to an environmental index and on the parameter S_{ij}^2 that estimates stability. It is considered stable when the parameter S_{ij}^2 is equal to 0 or unstable when S_{ij}^2 is different from 0.

$$Y_{ij} = B0_i + B1_i + I_j + S_{ij}^2 + E_{ij}$$

Where:

Y_{ij} = average dose "i" in environment "j";

$B0_i$ = general average of the dose "i";

$B1_i$ = linear regression coefficient, whose estimate represents the response of the dose "i" to the variation of the environment "j";

I_j = environmental index;

S^2_{ij} = regression deviation; and,

E_{ij} = average environmental error.

The Scott & Knott average comparison test was also carried out, regardless of the condition of the crop year, to analyze the biomass and grain yields at the nitrogen points.

A quadratic function adjustment was performed ($y= b_0 \pm b_1x \pm b_2x^2$) to estimate the maximum technical efficiency (MET) by the model [$MET = -(b_1)/(2b_2)$]. By the quadratic function involving the price of the product (w) and the price of the input (t) the maximum economic efficiency (MEE) is obtained from the equation [$MEE = (\frac{t}{w} - b_1)/(2.b_2)$]. The values used represent the average prices sold in January 2019 in the northwest region of Rio Grande do Sul, with the price of the oat product being US$ 1.46 kg^{-1}. Input prices were calculated separately in order to compare the maximum economic efficiency of each nitrogen source. The value of a liter of nitrogen from a liquid source is US$ 73.00, considering that in a liter of this product there is a concentration of 364 grams of nitrogen, so the cost of a kilogram of nitrogen is US$ 200.75. The price of a ton of urea (solid source of nitrogen) is US$ 5785.25, taking into account that there are 450 kilograms of nitrogen in each ton, the cost is US$ 12.84 per kilogram of solid nitrogen from a commercial urea source. Efficiency by stability was also observed, from the stable dose by the variation of agricultural years obtained by the Traditional models, by Wricke and Eberhart & Russel on the productivity of biomass and oat grains. All analyzes were performed using the GENES software.

Conclusions

The efficiency of use of nitrogen from a liquid source by foliar absorption in oats promotes results similar to the use of urea, the standard source of nutrient supply.

Regardless of the nitrogen source, doses of 45 and 75 kg ha^{-1} are more efficient in soybean/oat and corn/oat systems, respectively.

Although the technical efficiency of liquid source nitrogen is proven, the high cost of this technology does not guarantee economic efficiency for recommendation on a commercial scale.

Acknowledgements

To CAPES, CNPq, FAPERGS, UNIJUÍ and DUBAI Alimentos, for the financial support to the research and Scholarships for Scientific and Technological Initiation, Graduate Studies and Research Productivity. And to the postgraduate program in Environmental Systems and Sustainability and Mathematical and Computational Modeling at UNIJUÍ for the different resources made available in the development of this research.

Conflicts of interest

The authors declare no conflict of interest.

References

Alshaal T, El-Ramady H (2017) Foliar application: from plant nutrition to biofortification. Environment, Biodiversity and Soil Security. 1:71-83.

Anas M, Liao F, Verma KK, Sarwar MA, Mahmood A, Chen ZL, Li Q, Zeng XP, Liu Y, Li YR (2020) Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. Biological Research. 53(47): 1-20.

Arenhardt EG, Silva JAG, Gewehr E, Oliveira AC, Binello MO, Valdiero AC, Gzergorczick ME, Lima ARC (2015) The supply of nitrogen in wheat yield by year condition and succession system in southern Brazil. African Journal of Agricultural Research. 10(48):4322-4330.

Arenhardt EG, Silva JAG, Arenhardt LG, Silva DR, Gzergorcsick ME, Ceolin GP, Stülp, C, Figueiredo, R.G, Oliveira, A.C (2017) Technical and agronomic efficiency of oat cultivars as a function of nitrogen availability. Científica Jaboticabal. 45(3):257-270.

