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Sustainable management of nitrogen in oats based on stability parameters

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ABSTRACT. The productive performance of oats depends on proper management of nitrogen, a highly mobile element and of reduced efficiency in unfavorable cultivation conditions, generating productivity reduction with environmental pollution. This study aimed to find the most efficient and sustainable management of nitrogen in oats based on the nutrient dose at sowing and coverage with the timing of application, considering the main cereal succession systems in Brazil during favorable and unfavorable agricultural years, through parameters that scale performance and adaptability and stability. The experiment was conducted in 2015, 2016 and 2017, in a region of commercial oat cultivation, in the municipality of Augusto Pestana, RS, Brazil. The experimental design was randomized blocks with four replications, in a 4 x 4 factorial model, for four nitrogen rates at sowing (0, 10, 30 and 60 kg ha^{-1}), changing the coverage rate by the total supplied of 70 and 100 kg ha^{-1} (recommended doses for oats) in a soybean/oat and corn/oat succession system, respectively, with the expectation of a grain yield of 4000 kg ha^{-1}, with the supply in topdress, considering four application times (0, 10, 30 and 60 days after emergence). Regardless of the crop year condition, in the soybean/oat system, the highest nitrogen use efficiency with adaptability and stability for biomass and grain productivity occured in the condition of absence of nitrogen at sowing with the total dose in coverage at 10 and 30 days after emergence. In the corn/oat system, the highest yield efficiency with adaptability and stability was in the combination of the absence of nitrogen at sowing with the total coverage dose at 10 days after emergence.

Key words: *Avena sativa*; Seeding; Coverage; Dose; Time; Sustainability

INTRODUCTION

The growing demand for food is accompanied by the demand for new processes to reduce pollutants to soil, water, air, and food, minimizing the negative impacts of agricultural activities (Mamann et al., 2020). Nitrogen is the most absorbed nutrient and the most limiting for development and productivity (Brezolin et al., 2017). It is noteworthy that crops that do not perform biological fixation, such as cereals, demand about 50% of the nitrogen fertilizers produced in the world (Ladha et al., 2016; Kraisig et al., 2021).

The conditions of low soil moisture and high air temperature during nitrogen fertilization can result in losses to the environment of more than 70% (Vieira, 2017). Nitrogen fertilizers are the main pollutants of soil and water, due to their high mobility and ease of losses by volatilization and/or leaching (Petean et al., 2019). Negative impacts are also found in the manufacturing of nitrogen fertilizers, as they contribute to the emission of CO_2 and NO_2 gasses, precursors in the global warming process (Wick et al., 2012).

White oat (*Avena sativa*) is a cereal of great recognition in human and animal nutrition; it presents in its grains, high protein content and adequate levels of carbohydrates and lipids, with a high proportion of β-glucan soluble fiber, with functional activity in the reduction of LDL cholesterol (Mantai et al., 2020; Silva et al., 2020). For expectations seeking greater productivity with the species higher doses of nitrogen are provided, however, unfavorable conditions increase the doses of fertilization, increase production costs with generation of environmental pollution (Silva et al., 2016; Trautmann et al., 2021).

Oat productivity is associated with a great variability in growing conditions, with the agricultural year being the biggest contributing factor (Storck et al., 2014). Favorable and unfavorable crop years and succession systems of high and low N-residual release alter the dynamics of availability and the efficiency of nutrient use by the plant, generating instability in productivity (Arenhardt et al., 2015). Therefore, strategies that minimize nitrogen losses at the time of application and ensure better use by plants in obtaining satisfactory productivity are essential (Scremin et al., 2017). In the literature, studies can be found that evaluate the effect of different forms of nitrogen supply in sowing and coverage and application times on crop productivity, such as wheat (Trautmann et al., 2020; Kraisig et al., 2021), corn (Andrade et al., 2014), rice (Santos et al., 2017), oatmeal (Mantai et al., 2021; Reginatto et al., 2021), and others. However, the authors make use of approaches aimed at identifying doses of maximum technical and economic efficiency of nitrogen or times that provide greater productivity, without integrating concepts that involve the least environmental impact.

Therefore, adaptability and stability analysis models can be used to identify managements that maintain the same performance under different cultivation conditions and/or, better performance under specific microclimatic conditions (Carvalho et al., 1995; Arenhardt et al., 2015; Silva et al., 2016). Adaptability and stability models seek, through the quantification of their parameters, to define the response of genotypes/managements to specific environmental conditions (Benin et al., 2005; Silva et al., 2016). In this context, the model proposed by Eberhart and Russell (1966), stands out, which is based on the estimation of the linear regression coefficient (β_1i) in the analysis of adaptability and regression deviations (σ2di) as a criterion to evaluate the stability and, the model proposed by Wricke (1965), called ecovalence (ωi), based on the decomposition of the sum of squares of the interaction with the criterion of dimensioning stability. Thus, a management that optimizes the relationship between nitrogen management and the efficiency of use by oats is possible, aiming at satisfactory productivity with less environmental impact by parameters of adaptability and stability.

