Technical and agronomic efficiency of nitrogen use on the yield and quality of oat grains[1]

Eficiência técnica e agronômica do nitrogênio na produtividade e qualidade de grãos de aveia

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HIGHLIGHTS:

Sustainable cultivation management of oats should consider the efficiency of nitrogen in association with weather conditions.
Technical efficiency of nitrogen use showed doses that certify greater economic return with reduced environmental impact.
Agronomic efficiency of nitrogen indicated an unstable increase in productivity of oats affected by weather conditions.

ABSTRACT: The efficiency of nitrogen use by oats in association with climatic conditions is fundamental to the development of more sustainable managements with yield and quality. The objectives of this study were to define the agronomic efficiency of nitrogen by the ratio of the dose provided and product obtained, estimate the maximum technical efficiency of the nutrient on grain yield; and for the optimum dose, simulate the expression of the straw and industry yields, protein and total fiber in different conditions of the agricultural year in a soybean/oat system. The study was conducted from 2011 to 2016, in Augusto Pestana, RS, Brazil, in a randomized block design with four repetitions in a 4 x 2 factorial referring to nitrogen doses (0, 30, 60 and 120 kg ha^{-1}) and oat cultivars (Barbarasul and Brisasul) in a soybean/oat system. Nitrogen increased grain, straw, and industry yields and total grain protein, with agronomic efficiency of 7.8, 19.7 and 3.3 kg ha^{-1} and 0.10 g kg^{-1}, respectively, with reduction of the total fiber in 0.05 g kg^{-1} per kg of N supplied. The dose of maximum technical efficiency in the expression of grain yield is dependent on the weather conditions during cultivation. In general, the maximum efficiency of grain productivity was obtained with 86 kg ha^{-1} of N, with linear equations showing increased productivity of straw and industry yield, total protein, and reduction of the fiber content of oat grains by nitrogen use.

Key words: *Avena sativa* L., meteorological elements, sustainable agriculture

RESUMO: A eficiência do nitrogênio na aveia associada às condições climáticas são fundamentais no desenvolvimento de manejos sustentáveis com produtividade e qualidade. Objetivou-se neste estudo definir a eficiência agronômica do nitrogênio pela relação dose fornecida e produto obtido, estimar a máxima eficiência técnica do nutriente na produtividade de grãos, e pela dose ideal, simular a expressão da produtividade de palha e de indústria, proteína e fibra total em diferentes condições do ano agrícola no sistema soja/aveia. O estudo foi conduzido de 2011 a 2016, em Augusto Pestana, RS, em delineamento de blocos casualizados com quatro repetições em esquema fatorial 4 x 2 referente a doses de nitrogênio (0, 30, 60 e 120 kg ha^{-1}) e cultivares de aveia (Barbarasul e Brisasul) no sistema soja/aveia. O nitrogênio incrementa a produtividade de grãos, de palha, de indústria e o teor de proteína dos grãos, com eficiência agronômica de 7,8, 19,7 e 3,3 kg ha^{-1} e 0,10 g kg^{-1}, respectivamente, com redução na fibra total de grãos de 0,05 g kg^{-1} por kg de N fornecido. A dose de máxima eficiência técnica na expressão da produtividade de grãos depende das condições de cultivo. Em geral, a máxima eficiência de produtividade de grãos é obtida com 86 kg ha^{-1} de N, com equações lineares que mostram acréscimos da produtividade da palha e de indústria e a proteína total, e redução do teor de fibras dos grãos de aveia pelo uso do nitrogênio.

Palavras-chave: *Avena sativa* L., elementos meteorológicos, agricutura sustentável

INTRODUCTION

Inadequate management of N is one of the factors mostly impacting grain yield and quality, thereby making the process unsustainable (Romitti et al., 2017). For maximum expression of the yield and quality of oat grains, the adjustment of management technologies is recommended to improve the efficiency of nitrogen absorption and use (Scremin et al., 2017).

Meteorological conditions directly influence nitrogen losses, either by nitrate leaching or ammonia volatilization, thereby affecting nitrogen absorption by roots and reducing nitrogen use efficiency (Mamann et al., 2020). In addition, when applied in small doses, it limits yield, but in high doses, although it maximizes yield, it also promotes the lodging of plants thereby making harvesting difficult. This is accompanied with losses in grain yield and quality, resulting in economic and environmental damage (Marolli et al., 2018).

Advances are required in the development of strategies that promote better use of nitrogen in oats, adding efficiency with less environmental impact (Arenhardt et al., 2017). In this perspective, the agronomic efficiency of the input/product ratio obtained and the technical efficiency for estimating the optimal dose of the nutrient, can assist in decision making by promoting more sustainable processes of nitrogen management in oats.

