GMR
The Original by FUNPEC-RP

Nitrogen levels in oat grains and its relation to productivity

R.D. Mantai[1], J.A.G. da Silva[1], O.B. Scremin[1], I.R. Carvalho[1], D.A. Magano[1], J.M. Fachinetto[1], F. Lautenchleger[2], J.A. da Rosa[1], C.L. Peter[1], J.D. Berlezi[1] and C.M. Babeski[1]

[1] Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Ijuí, RS, Brasil
[2] Universidade Estadual do Centro-oeste, Guarapuava, PR, Brasil

Corresponding author: I.R. Carvalho
E-mail: carvalho.irc@gmail.com

Genet. Mol. Res. 19 (4): gmr18569
Received March 24, 2020
Accepted September 11, 2020
Published October 30, 2020
DOI http://dx.doi.org/10.4238/gmr18569

ABSTRACT. Analysis of the relationship of oat grain chemical components with productivity can yield information that determines crop production strategies. The market values high protein grain, but production and other nutritional components may be affected in the effort to increase protein levels. The objective of this study was to determine how the dynamics of the components of oat grain chemical composition relate to productivity when adding nitrogen to the soil, in order to develop nutrient management strategies that can combine productivity with grain quality. The study was conducted from 2011 to 2016 in Augusto Pestana, Brazil, in a randomized block design with four replications in a 4x2 factorial design for nitrogen rates (0, 30, 60 and 120 kg.ha^{-1}) and standard biotype oat cultivars used on a commercial scale (Barbarasul and Brisasul) in two succession systems soybean/oat and corn/oat, totaling 64 experimental units. The nitrogen doses were applied at the phenological stage of expanded fourth leaf using urea. The increase of nitrogen fertilization for topdressing promoted increase of the total protein of oat grains and reduction of the total fiber in both soybean/oat and corn/oat systems. Higher levels of grain protein due to nitrogen fertilization reduced grain production, regardless of the cropping system.

Key words: *Avena sativa*; Correlation and path; Biometrics, Food, Sustainability

INTRODUCTION

White oat (*Avena sativa*) is a cereal of excellent nutritional value, used in the processing of numerous food products (Weber et al., 2002; Silveira et al., 2016). It has high protein grain and adequate levels of carbohydrate and lipid content, with a high proportion of dietary fiber, especially β-glucan, related to cholesterol reduction, which is helpful to prevent diabetes, obesity and cancer (Crestani et al., 2012; Silveira et al., 2016). These qualities have attracted the interest of food industries in this cereal due to its various benefits for human health (Daou and Zhang, 2012; Redaelli et al., 2015).

In the commercialization process, it is necessary that the oat grains are produced by cultivars of high productivity and meeting the demands of the industry, such as a high proportion of grains larger than 2mm and the highest value of caryopsis in relation to the husk, a condition directly linked to management technologies in the promotion of physical and chemical modifications linked to the quality of caryopsis (Marolli et al., 2017; Aseeva and Melnichuk, 2018). Among the management technologies, the highlight is nitrogen fertilization, an essential element in the development and elaboration of oat grains (Mantai, 2019). Nitrogen directly participates in the biosynthesis of numerous organic compounds, altering the expression of indicators of grain yield and industrial and chemical quality (Lima et al., 2017; Obour et al., 2018). According to Ma et al. (2012), the crop can respond positively to nitrogen fertilization, in terms of plant growth; however, it can limit the use of high nitrogen rates for grain yield. The amount of nitrogen required for optimal productivity and responses to nitrogen additions are highly dependent on the cultivar, environmental conditions, soil type and cultivation history (Frosberg and Reeves, 1995).

The application of nitrogen fertilization, although it is often necessary to increase grain yield, can also reduce the physical and chemical quality of the grains (Mohr et al., 2012). According to Humphreys et al. (1994), the nitrogen fertilizer applied in the initialization stage (Zadoks 40-43) tends to increase the protein content, however, the β-glucan content does not respond significantly to the additional nitrogen. Therefore, in the most efficient management of nitrogen there is a need to know the dynamics of use by oats. Contribution and relationship analysis of the chemical quality components of oat grains with productivity by nitrogen stimulation can generate more efficient management information that benefits productivity with the elaboration of grains with high nutritional potential.