The objective of the study is the most efficient and sustainable management of nitrogen in oats in the combination of the nutrient dose at sowing and coverage with the moment of application, considering the main cereal succession systems in Brazil in favorable and unfavorable agricultural years, through parameters that scale performance and adaptability and stability.

MATERIAL AND METHODS

Study area and experimental design

The work was carried out in the field in the agricultural years of 2015, 2016 and 2017 in Augusto Pestana, RS, Brazil (28° 26’ 30’’ south latitude and 54° 00’ 58’’ west longitude). The soil of the experimental area was classified as Typical Dystroferric Red Latosol and the climate of the region, by the Köppen classification, Cfa type, with hot summer without dry season. Twenty days before sowing, the soil was analyzed and the chemical characteristics shown in Table 1 were determined.

Table 1. Chemical composition of the soil of the experimental area where oats were cultivated.

Cropping systems	Clay (%)	OM (%)	pH (H_2O)	P (mg dm^{-3})	K (mg dm^{-3})	AL ($cmol_c$ dm^{-3})	Ca ($cmol_c$ dm^{-3})	Mg ($cmol_c$ dm^{-3})
Maize/oat	52	2.9	6.2	40.8	239.7	0	6.5	2.5
Soybean/oat	54	3.2	6.5	26.9	179.5	0	6.3	2.7

OM= organic matter; P= phosphorus; K= potassium; Al= aluminum; Ca= calcium; Mg= magnesium.

In each cropping system (soybean/oats; corn/oats), two experiments were conducted, one to quantify the biomass yield rate and the other to estimate grain yield. In the four experiments, the design was randomized blocks with four replications in a 4 x 4 factorial scheme, for four nitrogen rates at sowing (0, 10, 30 and 60 kg ha^{-1}) changing the coverage rate by the total of nitrogen provided of 70 and 100 kg ha^{-1} in soybean/oat and corn/oat systems, respectively, in the expectation of grain yield of 4000 kg ha^{-1}, with topdressing at four application times (0, 10, 30 and 60 days after emergence), totaling 128 experimental units per succession system. Nitrogen rates at sowing and coverage with the urea source were provided according to the information in Table 2.

Table 2. Nitrogen supply conditions at sowing and oat cover in succession systems.

Dose N-sowing (kg ha^{-1})	Dose N-coverage (kg ha^{-1})	Dose N-total (kg ha^{-1})	Expectation Grain Productivity (kg ha^{-1})	Time N-coverage (DAE)
Soy/oat system				
0	70			
10	60	70	4000	0; 10; 30; 60
30	40			
60	10			
Corn/oat system				
0	100			
10	90	100	4000	0; 10; 30; 60
30	70			
60	40			

DAE= days after emergence, for nitrogen application on oat.

Crop management

Sowing was carried out in the third week of June with a seeder-fertilizer in the composition of the plot with 5 lines of 5 m in length and spacing between lines of 0.20 m, forming the experimental unit of 5 m^2. The population density used was 400 viable seeds m^{-2}. The oat cultivar used in all agricultural years was Brisasul, characterized by an early cycle and reduced height with great potential for productivity. During sowing, 45 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O were applied, associated with different amounts of nitrogen considering the dynamics of the experiment (except in the standard experimental unit – dose 0). Disease and weed control were carried out by applications of the fungicide tebuconazole (FOLICUR® CE), at a dose of 0.75 L ha^{-1} and the herbicide metsulfuron-methyl (ALLY®), at a dose of 4g ha^{-1}.

Traits measured

Biomass productivity was obtained by collecting one linear meter (ml $^{-1}$) of plant material from shoots, from three central lines of each plot, when the plants reached physiological maturity (120 DAE). Subsequently, the samples were packed in paper bags and kept in an oven with forced air circulation at 65 °C, until reaching a constant mass for estimating biomass productivity (BP – kg ha^{-1}). Grain yield was obtained by harvesting three central rows of each plot, when the plants reached physiological maturity, with grain moisture close to 22%. The collected samples were threshed in a stationary thresher and sent to the laboratory to correct the grain moisture to 13% and estimate grain yield (GY – kg ha^{-1}). The meteorological data were obtained from the automatic total station, installed 300 meters from the experiment.

Statistical analysis

Data were initially analyzed for homoscedasticity of residual variances and adherence of residuals to normal distribution, using the Bartlett ($p \leq 0.05$) and Shapiro-Wilk ($p \leq 0.05$) tests, respectively. Given the statistical assumptions, the data were subjected to analysis of variance (ANOVA) to detect the possible main effects and interaction between the years of cultivation and nitrogen management (N dose at sowing/coverage with the time of nutrient application). Therefore, the variation of the four doses of nitrogen (seeding and covering, from the total dose established in the expectation of productivity of 4000 kg ha^{-1}) with four times of application of the nutrient, made it possible to test 16 combinations of treatments in the management of nitrogen.