The objectives of this study were to define the agronomic efficiency of nitrogen by the ratio of dose provided and product obtained, estimate the maximum technical efficiency of the nutrient on grain yield, and for the optimum dose, simulate the expression of the straw and industry yields, protein and total fiber in different conditions of the agricultural year in a soybean/oat system.

MATERIAL AND METHODS

The experiments were conducted in a field, from 2011 to 2016, in the county of Augusto Pestana, RS, Brazil, geographically located at 28° 26' 30" S latitude and 54° 00' 58" W longitude. Soil obtained from the experimental area was classified as Oxisol and the climate of the region, according to the Köppen classification, is of the Cfa type, with hot summer without dry season (Kuinchtner & Buriol, 2001; Santos et al., 2006). The area in which the experiment was installed had a consolidated no till farming system. During summer, the area was occupied by soybean, characterized as the most used crop precedent in Southern Brazil. Ten days before each sowing of oat, a soil analysis was carried out, identifying, on average, the following chemical characteristics of the site (Tedesco et al., 1995): pH = 6.3; P = 34.1 mg dm^{-3}; K = 231 mg dm^{-3}; OM = 3.2%; Al = 0 cmol$_c$ dm^{-3}; Ca = 6.6 cmol$_c$ dm^{-3} and Mg = 2.9 cmol$_c$ dm^{-3}.

Sowing was carried out between the first and the second week of June with mechanized seeder-fertilizer. Each plot comprised five lines of 5 m in length and spacing between lines of 0.20 m, forming an experimental unit of 5 m^2. The population density used was 400 viable seeds per square meter. The seeds of the selected genotypes were submitted to germination and vigor tests in the laboratory, in order to correct the density of plants to constitute the desired population. During sowing,

45 and 30 kg ha^{-1} of P$_2$O$_5$ and K$_2$O were applied, respectively, based on the levels of P and K in the soil with the expectation of grain yield of 3 t ha^{-1}, and with 10 kg ha^{-1} of N at sowing (except in the control treatment), with the remainder of each dose applied as urea (N = 45%) topdressing, to complete the proposed doses of N-fertilizer applied in the phenological stage of the expanded fourth leaf, with the source urea. During the study, tebuconazole fungicide was applied at a rate of 0.75 L ha^{-1} and weeds were controlled with metsulfuron-methyl herbicide at a dose of 2.4 g ha^{-1} and additional hoeing when necessary.

The experimental design was a randomized block with four replicates, following a 4 x 2 factorial scheme refering to doses of N-fertilizer (0, 30, 60 and 120 kg ha^{-1}) and oat cultivars (Barbarasul and Brisasul), respectively. In each year of cultivation in the soybean/oat system, two experiments were conducted, one to quantify the total biomass yield (straw + grains) and the other to estimate grain yield. The biomass yield (BY, kg ha^{-1}) was obtained by cutting the three central lines of each plot close to the soil at the stage of physiological maturity. The biomass samples were sent to a forced air oven at a temperature of 65 °C, until reaching constant weight and converted to kg ha^{-1}. Grain yield (GY, kg ha^{-1}) was obtained by cutting the three central lines of each plot at the stage of harvest maturity with grain moisture around 22%. Thereafter, the plants were tracked with a stationary harvester and grains were sent to the laboratory to correct the moisture to 13%. Thus, the straw yield (SY, kg ha^{-1}) was obtained by subtracting the grain yield from the biomass yield. The number of grains larger than 2 mm (NG > 2 mm, n) was obtained by counting 100 grains from the sample in each plot, which were placed in a 2 mm mesh sieve and those above this dimension were counted. The husking index (HI, g g^{-1}) was determined by the ratio between the cariopsis mass of 50 grains larger than 2 mm and its grain weight. Industrial yield (INY, kg ha^{-1}) was obtained by the product of grain yield with the number of grains larger than 2 mm and the husking index (INY = GY x NG > 2 mm x HI). The determination of total protein (TP, g kg^{-1}) and total fiber (TF, g kg^{-1}) was conducted using near infrared spectrophotometry (NIRs) on a sample of unhulled grains. The device used was of the Perten brand, model Diode Array DA7200. The air temperature (°C) and rainfall (mm) information for analysis of the meteorological conditions of the agricultural years were obtained by the Automatic Station installed 500 m from the experiment. It is worth mentioning that meteorological conditions, together with grain yield, were used to classify the agricultural years as favorable, intermediate and unfavorable for the cultivation of oats. Data were subjected to analysis of variance to detect the main and interaction effects (not shown) and linear regression analysis, in the fitting of equations to estimate the agronomic efficiency of oats by the kilogram of nitrogen supplied per kilogram of product obtained. The grain yield data were also subjected to quadratic regression analysis, in the formulation of equations to estimate the maximum technical efficiency of nitrogen use by oats. Optimal nutrient doses were used to simulate straw and industry yields, protein and total fiber of the grains. Statistical analyses were performed with the aid of the GENES software.