The objective of this study was to measure and interpret the contribution and relationship dynamics of the components of oat grain chemical quality with grain and industry productivity by providing additional nitrogen to the soil, as part of nutrient management strategies that promote combining productivity with quality.

MATERIAL AND METHODS

The trials were carried out in the field, from 2011 to 2016, in the municipality of Augusto Pestana, RS, geographically located at 28°26'30" S latitude and 54°00'58" W longitude. The soil of the experimental area was classified as Typical Dystroferric Red Latosol (Oxisol) and the climate of the region, according to Köppen classification, type Cfa, with hot summer without dry season. The area of installation of the experiments is characterized by direct seeding for twenty years, characterizing a consolidated system. In the summer period the area is occupied with soybean and corn, reflecting in the two main cultural precedents of winter crops. In the implementation of the trial, about ten days before each sowing, a soil analysis was performed, identifying on average the following chemical characteristics of the site: pH = 6.3; P = 34.1 $mg.dm^{-3}$; K = 231 $mg.dm^{-3}$; OM = 3.2 %; Al = 0 $cmolc.dm^{-3}$; Ca = 6.6 $cmolc.dm^{-3}$ and Mg = 2.9 $cmolc.dm^{-3}$.

Sowing was carried out between the first and second week of June with a seeder-fertilizer. Each plot consisted of 5 lines with 5 meters in length and 0.20 m line spacing, corresponding to an experimental unit of 5 m^2. The population density was 400 viable seeds per square meter. The seeds of the selected genotypes were submitted to the germination and vigor test in the laboratory to correct the plant density to compose the desired population. In the experiments, 60 and 50 $kg.ha^{-1}$ of P_2O_5 and K_2O were applied at sowing based on soil P and K contents for 3 $t.ha^{-1}$ grain yield expectation, respectively, and N at sowing, with 10 $kg.ha^{-1}$ (except for the standard experimental unit), with the remainder applied for topdressing to cover the proposed N-fertilizer doses at the indicated phenological stage of the expanded fourth leaf, occurred approximately 35 days after the emergency, using urea source. During the study, 0.75 $L.ha^{-1}$ fungicide tebuconazole was applied and weed control with metsulfuron-methyl herbicide at a dose of 2.4 $g.ha^{-1}$ and additional weeding when necessary.

The experimental design was a randomized complete block with four replications, in a 4 x 2 factorial scheme in the sources of variation doses of N-fertilizer (0, 30, 60 and 120 $kg.ha^{-1}$) with urea source and standard biotype oat cultivars used on a commercial scale (Barbarasul and Brisasul), respectively, in soybean / oat and corn / oat succession system, totaling 64 experimental units. The analyzed cultivars represent the standard biotype of commercial interest, with shorter stature and cycle and higher caryopsis ratio in relation to grain husk. Grain yield estimation (GY, $kg.ha^{-1}$) was obtained by manually cutting the three central lines of each plot during the harvest maturity period (grain moisture close to 22%). Afterwards, the plants were tracked in a stationary harvester and the grains were directed to the laboratory for moisture correction to 13%. The estimate of industrial grain yield (IY, $kg.ha^{-1}$) was obtained by the product of grain yield with the number of grains greater than 2 mm and the husking index (IY = GY x NG> 2mm x HI). The number of grains larger than two millimeters (NG> 2mm, n) was obtained by the random count of one hundred grains, which are placed in a 2mm mesh sieve and counted those above this dimension. The husking index (HI, g g^{-1}) was determined by the ratio between the caryopsis mass of 50 grains greater than 2 mm and its grain mass. In the determination of the variables related to the chemical composition of grains, a sample of 300 unshelled grains was taken from each plot, in which total protein (TP, g kg^{-1}), total fiber (TF, $g.kg^{-1}$), starch (ST, $g.kg^{-1}$), neutral detergent fiber (NDF, $g.kg^{-1}$), ashes (ASH, $g.kg^{-1}$) and energy (EN, $MJ.kg^{-1}$) with the spectrometer were analyzed. The near infrared reflectance spectrometer (NIRS) is a Perten Diode Array DA7200 model. It is noteworthy that during the experiments, the information of air temperature (^{o}C) and rainfall (mm) throughout the cycle for analysis and classification of agricultural years were obtained by the Total Automatic Station installed 500 meters from the experiment.