The data were submitted to analysis of means by descriptive statistics in the decomposition of this interaction for each year of cultivation, forming three groups: superior, median and inferior, based on the mean plus or minus one standard deviation, in the analysis of biological and grain productivity. To identify the best combination between doses of nitrogen applied at sowing and coverage with the time of supply of the nutrient in coverage, the measured data were subjected to adaptability and stability analysis, according to the model proposed by Eberhart and Russell (1966) and the grouping of means was performed using the Scott & Knott test ($p \leq 0.05$), to classify the different combinations. To estimate stability by the ecovalence test, the model proposed by Wricke (1965) was used. The Wricke model was estimated based on the following equations:

$$\omega_i = \sum_{j-1}^{n} (DN)_{ij}^2 \quad \text{(Eq. 1)}$$

$$(DN)_{ij} = Y_{ij} - Y_i - Y_j - Y \quad \text{(Eq. 2)}$$

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,

$Y = m_1$ – general average.

According to this methodology, stability is indicated by low values of ω_i.

The Eberhart & Russell (1966) model is based on simple linear regression, measuring the oat yield response at each nitrogen dose, in the face of environmental variations:

$$Y_{ij} = B0_i + B1_i + I_j + S_{ij}^2 + E_{ij} \quad \text{(Eq. 3)}$$

Where:

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

$B0_i$ = general average of 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 stability of the combination of nitrogen applied at sowing and coverage with the time of supply was obtained by the parameter S2 ij. A treatment/condition is considered stable when S2ij = 0 and unstable when S2ij ≠ 0. All statistical analyzes were performed using the GENES software (Cruz, 2006).

RESULTS AND DISCUSSION

In 2015, rainfall was similar to the historical average of the last 25 years. High volumes of precipitation were observed at the beginning of the crop cycle, coinciding with topdressing fertilizations performed at 10 and 30 days after emergence (DAE) (Table 3). Nitrogen supply at 60 DAE was under low soil moisture conditions (Figure 1). Although the fertilization carried out in all periods has an expected yield of 4000 kg ha^{-1}, the average grain yield observed in this year, 3283 kg ha^{-1}, indicates an intermediate condition (IY) of oat cultivation.

Table 3. Temperatures and rainfall in the oat crop cycle and grain yield obtained in different agricultural years.

Months	Air temperature (°C)			Precipitation (mm)		GY (kg ha^{-1})	Class
	Minimum	Average	Maximum	25 years*	Occurred		
2015							
June	9.56	15.52	21.47	162.5	228.3		
July	10.5	15.55	20.59	135.1	211.5		
August	13.3	19.05	24.8	138.2	86.8	3283	IY
September	12.73	16.33	19.93	167.4	127.3		
October	16.7	20.95	25.2	156.5	161.8		
Total	–	–	–	909.4	815.7		
2016							
June	4.7	12	19.3	162.5	65.6		
July	8.5	15.03	21.55	135.1	80.5		
August	9.4	15.95	22.5	138.2	160	3925	FY
September	8.44	16.13	23.82	167.4	56.3		
October	13.3	19.55	25.8	156.5	325.8		
Total	–	–	–	909.4	688.2		
2017							
June	10.7	16.25	21.8	162.5	146.3		
July	8.3	16.36	24.42	135.1	10.7		
August	11.4	17.55	23.7	138.2	117.8	1979	UY
September	15.36	21.22	27.07	167.4	161.5		
October	14.7	21.25	27.8	156.5	304		
Total	–	–	–	909.4	740.3		

GY= grain yield; IY= intermediate year; FY= favorable year; UY= unfavorable year.