Results and Discussion

Based on the temperature, rainfall and mean yield of oat grains presented in Table 1, the years 2011 and 2013 were favorable (FY) to oat cultivation. The year 2011 was marked by well-distributed rainfall during the growing cycle, with volumes similar to the historical average of the last 25 years (1989-2016). Rainfall precipitations were observed in the moments preceding the application of nitrogen, providing adequate soil moisture for urea solubilization, as shown in Figure 1A. The maximum, minimum and average temperatures were stable throughout the growing cycle. In 2013, rainfall distribution occurred regularly between the months of growing, with volume below the historical average. At the time of fertilization, the soil moisture from rainfall, in previous days, may have favored greater nutrient use by the plant. In addition, temperatures were milder, reducing possible nitrogen losses through volatilization (Figure 1C).

The years 2012 and 2014 showed grain yield much lower than the desired expectation of 3 t ha^{-1}, justifying their classification as unfavorable agricultural years (UY) for oat growing. In 2012 (Figure 1B), there was water restriction at the beginning of development, however rainfall increased some days prior to fertilization and temperatures reached close to zero degrees during nutrient management (Table 1). At the end of the growing season, rainfall was frequent with a high accumulated value, promoting days of lower radiation quality and delaying grain harvesting. In 2014 (Figure 1D), the first days of the growing season were marked by above average rainfall and high air temperatures. These conditions affected the efficiency of photosynthesis and the consequent shoot formation and root growth.

The growing conditions showed the grain yield obtained in the years 2015 and 2016, as intermediates (IY) for oat cultivation. In 2015 (Table 1), the accumulated rainfall was close to the historical average. The rains before fertilization guaranteed soil moisture for nitrogen management, however, a long period of water restriction after fertilization, possibly affected the efficiency of nutrient use in yield components preparation. High temperatures during anthesis may impair the development of the reproductive system (Figure 1E). In the year 2016, milder temperatures and stability were recorded throughout the growing season, but with reduced rainfall in the grain filling period, and significant rainfall in the final phase of the season, when the grain yield was defined. This occurred with the possibility of losses on grain quality (Figure 1F).

Table 1. Air temperature and rainfall in the months and years of oat cultivation with average grain yield

Year	Month	Temperature (°C)			Rainfall (mm)		GYx (kg ha^{-1})	Class
		Min	Max	Av	Av of 25 years *	Occurred		
2011	June	7.9	18.4	13.1	136	191	3686 a	FY
	July	8.3	19.2	13.7	134	201		
	August	9.3	20.4	14.8	122	234		
	September	9.5	23.7	16.6	165	46		
	October	12.2	25.0	18.6	236	211		
	Total	-	-	-	793	983		
2012	June	8.8	22.0	15.4	136	57	2378 c	UY
	July	6.4	19.7	13.0	134	180		
	August	12.9	23.4	18.1	122	61		
	September	12.0	23.0	17.5	165	195		
	October	15.0	25.5	20.2	236	287		
	Total	-	-	-	793	780		
2013	June	8.9	20.0	14.5	136	74	3731 a	FY
	July	7.0	20.6	13.8	134	103		
	August	6.6	19.8	13.2	122	169		
	September	9.6	21.0	15.3	165	123		
	October	13.2	27.1	20.2	236	144		
	Total	-	-	-	793	613		
2014	June	9.2	20.7	16.1	136	412	2181 d	UY
	July	9.7	21.8	15.7	134	144		
	August	8.8	23.7	16.2	122	78		
	September	13.3	23.5	18.4	165	275		
	October	16.0	27.7	21.8	236	231		
	Total	-	-	-	793	1140		
2015	June	9.7	21.1	15.4	136	228	3451 b	IY
	July	10.2	18.7	14.4	134	212		
	August	13.4	24.6	19.0	122	87		
	September	12.4	19.6	16.0	165	127		
	October	16.1	24.8	20.4	236	162		
	Total	-	-	-	793	816		
2016	June	4.7	19.3	12.0	136	12	3335 b	IY
	July	8.2	21.2	14.7	134	81		
	August	9.4	22.5	15.9	122	169		
	September	8.4	23.8	16.1	165	56		
	October	13.2	26.8	20.0	236	326		
	Total	-	-	-	793	644		