Assis GA, Melo MRP, Soares MA, Assis FA, Martins WER, Silva LR (2018) Níveis de adubação n e k em cafeeiros fertirrigados e sua função de resposta. Ciência Agrícola. 16(3): 65-73.

Avellan A, Yun J, Morais BP, Clement ET, Rodrigues SM, Lowry GV (2021) Critical review: role of inorganic nanoparticle properties on their foliar uptake and in planta translocation. Environmental Science & Technology. 55: 13417–13431.

Barbosa JA, Faria RT, Coelho AP, Dalri AB, Palaretti LF (2020) Nitrogen fertilization management in white oat using spectral indices. Pesquisa Agropecuária Tropical. 50(e64924): 1-9.

Beig B, Niazi MBK, Jahan Z, Hussain A, Zia MH, Mehran MT (2020) Coating materials for slow release of nitrogen from urea fertilizer: a review. Journal of Plant Nutrition. 1510-1533.

Bredemeier C, Mundstock CM (2000) Regulação da absorção e assimilação do nitrogênio nas plantas. Ciencia Rural. 30(2): 365-372.

Coelho AP, Faria RT, Leal FT, Barbosa JA, Lemos LB (2020) Biomass and nitrogen accumulation in white oat (*Avena sativa* L.) under water déficit. Revista Ceres. 67(1):1-8.

Companhia Nacional de Abastecimento (CONAB). Disponível em: https://www.conab.gov.br/info-agro/safras/graos. Acesso em: 28 de junho de 2022.

Eberhart SA, Russell WA (1966) Stability parameters for comparing varieties. Crop Science. Madison, 6: 36-40.

Fageria NK, Barbosa Filho MP, Moreira A, Guimarães CM (2009) Foliar Fertilization of Crop Plants. Journal of Plant Nutrition. 32(6): 1044-1064.

Fernández V, Brown PH (2013) From plant surface to plant metabolism: the uncertain fate of foliar-applied nutrients. Frontiers Plant Science. 4(289); 1-5.

Good AG, Beatty PH (2011) Fertilizando a natureza: Uma tragédia do excesso nos comuns. PLoS Biol. 9(e1001124): 1-9.

Gooding MJ, Davies WP (1992) Foliar urea fertilization of cereals: a review. Fertilizer Research. 32: 209-222.

Hammad HM, Farhad W, Abbas F, Fahad S, Saeed S, Nasim W, Bakhat HF (2017) Maize plant nitrogen uptake dynamics at limited irrigation water and nitrogen. Environmental Science and Pollution Research, 24: 2549–2557.

Indicações Técnicas. Danielowski R, Caraffa M, Moraes CS, Lângaro NC, Carvalho IQ. Cultivares de aveia, qualidade de sementes e implantação da cultura. In: Danielowski R, Caraffa M, Moraes CS, Lângaro NC, Carvalho IQ. Indicações técnicas para a cultura de aveia: 40ª Reunião da Comissão Brasileira de Pesquisa de Aveia (p. 48-56). Três de Maio: Sociedade Educacional Três de Maio (SETREM), 2021.

Karthika KS, Rashmi I, Parvathi MS. Funções biológicas, absorção e transporte de nutrientes essenciais em relação ao crescimento das plantas. In: Hasanuzzaman M, Fujita M, Oku H, Nahar K, Hawrylak-Nowak B. (eds) Nutrientes de plantas e tolerância ao estresse abiótico. Springer, Singapura, 2018.

Kraisig AR, Silva JAG, Carvalho IR, Mamann ÂTW, Corso JS, Norbert L (2020) Time of nitrogen supply in yield, industrial and chemical quality of oat grains. Revista Brasileira de Engenharia Agrícola e Ambiental. 24(10): 700-706.

Krüger CAMB, Medeiros SLP, Silva JAG, Dalmago GA, Valentini APF, Wagner JF (2016) Rapeseed population arrangement defined by adaptability and stability parameters. Revista Brasileira Engenharia Agrícola e Ambiental. 20(1): 36–41.

Lebedev VG, Popova AA, Shestibratov KA (2021) Genetic engineering and genome editing for improving nitrogen use efficiency in plants. Cells, 10(12): 1-40.