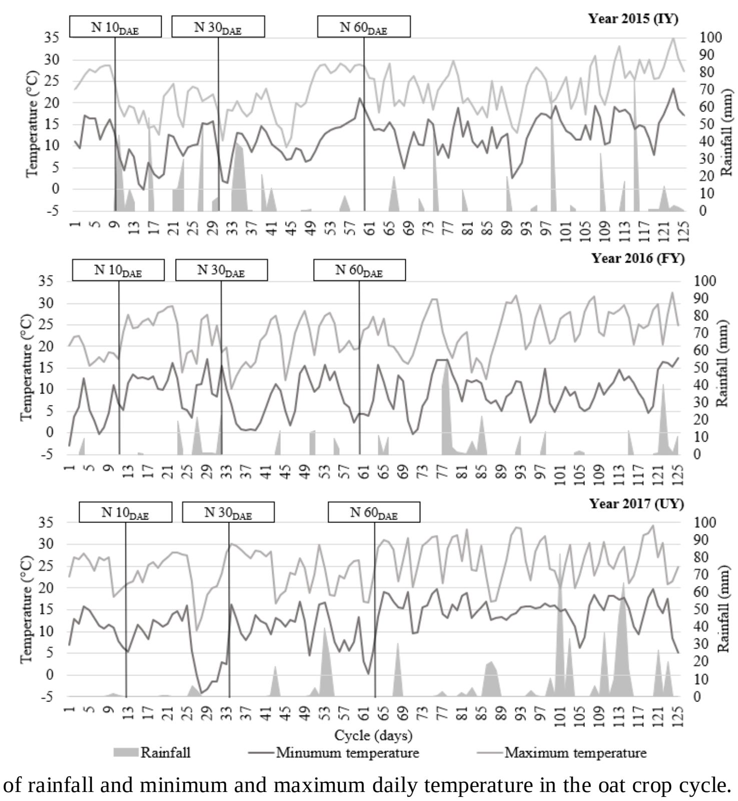

Figure 1. Data of rainfall and minimum and maximum daily temperature in the oat crop cycle. IY= intermediate year; FY= favorable year; UY= unfavorable year.

For 2016, the accumulated rainfall was lower than the historical average, however, with a more uniform distribution throughout the cycle and with milder and more stable temperatures (Table 3, Figure 1). Nitrogen applications at 10 and 30 DAE were carried out under conditions of adequate soil moisture, due to the occurrence of precipitation in the days prior to fertilization (Figure 1). The uniform distribution of rainfall, associated with mild temperatures during the cycle, resulted in average grain yield similar to the expectation (4000 kg ha^{-1}), justifying the occurrence of a favorable year (FY) for oat cultivation.

In 2017, the volume of rainfall was also lower than the historical average, however, with an uneven distribution during the crop cycle. In addition, greater variability was observed in thermal conditions, associated with the occurrence of higher temperatures, compared to other years. Fertilizations carried out at 10 and 30 DAE were carried out in conditions of low soil moisture, due to the occurrence of long periods without precipitation, with the exception of fertilization carried out at 60 DAE (Table 3, Figure 1). The combination of higher temperatures with low soil moisture at fertilization times resulted in an average grain yield of 1979 kg ha^{-1}, much lower than expected, justifying the unfavorable year (UY) for oat cultivation.

Weather conditions directly influence the growth, development and consequently the productivity of crops. Thus, the interannual variability of meteorological elements can result in large fluctuations in agricultural production over the years (Santos et al., 2011; Caron et al., 2017). Among the meteorological elements, rainfall stands out as one of the main factors responsible for these variations (Marolli et al., 2017), either due to the occurrence of volumes below the crop demand or the uneven distribution throughout the cycle. For winter cereals, such as oats, the occurrence of rainfall in volumes that provide adequate soil moisture and well distributed throughout the cycle, characterize favorable environmental conditions for obtaining high production levels.

In addition to rainfall, air temperature has a direct influence on the expression of crop productivity, as it acts as a catalyst for biological processes. Each culture requires a minimum and maximum temperature for metabolic activities to be performed properly (Tonin et al., 2014; Marolli et al., 2017). In crops such as oats and wheat, the occurrence of lower temperatures and adequate availability of solar radiation favor tillering and grain filling, components that directly impact productivity (Castro et al., 2012; Arenhardt et al., 2015).

However, variations in meteorological conditions do not only influence the performance of crops by acting on physiological processes, but by impacting the entire management dynamics of the production system. For nitrogen management, for example, very intense rains soon after fertilization result in large leaching losses in the soil profile. On the other hand, higher temperatures at the time of fertilization cause considerable losses of nitrogen through volatilization, partial closure of stomata and lower transpiration rate of plants, are impacting on the lower absorption of the nutrient, essential for the productive performance of the crop (Ercoli et al., 2013; Scremin et al., 2017).

According to the analysis of variance (ANOVA) there was a significant interaction between year and nitrogen management on the expression of biomass and grain productivity (Table 4), providing the opportunity to unfold the interaction in the analysis in different conditions of agricultural year and use of models that scale adaptability and stability.

In the soybean-oat succession system, the conditions without nitrogen application at sowing with the total supply of the nutrient at 10 DAE, promote superiority in grain yield, in relation to the other combinations, regardless of the characterization of the agricultural year (Table 5). In this system, under conditions of an intermediate and favorable year, the management of fertilization with 0 and 10 kg ha^{-1} at sowing and the complementary supply carried out at 30 DAE, also promotes superiority of grain productivity. In the case of an unfavorable year, the anticipation of nitrogen supply in cover to 10 DAE is a strategy that favors the expression of grain yield with 0 and 10 kg ha^{-1} of the nutrient at sowing. Also, in the soybean/oat succession system, the highest biomass productivity was observed without nitrogen application in the sowing with total coverage dose at 30 DAE, regardless of the characterization of the agricultural year. For intermediate and favorable year conditions, the use of seeding fertilization of 10 and 30 kg ha^{-1} and complementary fertilization provided at 30 DAE, also favor superiority in biomass productivity.