Min - Minimum; Max - Maximum; Av - Average; GYx - Average grain yield; * - Average rainfall from May to October 1989 to 2016; Averages followed by the same letter in the column do not differ at the probability of 0.05 error by the Scott & Knott test; IY - Intermediate year; FY - Favorable year; UY - Unfavorable year
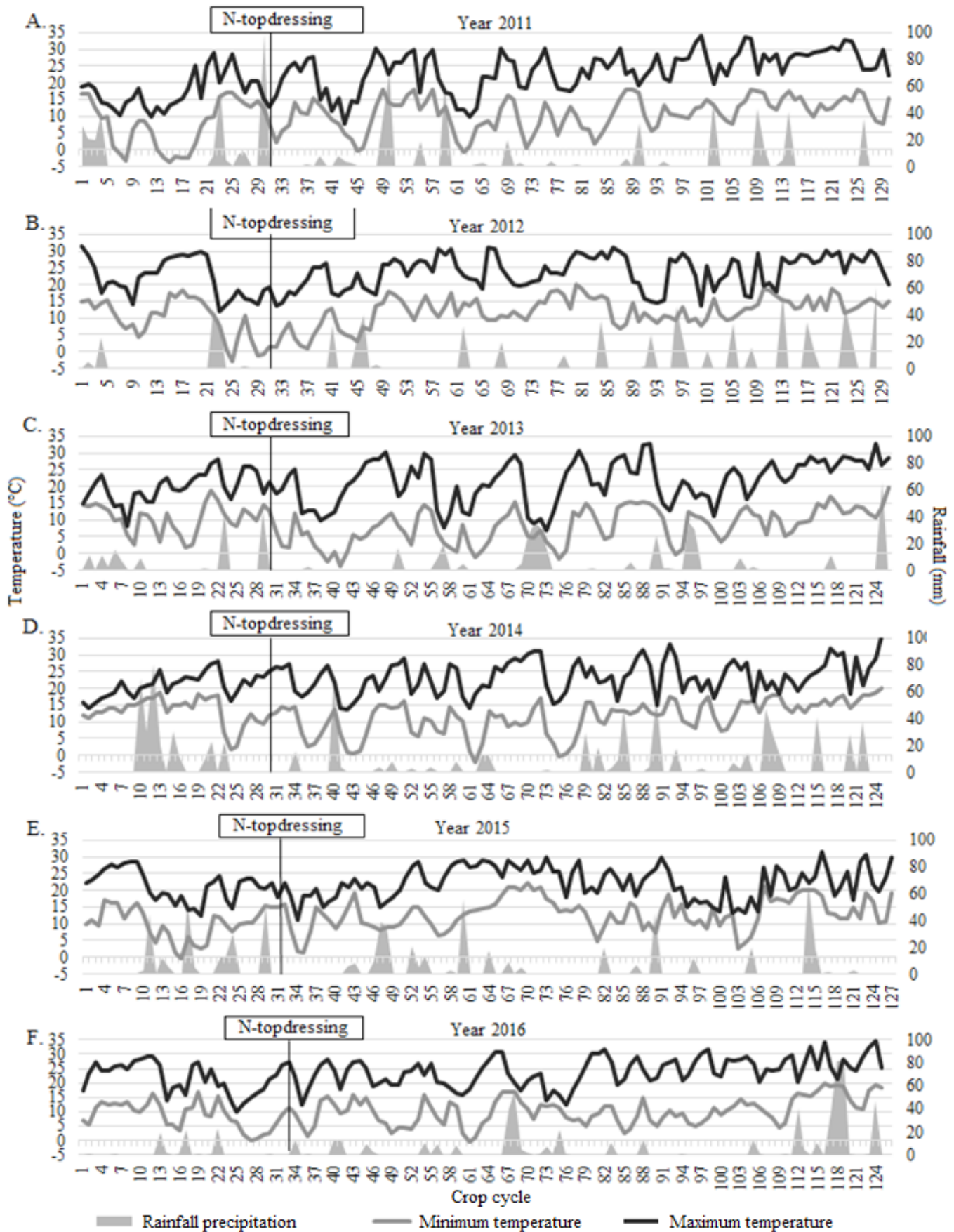
Figure 1. Meteorological data of temperature and rainfall in the crop growing years

White oats are a highly adaptable species; however, the occurrence of leaf diseases and meteorological restrictions are limiting the expression of the maximum crop yield (Silva et al., 2016). Among the meteorological factors, temperature and rainfall maximized the yield and quality of oat grains the most, as the environmental conditions improved (Klink et al., 2014; Trautmann et al., 2020). In oats, a favorable environment is characterized by rainfall with small volumes

adequately distributed during the growing season and with mild temperatures from the vegetative phase until grain filling (Souza et al., 2013; Marolli et al., 2017).

The analysis of variance results showed significant effects in the variables analyzed both for the main effects years and nitrogen doses and for the interaction, configuring the need to analyze the efficiency of nitrogen use in each year of cultivation (data not shown).