Relative contribution analysis of the effect of nitrogen was measured based on the Mahalanobis distance. Relative contribution was evaluated by the Singh method based on $S_{.j}$ statistics. So:

$$D^2_{ii'} = \delta' \psi^{-1} \delta = \sum_{j=1}^{n} \sum_{j'=1}^{n} \omega_{jj'} d_j d_{j'} \quad \text{(Eq. 1)}$$

in which:

$D^2_{ii'}$: Mahalanobis distance between treatments i and i';

ψ : residual variance and covariance matrix;

$\delta' = [d_1 \ \ d_2 \ \ \ldots \ \ d_n]$, being $d_j = Y_{ij} - Y_{i'j}$;

Y_{ij} : mean of the nth dose in relation to the jth character;

ω : element of the jth row and jth column of the inverse of residual variance and covariance matrix.

The total of the distances involving all treatment pairs is given by,

$$\sum_{i<} \sum_{i'} D^2_{ii'} = \sum_{m} D^2_m = \sum_{j=1} S_{.j} \quad \text{(Eq. 2)}$$

where the percentages of $S_{.j}$ make up the measure of the relative importance of the variable j.

In the correlation analysis, the joint effect of the sources of variation of agricultural and cultivar years was considered, since according to Krüger et al. (2012), the inclusion of sources of variation in the correlation model is an effective way of knowing with greater fidelity the strength of these relationships. Afterwards, path analysis was performed to detect direct and indirect effects of variables on grain yield and industry by decomposition of phenotypic correlation, which includes simultaneously parts attributed to genetic and environmental effects. The main variables considered were grain yield (GY, $kg.ha^{-1}$) and industry productivity (IY, $kg.ha^{-1}$). Since Y (grain yield and industry) is the main variable, X_n is the result of the joint action of other explanatory variables (components of chemical grain quality), obtained by the model:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \quad \text{(Eq. 3)}$$

where $X_1, X_2, \ldots, X_n$ are explanatory variables and Y is the main (or dependent) variable.

Considering,

$$y = \frac{Y - \overline{Y}}{\hat{\sigma}_y} \quad \text{(Eq. 4)}$$

$$x = \frac{X_i - \overline{X}_i}{\hat{\sigma}_{xi}} \quad \text{(Eq. 5)}$$

$$u = \frac{\varepsilon}{\hat{\sigma}_\varepsilon} \quad \text{(Eq. 6)}$$

$$p = \frac{\hat{\sigma}_\varepsilon}{\hat{\sigma}_y} \qquad \text{(Eq. 7)}$$

$$p_{oi} = \frac{b_{oi}\hat{\sigma}_{xi}}{\hat{\sigma}_y} \qquad \text{(Eq. 8)}$$

there is,

$$y = p_1x_1 + p_2x_2 + ... + p_nx_n + p_\varepsilon u \qquad \text{(Eq. 9)}$$

Through this model, the direct and indirect effects of the explanatory variables on the main variable were obtained. The trail coefficients were estimated from the system of equations $X'X\hat{\beta} = X'Y$,

$$X'Y = \begin{bmatrix} r_{1y} \\ r_{2y} \\ \vdots \\ r_{ny} \end{bmatrix} \qquad \text{(Eq. 10)}$$

$$X'X = \begin{bmatrix} 1 & r_{12} & \cdots & r_{1n} \\ r_{12} & 1 & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{1n} & r_{2n} & \cdots & 1 \end{bmatrix} \qquad \text{(Eq. 11)}$$

$$\hat{\beta} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} \qquad \text{(Eq. 12)}$$

Therefore,

$$r_{ij} = p_i + \sum_{j \neq 1}^{n} p_j r_{ij} \qquad \text{(Eq. 13)}$$

with:

r_{ij} : correlation between the main variable (y) and the ith explanatory variable;

p_i : measure of the direct effect of variable i on the main variable;

$p_j r_{ij}$: measure of indirect effect of variable i via variable j on the main variable.