Li G, Zhao B, Dong S, Zhang J, Liu P, Lu W (2020) Controlled-release urea combining with optimal irrigation improved grain yield, nitrogen uptake, and growth of maize. Agricultural Water Management. 227(105834): 1-13.

Lyu X, Liu Y, Li N, Ku L, Hou Y, Wen X (2022) Foliar applications of various nitrogen (N) forms to winter wheat affect grain protein accumulation and quality via N metabolism and remobilization. The Crop Journal. 10(4): 1165-1177.

Mamann ÂTW, Silva JAG, Scremin OB, Trautmann APB, Argenta CV, Matter EM (2020) Diffuse system simulating wheat productivity by nitrogen and temperature in the use of biopolymers. Revista Brasileira de Engenharia Agrícola e Ambiental. 24(5): 289-297.

Mantai RD, Silva JAG, Arenhardt MG, Heck TG, Sausen ATZR, Krüger CAM, Cardoso AM, Goi Neto CJ, Krysczun DK (2015) The effect of nitrogen dose on the yield indicators of oats. African Journal of Agricultural Research. 10(39): 3773-3781.

Mantai RD, Silva JAG, Carbonera R, Carvalho IR, Lautenchleger F, Pereira LM (2021) Technical and agronomic efficiency of nitrogen use on the yield and quality of oat grains. Revista Brasileira de Engenharia Agrícola e Ambiental. 25(8): 529-537.

Mantai RD, Silva JAG, Arenhardt EG, Scremin OB, Mamann ÂTW, Frantz RZ, Valdiero AC, Pretto R, Krysczun DK (2016) Simulation of oat grain (*Avena sativa*) using its panicle components and nitrogen fertilizer. African Journal Agricultural of Crop Science. 11(40): 3975-3983.

Marolli A, Silva JAG, Sawicki S, Binelo MO, Scremin AH, Reginatto DC, Dornelles EF, Lambrecht DM (2018) A simulação da biomassa de aveia por elementos climáticos, nitrogênio e regulador de crescimento. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 70(2): 535-544.

Mortate RK, Nascimento EF, Gonçalves EGS, Lima MWP (2018) Resposta do milho (*Zea mays* L.) à adubação foliar e via solo de nitrogênio. Revista de Agricultura Neotropical, 5(1): 1-6.

Muratore C, Espen L, Prinsi B (2021) Nitrogen uptake in plants: the plasma membrane root transport systems from a physiological and proteomic perspective. Plants. 10(4): 1-26.

Omara P, Aula L, Oyebiyi F, Raun WR (2019) World cereal nitrogen use efficiency trends: review and current knowledge. Agrosystems, Geosciences and Environment. 2(180045).

Pereira LM, Tissot-Squalli ML, Wildner G, Dornelles EF, Heck TG, Silva JAG (2018) Oxidative stress measurements can indicate the best dose and period of nitrogen fertilizer in white oat crop. International Journal of Development Research. 8(1): 18468-18474.

Qiao Y, Yin L, Wang B, Ke Q, Deng X, Wang S (2019) Melatonin promotes plant growth by increasing nitrogen uptake and assimilation under nitrogen deficient condition in winter wheat. Plant Physiology and Biochemistry. 139: 342-349.

Qureshi A, Singh DK, Dwivedi S (2018) Nano-fertilizers: a novel way for enhancing nutrient use efficiency and crop productivity. International Journal of Current Microbiology and Applied Sciences. 7(2): 3325-3335.

Reginatto DC, Silva JAG, Carvalho IR, Lautenchlegere F, Rosa JA, Peter CL, Henrichsen L, Jung MS, Basso NCF, Argenta CV, Norbert L, Babeski CM (2021) Nitrogen management at sowing and topdressing with the time of supply in the main biotype of oats grown in southern Brazil. Australian Journal of Crop Science. 15(04): 524-530.