Table 2 presents analysis of the agronomic efficiency of the kilogram ratio of nitrogen supplied per kilogram of product obtained. In these conditions, grain yield showed efficiency range between 7.0 and 9.8 kg ha⁻¹ of grains per kg of N among the agricultural year conditions, with average trend of 7.8 kg ha⁻¹. In general, grain yield showed a reduced variation in efficiency due to nitrogen use; however the linear coefficient was significant in indicating the starting point for nitrogen use. This resulted in the classification of 2011 and 2013 as favorable years for oat production.

In the expression of straw yield (Table 2), agronomic efficiency showed greater amplitude, ranging from 8.6 to 28.8 kg ha⁻¹. The most significant values of this efficiency for nitrogen to straw yield were recorded in the intermediate years. Regardless of the agricultural condition, each kilogram

of nitrogen supplied produced a return of 19.7 kg ha⁻¹ of straw yield. In general, in the expression of straw yield, the most expressive intercepts were observed in the intermediate and favorable years to oat cultivation.

In the analysis of industry yield (Table 2), the agronomic efficiency of nitrogen use did not show any relationship with the agricultural year, showing for example, that the favorable year of 2013 and the unfavorable year of 2012, showed similar agronomic efficiency of 5 kg ha⁻¹ of industrial yield per kg of N supplied. Although the year 2016 recorded high agronomic efficiency on grain and straw yield, it showed the lowest efficiency on industry yield. A fact that highlights the importance of the individualized analysis of the variables that make up the estimate of industrial grain yield, such as the husking index and the number of grains greater than 2 mm.

In the expression of total protein (Table 2), the most expressive values of agronomic efficiency were obtained in favorable (2011), unfavorable (2012) and intermediate (2016) years of growing, indicating no relationship with the year of cultivation. In the general equation, regardless of the condition of the agricultural year, the observed agronomic efficiency was 0.10 g of protein per kilogram of grain for each kilogram of nitrogen supplied per hectare, with an initial concentration of

Table 2. Equations of agronomic efficiency and average values of yield and industrial and nutritional quality of oat grains in different years of cultivation

| Y	Year	Mean values/N dose (kg ha⁻¹)				y	Equation	P	R²
		0	30	60	120		y = b₀ + b₁x	(b₁x)	(%)
Grain yield (kg ha⁻¹)	2011 (FY)	2989	3694	4124	3938	3686 a	3308 + 7.2x	*	75
	2012 (UY)	1745	2361	2751	2654	2378 c	2011 + 7.0x	*	82
	2013 (FY)	3036	3721	4174	3994	3731 a	3345 + 7.3 x	*	77
	2014 (UY)	1645	2132	2426	2522	2181 c	1820 + 7.0 x	*	90
	2015 (IY)	2746	3361	3825	3871	3451 b	2983 + 8.9x	*	96
	2016 (IY)	2461	3279	3884	3717	3335 b	2821 + 9.8x	*	82
	x	2437 C	3091 B	3531 A	3449 A	3127	2715 + 7.8x	*	87
Straw yield (kg ha⁻¹)	2011 (FY)	6722	6696	7067	7674	7040 b	6590 + 8.6x	*	93
	2012 (UY)	4626	4669	4329	6340	4991 c	4241 + 14.3x	*	84
	2013 (FY)	6884	7350	7794	8876	7726 b	6854 + 16.6x	*	99
	2014 (UY)	4519	4333	4368	7198	5105 c	3879 + 23.3x	*	93
	2015 (IY)	6767	7484	8072	10004	8082 a	6668 + 26.9x	*	99
	2016 (IY)	6806	7872	8388	10345	8353 a	6841 + 28.8x	*	99
	x	6054 C	6401 B	6670 B	8406 A	6883	5845 + 19.7x	*	99
Industry yield (kg ha⁻¹)	2011 (FY)	1109	1578	1698	1560	1486 b	1324 + 3.1x	*	87
	2012 (UY)	1037	1440	1665	1689	1458 b	1194 + 5.0x	*	73
	2013 (FY)	1504	1810	2169	2108	1898 a	1639 + 4.9x	*	88
	2014 (UY)	891	1100	1294	1393	1170 c	955 + 4.1x	*	89
	2015 (IY)	1098	1453	1701	1442	1424 b	1292 + 2.5x	*	77
	2016 (IY)	315	403	424	355	374 d	364 + 0.2x	ns	70
	x	992 C	1297 B	1492 A	1425 A	1302	1128 + 3.3x	*	79
Total protein (g kg⁻¹)	2011 (FY)	104.9	106.8	111,.8	118.6	110.5 a	104.3 + 0.12x	*	98
	2012 (UY)	103.1	105.9	110.1	119.5	110.0 a	102.4 + 0.14x	*	99
	2013 (FY)	98.1	102.3	102,5	107.0	102.5 b	98.9 + 0.07x	*	94
	2014 (UY)	98.5	101.1	102,9	105.9	102.1 b	98.9 + 0.06x	ns	98
	2015 (IY)	107.8	108.5	109,5	112.0	109.5 a	107.6 + 0.03x	ns	98
	2016 (IY)	94.8	97.1	102,4	115.0	102.3 b	93.2 + 0.17x	*	97
	x	101.2 D	103.6 C	106.5 B	113.0 A	106.1	100.9 + 0.10x	*	99
Total fiber (g kg⁻¹)	2011 (FY)	128.5	123.4	121.9	120.8	123.6 d	126.6 − 0.06x	*	86
	2012 (UY)	136.9	135.8	132.6	131.5	134.2 a	136.6 − 0.05x	*	90
	2013 (FY)	118.9	117.6	116.9	115.3	117.2 e	118.7 − 0.03x	ns	99
	2014 (UY)	133.3	132.3	130.2	128.5	131.1 b	133.1 − 0.04x	*	98
	2015 (IY)	134.0	129.8	128.0	128.0	130.0 b	132.2 − 0.04x	ns	85
	2016 (IY)	127.8	126.4	124.4	123.0	125.4 c	127.4 − 004x	ns	94
	x	129.9 A	127.5 B	125.7 C	124.5 D	126.9	129.2 − 0.05x	*	91