The coefficient of determination of the path diagram is given by:

$$R^2 = p_2r_{1y} + p_2r_{2y} + ... + p_nr_{ny} \qquad \text{(Eq. 14)}$$

and the residual effect is estimated by:

$$\hat{p}_{\varepsilon} = \sqrt{1 - R^2} \qquad \text{(Eq. 15)}$$

Relative contribution and correlation and path analyses were performed using the computer program GENES (Quantitative Genetics and Experimental Statistics, version 2015.5.0).

RESULTS

Table 1 presents information on rainfall, air temperature, and oat grain yield in the soybean / oat and corn / oat cropping systems from 2011 to 2016. 2011 showed well-distributed rainfall during the growing season, especially in the moments prior to nitrogen application, providing adequate soil moisture for urea solubilization (Figure 1A). Maximum, minimum and average air temperatures remained stable throughout the cycle. In 2013, there was a uniform distribution of rainfall between the months of cultivation, with accumulated values below the historical average. The timing of N-fertilizer fertilization was also marked by adequate soil moisture due to rainfall in previous days, favoring the nutrient utilization by the plant. This year, air temperatures were milder, reducing possible nitrogen losses from volatilization (Figure 1C). Yields above 3 $t.ha^{-1}$ of grains were observed in both fast N-residual (soybean / oat) and slow N-residual (corn / oat) systems. These conditions categorize the years 2011 and 2013 as favorable (FY) to oat grain yield.

In 2012 (Table 1), reduced rainfall was observed at the time of nitrogen application, together with high temperatures, a fact that possibly caused the volatilization of the nutrient. At the end of the cycle, the occurrence of high volume rainfall made it difficult to harvest. In 2014, the first days of the cycle were marked by a significant volume of rainfall above the historical average, along with high temperatures, a condition that can affect photosynthesis efficiency and consequent shoot formation and root growth. At the time of fertilization, although the soil presented satisfactory humidity, the air temperature was high, a condition that may have contributed to nitrogen volatilization, reducing nutrient absorption. These conditions justify the classification of the years 2012 and 2014 as unfavorable (UY) to oat grain yield.

In 2015 (Table 1), accumulated rainfall showed a volume close to the observed average of 25 years. The air temperature and soil moisture conditions were adequate for nitrogen absorption, but a drought period was observed after fertilization, which may have affected crop development (Figure 1E). High temperatures occurred during anthesis, at which time the development of the reproductive system is particularly sensitive to thermal and water stress. In 2016, reduced rainfall was observed during the grain filling period, with heavy rainfall occurring in the final phase of the cycle, which may have negative effects on grain quality. Under these agricultural conditions, the low C / N (soybean / oat) ratio system, possibly due to the higher N-residual intake, favored grain yield higher than 3 $t.ha^{-1}$, a fact not found in the high C / N ratio system. N (corn / oat). These facts classify the years 2015 and 2016 as intermediates (IY) to oat grain yield.

Table 1. Average values of temperature and rainfall in months of cultivation and average grain yield of oats in succession systems.

Year	Month	Temperature (°C)			Rainfall (mm)		GY_{XS} ($kg.ha^{-1}$)	GY_{XC} ($kg.ha^{-1}$)	Class
		Min	Max	Av	25 years average*	Occurred			
2011	June	7.9	18.4	13.1	136	191	3686 a	3122 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	1984 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	3269 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	1765 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	2732 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	2782 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; GYXS = average grain yield of soybean / oat system; GYXC = average grain yield of the corn / oat system; * = Average rainfall obtained from May to October 1989 to 2016; Means followed by the same letter in the column do not differ from each other in the probability of 5% error by Scott & Knott's test; IY = intermediate year; FY = favorable year; UY = unfavorable year.

Cereals such as oat and wheat have high sensitivity to weather conditions, so that when satisfactory and properly managed, crop yields are high, otherwise crop frustrations may occur, commensurate with the duration and intensity of adverse conditions (Castro et al., 2012; Arenhardt et al., 2015). Research indicates that an environment favorable to winter grain cultivation requires well-distributed rainfall throughout the cycle and in small volumes, and with lower air temperatures from germination to grain filling (Leonard and Martinelli, 2005; Marolli et al., 2017). Meteorological factors have a significant effect on the expression of oat yield potential, being air temperature and rainfall the most affecting grain yield and quality (Silva et al., 2016; Silva et al., 2020). Peltonen-Sainioet et al. (2017) showed that high rainfall at the end of the crop cycle has a negative impact on oat productivity. In addition, it can affect quality by reducing hectolitic mass and giving dark color to grains, an undesirable condition for the food industry (Marolli et al., 2018; Silva et al., 2020). In addition, excessive rainfall coupled with high humidity and air temperature hinder plant development, as well as favoring the emergence of diseases, causing reduced yield and poor grain quality (Penning de Vries et al., 1989; Castro et al., 2012). Therefore, more nitrogen-adjusted technological propositions along with crop weather information is decisive in the pursuit of sustainable agriculture (Prando et al., 2013; Aseeva and Melnichuk, 2018).