Table 4. Summary of the analysis of variance of the effect of the year of cultivation and the management of nitrogen, considering doses of the nutrient at sowing and coverage with the time of supply in the oat crop.

Source of variation	DF	Medium Square	
		Grain Yield (GY, kg ha^{-1})	Biomass Productivity (BP, kg ha^{-1})
		soy/oat system	
Block	3	125104	440011
Year	2	30406340*	310899754*
N (sowing/covering management)	15	1618596*	10136799*
Year × N	30	193081*	1376379*
Error	141	55136	321232
Total	191		
General Average		2633	8219
CV (%)		18,92	16,90
		Corn/oat system	
Block	3	39257	257132
Year	2	43686193*	372091739*
N (sowing/covering management)	15	3059623*	10991139*
Year × N	30	115187*	953095*
Error	141	62580	316576
Total	191		
General average		2487	7621
CV (%)		10,06	17,38

*= Significant at 5% probability of error; N= nitrogen; DF= degrees of freedom; GY= grain yield; BP= biomass productivity; CV= coefficient of variation.

In the corn/oat succession system, the superiority of grain yields also occurs without the use of nitrogen at sowing and full coverage at 10 and 30 DAE (Table 5). In addition, the sowing fertilization of 10 kg ha^{-1} of nitrogen, associated with the supplementary supply in coverage at 10 and 30 DAE, also favors the achievement of higher average values for grain yield, regardless of the condition of the crop year. On the other hand, for biomass productivity, superiority was observed in the maize/oats succession system, under the conditions of 0 and 10 kg ha^{-1} of nitrogen applied at sowing, associated with the supplementary supply in coverage at 30 DAE.

In general, regardless of the agricultural year and succession systems, the mean values plus one standard deviation for oat grain yield suggest the existence of a nitrogen dose at sowing that varies from 0 to 10 kg ha^{-1}, with supply of complementary fertilization in coverage of 10 to 30 DAE. In contrast, the application of nitrogen at sowing in the range from 0 to 10 kg ha^{-1}, promotes superiority in biomass productivity, provided that the supplementary nitrogen supply is carried out at about 30 DAE.

Table 5. Average yield of biomass and oat grains considering nitrogen doses at sowing and coverage with the time of supply in different years and cropping systems.

Dose N Seeding - Coverage (kg ha^{-1})	Season N Coverage (days)	GY (kg ha^{-1}) 2015 (IY)	GY (kg ha^{-1}) 2016 (FY)	GY (kg ha^{-1}) 2017 (UY)	BP (kg ha^{-1}) 2015 (IY)	BP (kg ha^{-1}) 2016 (FY)	BP (kg ha^{-1}) 2017 (UY)
Soy/oat system							
0 - 70	0	2016 [I]	2649 [I]	1421 [I]	5771 [I]	8051 [I]	4624 [I]
0 - 70	10	3224 [S]	3730 [S]	2496 [S]	8530	10970	6870 [S]
0 - 70	30	3525 [S]	4056 [S]	2006	11228 [S]	11192 [S]	6422 [S]
0 - 70	60	2330	2873 [I]	1862	7682	9073 [I]	5335
10 - 60	0	2059 [I]	2846 [I]	1505 [I]	6717 [I]	8586 [I]	5072 [I]
10 - 60	10	3094	3495	2274 [S]	8670	10350	6537 [S]
10 - 60	30	3440 [S]	3795 [S]	1951	10562 [S]	11446 [S]	6325
10 - 60	60	2314	3073	1887	7888	9416	5889
30 - 40	0	2104 [I]	3036	1722	8612	10004	5119 [I]
30 - 40	10	2825	3375	2201	9291	10667	5929
30 - 40	30	3393 [S]	3611	1942	10602 [S]	11118 [S]	5887
30 - 40	60	2355	3339	1901	8194	10586	5875
60 - 10	0	2369	2840	1778	8269	9817	5492
60 - 10	10	2690	3207	1912	9344	9899	5722
60 - 10	30	3138	3375	1882	9244	10362	5829
60 - 10	60	2410	3236	1831	9335	10276	5880
Average		2705	3283	1911	8746	10113	5800
Average + 1SD		3233	3675	2174	10151	11067	6382
Average – 1SD		2177	2891	1648	7341	9159	5218
Corn/oat system							
0 - 100	0	1794 [I]	2275 [I]	1063 [I]	5894 [I]	6846 [I]	3585 [I]
0 - 100	10	3592 [S]	4220 [S]	2305 [S]	8649	10293	5888 [S]
0 - 100	30	3364 [S]	4073 [S]	2113 [S]	10654 [S]	10581 [S]	5930 [S]
0 - 100	60	2394	2687	1358	8272	8916	4740
10 - 90	0	1984 [I]	2501 [I]	1078 [I]	6460 [I]	7654 [I]	3797 [I]
10 - 90	10	3379 [S]	3879 [S]	2129 [S]	8621	10551	5997 [S]
10 - 90	30	3409 [S]	3780 [S]	2002 [S]	10351 [S]	10829 [S]	5640 [S]
10 - 90	60	2388	2783	1351	8281	9194	4437
30 - 70	0	2288	3077	1130 [I]	7595	9587	4782
30 - 70	10	3038	3235	1973	8742	9945	5505
30 - 70	30	3415 [S]	3366	1665	9961 [S]	10406	5540
30 - 70	60	2442	3009	1384	8635	9982	4851
60 - 40	0	2331	2780	1048 [I]	7385	9366	4723
60 - 40	10	2669	3122	1647	8393	9363	4857
60 - 40	30	3022	2967	1592	8709	9596	4431
60 - 40	60	2331	2854	1226	8618	9122	4176
Average		2734	3163	1566	8451	9508	4905
Average + 1SD		3301	3728	1992	9702	10566	5640
Average – 1SD		2167	2598	1140	7200	8450	4170