FY - Favorable year; UY - Unfavorable year; IY - Intermediate year; R² - Coefficient of determination; P (bix) - Probability of the slope parameter of the line; * - Significant at p ≤ 0.05, by t test; ns - Not significant at p ≤ 0.05, by t test; Averages followed by the same lowercase letters in the column and uppercase letters in the row, constitute a statistically homogeneous group using the Skott-Knott model at p ≤ 0.05

100.9 g kg⁻¹. However, the increase in nitrogen dose resulted in a decrease in total fiber, indicating an average reduction of around 0.05 g of fiber per 100 kg of grains for each kilogram of the nutrient added per hectare in the oat crop, regardless of the growing year condition. Thus, higher fiber contents were found under more restrictive nitrogen use, especially in years unfavorable to cereal cultivation.

Evaluating the agronomic efficiency of urea, Arenhardt et al. (2017) observed the existence of genetic differences in the expression of grain yield, where the greatest efficiency was obtained with the cultivar URS Taura with 4.68 kg of grains produced per kg of N supplied. Although more efficient, it produced the lowest grain yield, starting from a lower linear coefficient when compared to cultivars with lower angular coefficients. Agronomic efficiency is obtained by the slope of the linear equation, indicating the relationship with which the variable of interest answers per unit of nitrogen (Moll et al., 1982). However, the linear coefficient of the equation must also be considered, as it determines the nutrient performance starting point (Arenhardt et al., 2017).

The differences between results of agronomic efficiency have been attributed to the predecessor crop, cultivar used and meteorological conditions (Prando et al., 2013). Some authors (Martinez et al., 2010; Hawerroth et al., 2013) have reported that the protein and fiber content of oat grains are also influenced by nitrogen availability and cultivation conditions with high temperature and reduced air humidity during maturation of grains (Monteiro, 2009). Contradictory results of this research were obtained by Zakirullah et al. (2017), indicating gradual increments in the percentage of crude fiber in oats with an increase in the nitrogen level.