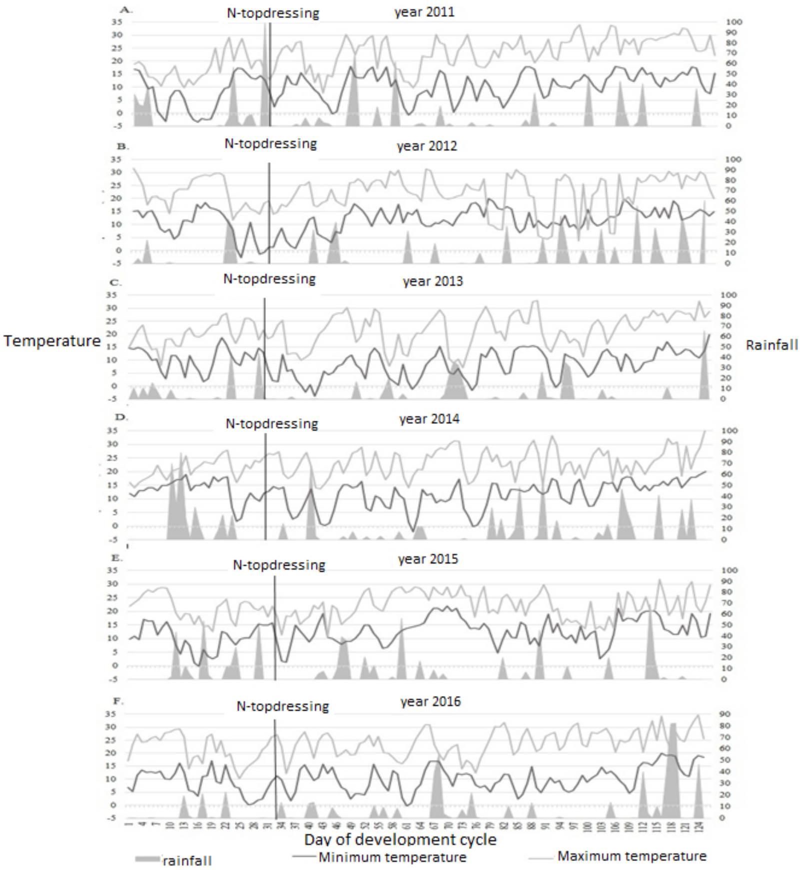

Figure 1. Meteorological data of temperature and rainfall in the years of cultivation.

In Table 2, of the mean values and relative contribution by the effect of nitrogen on soy / oat system, the indicators of chemical grain quality showed effective change in the vast majority of variables, except for total protein and energy. It is noteworthy that the total fiber shows reduced expression with increasing nitrogen dose, unlike protein and starch that show elevation. In the corn / oat system, the effect of nitrogen also changed most of the analyzed variables, mainly neutral detergent fiber, protein, starch and total fiber, with lower participation of ashes and energy. There is a tendency of increase of total protein and starch and reduction of total fiber by nitrogen increase, a condition also verified in the soybean / oat system.

Table 2. Mean values and relative contribution of nitrogen to oat grain industrial quality indicators in cropping systems.