Ren F, Sun N, Misselbrook T, Wu L, Xu M, Zhang F, Xu W (2022) Responses of crop productivity and reactive nitrogen losses to the application of animal manure to China's main crops: A meta-analysis. Science of The Total Environment, 850(158064): 1-12.

a Rosa TC, Carvalho IR, Silva JAG, Szareski VJ, Segatto TA, Port ED, Loro MV, Almeida HCF, Oliveira AC, Maia LC, Souza VQ (2021) Genetic parameters and multi-trait selection of white oats for forage. Genetcs and Molecular Research, 20(2): 1-13.

b Rosa JA, Mantai JD, Kraisig AR, Silva JAG, Carvalho IR, Pereira LM, Pansera V, Alessi O (2021) Modelos para estimativa da eficiência econômica e de estabilidade de uso de nitrogênio na produtividade da aveia. Proceeding Series of the Brazilian Society of Computational and Applied Mathematics, 8(1):1-7.

Scremin OB, Silva JAG, Carvalho IR, Mamann ÂTW, Kraisig AR, Rosa JA, Peter CL, Warmbier E, Pereira LM, Basso NCF, Argenta CV, Matter EM (2020) Artificial intelligence by artificial neural networks to simulate oat (*Avena sativa* L.) grain yield through the growing cycle. Journal of Agricultural Studies, 8(4): 1-19.

Silva JAG, Mamann ÂTW, Scremin OB, Carvalho IR, Pereira LM, Lima ARC, Lautenchleger F, Basso NCF, Argenta CV, Berlezi JD, Porazzi FU, Matter EM, Norbert L (2020) Biostimulants in the indicators of yield and industrial and chemical quality of oat grains. Journal of Agricultural Studies, 8(2): 68-87.

Silva JAG, Goi Neto CJ, Fernandes SBV, Mantai RD, Scremin OB, Pretto R (2016) Nitrogen efficiency in oats on grain yield with stability. Revista Brasileira de Engenharia Agrícola e Ambiental, 20(12): 1095-1100.

a Silva JAG, Arenhardt EG, Krüger CAMB, Lucchese OA, Metz M, Marolli A (2015) A expressão dos componentes de produtividade do trigo pela classe tecnológica e aproveitamento do nitrogênio. Revista Brasileira de Engenharia Agrícola e Ambiental, 19(1): 27–33.

b Silva JAG, Wohlenberg MD, Arenhardt EG, Oliveira AC, Mazurkievicz G, Müller M, Arenhardt LG, Binelo MO, Arnold G, Pretto R (2015) Adaptability and stability of yield and industrial grain quality with and without fungicide in brazilian oat cultivars. American Journal of Plant Sciences. 6: 1560-1569.

Siqueira Neto M, Piccolo MDC, Venzke Filho SDP, Feigl BJ, Cerri CC (2010) Mineralização e desnitrificação do nitrogênio no solo sob sistema plantio direto. Bragantia, 69: 923-936.

Suherman WMD (2010) Producing sulfur coated urea by fluid bed wet coating method: drying kinetics and product quality. International Review of Chemical Engineering. 2(6): 707-712.

Trautmann APB, Silva JAG, Carvalho IR, Colet CF, Lucchese OA, Basso NCF, Alessi O, Sgarbossa J, Dias JEL, Peter CL (2022) Sustainable nitrogen efficiency in wheat by the dose and mode of supply. Revista Brasileira de Engenharia Agrícola e Ambiental. 26(9): 670-679.

Vasundhara D, Chhabra V (2021) Foliar nutrition in cereals: A review. The Pharma Innovation Journal. 10(8): 1247-1254.

Wang R, Zeng J, Chen K, Ding Q, Shen Q, Wang M, Guo S (2022) Nitrogen improves plant cooling capacity under increased environmental temperature. Plant and Soil. 472: 329–344.

Wricke GZ (1965) Berechnung der Okovalenz bei Sommerweizen und Hafer. Zeitschrift für Pflanzenzüchtung. 52: 127-138.

Zhao XQ, Shen RF (2018) Aluminum–nitrogen interactions in the soil–plant system. Frontiers Plant Science. 8(8-7): 1-15.