Figure 2 shows the estimates of the maximum technical efficiency of nitrogen use for grain yield. In this perspective, the favorable year (2011) indicated maximum technical efficiency similar to the unfavorable year (2012), with 82 and 86 kg ha⁻¹ of N, respectively. However, the 2011 simulation shows grain yield of 4200 kg ha⁻¹, compared to 2012 with simulation for 2841 kg ha⁻¹. Although the nitrogen dose is similar, the product efficiency was very expressive, indicating the importance of environmental relationships and the greater
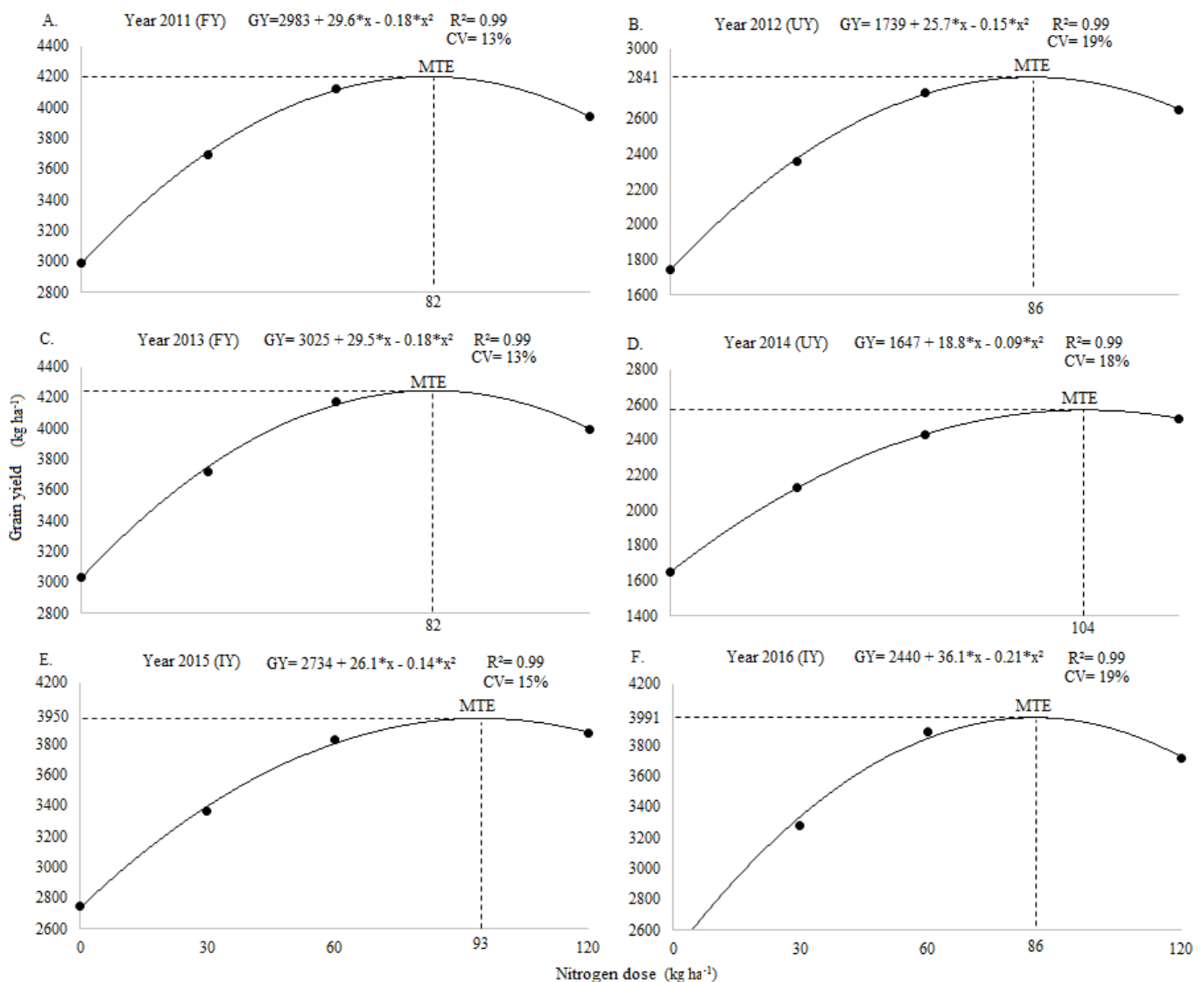
FY - Favorable year; IY - Intermediate year; UY - Unfavorable year; MTE - Maximum technical efficiency; GY - Grain yield; R² - Coefficient of determination; CV - Coefficient of variation; * - Significant at p ≤ 0.05 by F test

Figure 2. Oat grain yield as a function of nitrogen doses and its maximum technical efficiency of nitrogen use

efficiency of nitrogen use for oat plant yield. This fact is even more evident in the favorable cultivation year of 2013, with maximum technical efficiency of nitrogen use of 82 kg ha^{-1} compared to the unfavorable year of 2014, with maximum efficiency of 104 kg ha^{-1}.

In addition to the need for greater nitrogen use in 2014 for maximum yield, the result obtained was much lower compared to 2013, with the lowest dose of the nutrient (Figure 2). It is noteworthy that the intermediate years of 2015 and 2016 showed similarity of the optimal dose of nitrogen use with similar values of maximum yield. The results presented suggest that the use of optimum doses for the expression of yield, takes into account the environmental conditions at the time of application of the nutrient and is based on meteorological forecasts during the cultivation cycle, in search of greater economic return and reduction of environmental impacts due to the ease of losses by volatilization or leaching under restrictive growing conditions.

The maximum technical efficiency of nitrogen use is given by the response of higher yields with less supply of the input (Arenhardt et al., 2017). Using 75 kg ha^{-1} of N, Kolchinski & Schuch (2003) determined the maximum technical efficiency of nitrogen use for the yield of oat grains. Silva et al. (2016) observed that the maximum technical efficiency of nitrogen use is strongly dependent on environmental conditions. These authors reported a technical efficiency of nitrogen use with 86 kg ha^{-1}, generating an expected grain yield of 4181 kg ha^{-1} in a favorable year. However, under restrictive conditions, they found maximum technical efficiency in the use of nitrogen with 119 kg ha^{-1}, with yield of 2930 kg ha^{-1} of grains. The results are similar to those obtained, corroborating that the wide range of grain yield is associated with the high variability of growing conditions, with the year factor being the component of greatest influence on the variations in expectation (Storck et al., 2014).