N= nitrogen; GY= grain yield; BP= biomass productivity; IY= intermediate year; FY= favorable year; UY= unfavorable year; SD= standard deviation; [S]= greater than the mean plus one standard deviation; [I]= less than the mean plus one standard deviation.

The application of nitrogen to the oat crop under inadequate conditions, such as direct exposure to sunlight, high temperatures and restriction of available water in the soil, facilitates nitrogen losses by volatilization (Hawerroth et al., 2013). The type of vegetation cover also modifies nutrient losses, increasing nitrogen use efficiency (Viola et al., 2013). Thus, the biochemical composition of the residues affects the dose and timing of nitrogen supply in relation to the rate of nutrient release in the soil and decomposing tissues (Siqueira Neto et al., 2010). In this way, the amount applied and the most appropriate moment of supply of the nutrient must be explored, since high doses and early or late applications alter physiological processes linked to grain production and quality (Silva et al., 2016). Therefore, nitrogen use efficiency in oats is directly dependent on air temperature and soil moisture conditions, solar radiation, cropping systems and nutrient management (Mantai et al., 2016).

In the search for more sustainable managements for the use of nitrogen, considering the combination between the dose of the nutrient applied at sowing and coverage with the supply season, tables 6 and 7 show the parameters of the adaptability and stability model by Eberhart and Russell (1966) to obtain an environmental index and the Wricke (1965), model for estimating ecovalence.

In the soybean/oat succession system, there is a great contribution in the absence of nitrogen at sowing with the total supply of the nutrient in coverage at 10 DAE, evidencing higher grain yield with general adaptability and stability, according to the Eberhart and Russell model, as well as the lowest value of the ωi, statistic, indicating high stability by the Wricke model. The management with absence or 10 kg ha^{-1} of nitrogen at sowing associated with the supplementary supply of nitrogen in coverage at 30 DAE, also resulted in higher grain productivity, however, they require more favorable environmental conditions for management, according to the model of Eberhart and Russell (b_1>1) and with grain yield instability observed in both models.

In the corn/oat succession system, the highest average grain yield with stability was also obtained in the absence of nitrogen at sowing and with the supplementary supply in topdressing at 10 DAE (Table 6). This management condition is also suitable for conditions favorable to cultivation, with specific adaptability (b_1>1), according to the Eberhart and Russell model. General adaptability with stability was observed with the use of 10 kg ha^{-1} of nitrogen at sowing and supplementary dose in coverage provided between 10 and 30 DAE. However, these combinations showed productivity averages with the second best performance “b”. In this perspective, although grain productivity is lower, satisfactory production is justified, guaranteeing more stable conditions and adaptability to favorable and unfavorable conditions in the agricultural environment.

In the soybean/oat succession system, the highest biomass productivity was obtained with the absence and supply of 10 and 30 kg ha^{-1} of nitrogen at sowing, combined with the supplementary supply in coverage of the nutrient at 30 DAE. It is noteworthy that these combinations of sowing rate and coverage with the time of application require favorable conditions for oat cultivation (b1>1), not guaranteeing stability in biomass productivity ($S^2_{ij} \neq 0$). The results show that in this system it is possible in this system a greater range of management of the application rate at sowing and coverage with general adaptability and stability when considering the productivity slightly lower "b" to the management of better performance, with application of nitrogen at sowing of 10, 30 and 60 kg ha^{-1}, with application of complementary nitrogen to reach the desired expectation applied at 10, 30 and 60 DAE, although these conditions are not the most suitable for grain production, but leaves and stems, configuring an adequate management focused on the production of biomass for animal feed.

In the corn/oat succession system, the highest biomass yield with general adaptability and stability was obtained in the combination with 30 kg ha^{-1} of nitrogen at sowing and supplementary supply of the nutrient in topdressing at 10 DAE (Table 7). It is noteworthy in this system that the application of 0 and 10 kg ha^{-1} of nitrogen, also promote the attainment of higher values of biomass productivity with general adaptability, provided that the supplementary nitrogen fertilization in coverage is provided at 10 DAE, even that does not represent a combination that promotes stability.