In Table 3, the nitrogen doses indicated by the maximum technical efficiency for the expression of grain yield by agricultural year condition were used to estimate the expression of the straw and industry yields, protein and total fiber, from the equations that established the behavioral trend. Therefore, the biological interpretation of nitrogen use in these variables is sought considering the optimum dose of grain yield regardless of agricultural year. In this perspective, with 86 kg ha^{-1} of N there is an expectation of 7539 kg ha^{-1} of straw, 1412 kg ha^{-1} of industry yield and 109.5 and 124.9 g kg^{-1} of protein and total fiber, respectively.

Studies have reported positive results from the use of nitrogen for straw yield; however, high doses of fertilization result in the lodging of plants, causing significant yield losses (Zakirullah et al., 2017; Marolli et al., 2018). Hawerroth et al. (2013), Sunilkumar & Tareke (2016) and Lima et al. (2017) confirmed that the application of nitrogen as topdressing increases the protein concentration in oat grains. However, the nutrient absorption capacity varies between cultivars, soil fertility and meteorological and environmental factors such as humidity, temperature, photoperiod and radiation. Moreira et

Table 3. Simulation of straw and industry yields, total protein and total fiber for maximum technical efficiency of grain yield

Y	Year	y= b$_0$ + b$_1$x	P (b$_1$x^i)	R^2 (%)	x$_{ideal}$	y$_E$
SY (kg ha^{-1})	2011 (FY)	6590 + 8.6x	ns	93	82	7295
	2012 (UY)	4241 + 14.3x	*	64	86	5471
	2013 (FY)	6854 + 16.6x	*	99	82	8215
	2014 (UY)	3879 + 23.3x	*	73	104	6302
	2015 (IY)	6668 + 26.9x	*	99	93	9170
	2016 (IY)	6841 + 28.8x	*	99	86	9318
	x	5845 + 19.7x	*	99	86	7539
INY (kg ha^{-1})	2011 (FY)	1324 + 3.1x	ns	37	82	1578
	2012 (UY)	1194 + 5.0x	*	73	86	1624
	2013 (FY)	1639 + 4.9x	*	68	82	2041
	2014 (UY)	955 + 4.1x	*	89	104	1381
	2015 (IY)	1292 + 2.5x	ns	27	93	1524
	2016 (IY)	364 + 0.2x	ns	4	86	381
	x	1128 + 3.3x	*	59	86	1412
TP (g kg^{-1})	2011 (FY)	104.3 + 0.12x	*	98	82	114.1
	2012 (UY)	102.4 + 0.14x	*	99	86	114.4
	2013 (FY)	98.9 + 0.07x	*	94	82	104.6
	2014 (UY)	98.9 + 0.06x	ns	98	104	105.1
	2015 (IY)	107.6 + 0.03x	ns	98	93	110.4
	2016 (IY)	93.2 + 0.17x	*	97	86	107.8
	x	100.9 + 0.10x	*	99	86	109.5
TF (g kg^{-1})	2011 (FY)	126.6 – 0.06x	*	76	82	121.7
	2012 (UY)	136.6 – 0.05x	*	90	86	132.3
	2013 (FY)	118.7 – 0.03x	ns	99	82	116.2
	2014 (UY)	133.1 – 0.04x	*	98	104	128.9
	2015 (IY)	132.2 – 0.04x	ns	65	93	128.5
	2016 (IY)	127.4 – 0.04x	ns	94	86	124.0
	x	129.2 – 0.05x	*	91	86	124.9

SY - Straw yield; INY - Industrial yield; TP -Total protein; TF -Total fiber; R^2 - Coefficient of determination; P (bix) - Probability of the slope parameter of the line; x$_{ideal}$- Nitrogen dose for maximum technical efficiency of grain yield; y$_E$ - Value estimated by the dose given by the maximum technical efficiency; * - Significant at p ≤ 0.05 by the F test; ns - Not significant

al. (2001) highlighted that the fiber content of oats does not change with increased nitrogen supply. Silveira et al. (2016) stated that the fiber concentration of oats is predominantly dependent on the cultivar and on the weather conditions during cultivation.

Conclusions

1. Nitrogen increases grain, straw, and industry yields and total grain protein, with agronomic efficiency of 7.8, 19.7 and 3.3 kg ha^{-1} and 0.10 g kg^{-1}, respectively, with reduction of the total fiber by 0.05 g kg^{-1} per kg of the nutrient supplied.

2. The dose of maximum technical efficiency in expressing grain yield is dependent on the weather conditions during the growing season. In general, the maximum efficiency of grain productivity is obtained with 86 kg ha^{-1} of N, with linear equations that show increase in the productivity of straw and industry yield and the total protein, and reduction of the fiber content of oat grains by use of nitrogen.

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