Table 6. Parameters of adaptability and stability of the management of nitrogen rates at sowing and coverage with the time of supply on oat grain yield in cropping systems.

Dose N Seeding - Coverage	**Season N Coverage**	**GY**	**Eberhart & Russel**			**Wricke**	
(kg ha^{-1})	**(days)**	**(kg ha^{-1})**	**b_1**	**S^2_{ij}**	**R^2**	**ω_i**	**ω_i (%)**
Soy/oat system							
0 - 70	0	2029 d	0.89^{ns}	-4878^{ns}	99	85158	1.47
0 - 70	10	3150 a	0.90^{ns}	-13660^{ns}	100	38446	0.66
0 - 70	30	3196 a	1.52*	59265*	97	1311865	22.65
0 - 70	60	2355 c	0.73*	-4627^{ns}	98	318542	5.50
10 - 60	0	2137 d	0.96^{ns}	18912^{ns}	96	136789	2.36
10 - 60	10	2954 b	0.90^{ns}	-5316^{ns}	99	73709	1.27
10 - 60	30	3062 a	1.38*	103801*	94	1005514	17.36
10 - 60	60	2424 c	0.84^{ns}	30739*	94	270180	4.66
30 - 40	0	2287 c	0.93^{ns}	80896*	90	398425	6.88
30 - 40	10	2800 b	0.85^{ns}	-11791^{ns}	100	92382	1.59
30 - 40	30	2982 b	1.25*	141732*	91	865242	14.94
30 - 40	60	2531 c	1.02^{ns}	80934*	91	380197	6.56
60 - 10	0	2329 c	0.77*	-13414^{ns}	100	199780	3.45
60 - 10	10	2603 c	0.95^{ns}	-13245^{ns}	100	13462	0.23
60 - 10	30	2798 b	1.12^{ns}	87363*	92	457159	7.89
60 - 10	60	2492 c	1.01^{ns}	22584^{ns}	96	145600	2.51
Corn/oat system							
0 - 100	0	1710 f	0.73*	-672^{ns}	98	454437	13.15
0 - 100	10	3372 a	1.18*	-7645^{ns}	100	208003	6.02
0 - 100	30	3183 b	1.20*	4996^{ns}	99	289245	8.37
0 - 100	60	2146 e	0.84^{ns}	-13037^{ns}	100	142619	4.13
10 - 90	0	1854 f	0.87^{ns}	-4397^{ns}	99	141684	4.10
10 - 90	10	3095 b	1.07^{ns}	-5165^{ns}	99	70701	2.05
10 - 90	30	3063 b	1.13^{ns}	-8452^{ns}	100	125212	3.62
10 - 90	60	2174 e	0.90^{ns}	-15584^{ns}	100	60269	1.74
30 - 70	0	2165 e	1.17^{ns}	28239*	98	336202	9.73
30 - 70	10	2749 c	0.82*	-3069^{ns}	99	234698	6.79
30 - 70	30	2815 c	1.16^{ns}	143577*	92	770509	22.30
30 - 70	60	2279 e	1.00^{ns}	-5129^{ns}	99	42226	1.22
60 - 40	0	2053 e	1.09^{ns}	-15479^{ns}	100	42464	1.23
60 - 40	10	2479 d	0.91^{ns}	-13718^{ns}	100	48226	1.40
60 - 40	30	2527 d	0.94^{ns}	96820*	91	470745	13.62
60 - 40	60	2137 e	1.00^{ns}	-11076^{ns}	100	18385	0.53

Means followed by the same letters constitute a statistically homogeneous group by the Skott & Knott test with an error probability of 5%; N= nitrogen; GY= grain yield; b_1= adaptability coefficient; S^2_{ij}= regression deviations; R2= coefficient of determination, obtained by the method of Eberhart & Russell (1966); ω_i= s tability coefficient obtained by the method of Wricke (1965); *= significant at 5% error probability by the F test; ^{ns}= not significant by the F test.

In general, the highest nitrogen use efficiency in oats is obtained with lower doses of the nutrient at sowing and with higher doses in the coverage at 10 and 30 days after emergence in cropping systems. However, these results, although consistent, were obtained in climate and soil conditions characteristic of the northwest region of the state of Rio Grande do Sul, and there may be more efficient ways of using nitrogen under other cultivation conditions. Cultivation techniques strongly influence the efficiency of nitrogen use in cereals (Prando et al., 2013; Mantai et al., 2015). Research on wheat indicates that the fractional supply of nitrogen can reduce nutrient losses by doses partitioned at times more conducive to fertilization (Brezolin et al., 2017). Analyzes involving the adaptability and stability models of Eberhart and Russell can help to identify cultivars and more stable and efficient management for productivity (Cavalcante et al., 2014; Arenhardt et al., 2015).

Therefore, it is possible to identify managements that promote predictable behavior and with satisfactory productivity in the face of environmental conditions, generating more efficient and sustainable management in cropping systems (Silva et al., 2016; Reginatto et al., 2018). The results presented show the perspective of a more sustainable management of oat productivity with the minimum dose or absence of nitrogen at sowing, since the use of the complementary dose in coverage is conditioned to the adjusted application time, according to the cultivation system and purpose (biomass or grains). The results observed in the two main oat crop succession systems, regardless of the crop year classification condition, show security for the dissemination of results and in the technical recommendation to farmers.

Table 7. Parameters of adaptability and stability of the management of nitrogen rates at sowing and coverage with the time of supply on the productivity of oat biomass in cropping systems.

Dose N Seeding - Coverage (kg ha^{-1})	**Season N Coverage (days)**	**BP (kg ha^{-1})**	**Eberhart & Russel**			**Wricke**	
			b_1	**S^2_{ij}**	**R²**	**ω_i**	**ω_i (%)**
Soy/oat system							
0 - 70	0	6149 e	0.73*	828864*	85	6471927	15.67
0 - 70	10	8790 b	0.89^{ns}	748959*	90	3798190	9.20
0 - 70	30	9614 a	1.19*	1448404*	90	7516339	18.20
0 - 70	60	7363 c	0.86^{ns}	-53041^{ns}	100	918315	2.22
10 - 60	0	6792 d	0.77*	283328*	94	3440356	8.33
10 - 60	10	8519 b	0.86^{ns}	61611^{ns}	98	1346345	3.26
10 - 60	30	9444 a	1.23*	268285*	98	3403429	8.24
10 - 60	60	7731 c	0.80*	26785^{ns}	98	2052846	4.97
30 - 40	0	7912 c	1.14^{ns}	-64724^{ns}	100	837729	2.03
30 - 40	10	8629 b	1.11^{ns}	-70227^{ns}	100	471543	1.14
30 - 40	30	9203 a	1.27*	752251*	95	6263014	15.17
30 - 40	60	8218 b	1.04^{ns}	434638*	95	2133895	5.17
60 - 10	0	7859 c	0.99^{ns}	-60114^{ns}	100	82577	0.20
60 - 10	10	8321 b	1.01^{ns}	297519*	96	1515343	3.67
60 - 10	30	8478 b	1.07^{ns}	-15250^{ns}	99	441786	1.07
60 - 10	60	8497 b	1.04^{ns}	50525^{ns}	99	597743	1.45
Corn/oat system							
0 - 100	0	5798 d	0.69*	-53936^{ns}	100	4461308	15.60
0 - 100	10	8277 a	0.91^{ns}	163450*	98	1331978	4.66
0 - 100	30	8355 a	1.08^{ns}	821506*	94	3868254	13.53
0 - 100	60	6618 c	0.93^{ns}	-19029^{ns}	99	470140	1.64
10 - 90	0	5970 d	0.82*	-21504^{ns}	99	1807055	6.32
10 - 90	10	8389 a	0.93^{ns}	396077*	95	2154376	7.53
10 - 90	30	8606 a	1.27*	314753*	98	5007564	17.51
10 - 90	60	6970 c	1.05^{ns}	-59760^{ns}	100	176526	0.62
30 - 70	0	6987 c	0.98^{ns}	400027*	96	1934581	6.77
30 - 70	10	8064 a	0.95^{ns}	-58542^{ns}	100	192346	0.67
30 - 70	30	7044 b	1.11^{ns}	195563*	98	1612633	5.64
30 - 70	60	7189 b	1.10^{ns}	-61810^{ns}	100	559265	1.96
60 - 40	0	7158 b	0.94^{ns}	429764*	95	2185106	7.64
60 - 40	10	7538 b	0.98^{ns}	-76628^{ns}	100	22634	0.08
60 - 40	30	7579 b	1.14*	-24626^{ns}	100	1174441	4.11
60 - 40	60	7305 b	1.12^{ns}	163624*	98	1634643	5.72

Means followed by the same letters constitute a statistically homogeneous group by the Skott & Knott test with an error probability of 5%; N = nitrogen; BP= biomass productivity; b_1 = adaptability coefficient; S^2_{ij} = regression deviations; R^2 = coefficient of determination, obtained by the Eberhart & Russell method (1966); ω_i = stability coefficient obtained by the Wricke method (1965); *= significant at 5% error probability by the F test; ^{ns}= not significant by the F test.

Regardless of the crop year condition, in the soybean/oat system, the greatest nitrogen use efficiency with adaptability and stability for biomass and grain productivity occurs in the condition of absence of nitrogen at sowing with the total dose in coverage at 10 and 30 days after emergence. In corn/oat system, the highest efficiency of biomass and grain productivity with adaptability and stability is in the combination of absence of nitrogen at sowing with the total dose in coverage at 10 days after emergence.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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