Variables	**N dose (kg.ha^{-1})**				**Relative contribution**	
	0	**30**	**60**	**120**	**S.j**	**S.j (%)**
	(2011+2012+2013+2014+2015+2016)					
	soybean / oat system					
GY	2437	3091	3531	3449	-	-
IY	989	1297	1492	1424	-	-
TP	101	104	107	113	0.14	4.25
TF	130	127	126	124	8.55	19.50
ST	431	433	435	437	21.29	42.60
NDF	331	311	314	315	3.52	10.38
ASH	41	37	33	37	7.90	18.31
em	12.1	12.2	11.8	12.0	3.76	4.96
	corn / oat system					
GY	1628	2462	3017	3328	-	-
IY	644	953	1255	1344	-	-
TP	91	94	97	106	10.25	21.43
TF	132	130	128	126	5.28	11.04
ST	427	430	431	436	5.82	12.16
NDF	337	319	369	317	20.12	42.06
ASH	40	38	35	38	4.29	8.96
EN	12.0	12.1	11.8	12.0	2.08	4.35

GY = grain yield (kg.ha^{-1}); IY = industrial yield (kg.ha^{-1}); TP = total protein (g.kg^{-1}); TF = total fiber (g.kg^{-1}); ST = starch (g.kg $^{-1}$); NDF = neutral detergent fiber (g.kg^{-1}); ASH = ashes (g.kg^{-1}); EN = energy (MJ.kg^{-1}).

Oat stands out for its high carbohydrate content, with starch being the main constituent, ranging from 40-60%. Important polysaccharides of non-starch origin include β-glucans, which are divided into soluble and insoluble polysaccharides, respectively. Among the basic cereals, oat has the highest protein content, ranging from 15-20% and their content increases from the interior of the grain to the periphery (Englyst et al., 1989; Tang et al., 2018). The expression of chemical constituents in oat grains depends directly on genetic, meteorological and management effects (Gutkoski and Pedó, 2000). According to the literature, nitrogen application significantly increases protein content in oat grains with decreased total fiber (Kumar et al., 2001; Rawat and Agrawal, 2010). Sharma et al. (2018) state that increasing nitrogen levels reduce fiber content due to the greater role of nitrogen in the elaboration of protein synthesis.

Table 3 shows the soybean / oat correlation and path of grain and industry yield on indicators of chemical quality in nitrogen use, grain yield with total protein shows a negative correlation in all conditions of nutrient use, mainly by direct grain yield and indirect by starch content. The negative correlation between grain yield and ashes was observed at 30 kg.ha^{-1} and 60 kg.ha^{-1} nitrogen doses, due to the negative indirect effect via total protein. In the analysis of the industry productivity with the indicators of the chemical quality, it was observed negative correlation of the industry yield with the total protein, mainly by the direct effect via the industry yield. It is noteworthy that at 60 kg.ha^{-1} nitrogen, there is a large negative indirect contribution by total fiber, starch, neutral detergent fiber and energy. Industry yield is positively correlated with total fiber under the conditions of 30 kg.ha^{-1} and 60 kg.ha^{-1} nitrogen, with direct contribution via industry yield, and indirect via starch and energy. Industry yield is negatively correlated with starch, especially at intermediate doses of nitrogen supply, highlighting the large direct effect via industry yield, and indirect effect via energy.

The industrial yield was also positively correlated with neutral detergent fiber under the conditions of 30 kg.ha^{-1} and 60 kg.ha^{-1} nitrogen, mainly due to the positive indirect effect via total fiber, starch and energy (Table 3). It is noteworthy that the extreme conditions of nitrogen use (0 kg.ha^{-1} and 120 kg.ha^{-1}) show negative relationship, mainly via energy in the absence and direct negative by industrial yield in the high dose. The correlation between industry yield and energy is negative under nitrogen use conditions, mainly via direct through industry yield, and indirect via total fiber and starch under conditions of 30 kg.ha^{-1} and 60 kg.ha^{-1} of nitrogen and, indirect via total protein at the highest dose of nitrogen. Under these conditions, it is noteworthy that high doses of nitrogen increase the protein content of oat grain, but reflect on the reduction of grain and industry yield. Distinctly, high nitrogen doses reduce the oat grain fiber content, but increase the industry yield.

Table 3. Correlation and path of grain nutritional quality indicators on oat grain and industry yield in nitrogen use in the soybean / oat system.

VAR	EF	Doses of N (kg.ha^{-1})				EF	Doses of N (kg.ha^{-1})			
		0	30	60	120		0	30	60	120
	(2011+2012+2013+2014+2015+2016)									
TP	r (GYxTP)	-0.92*	-0.69*	-0.47*	-0.63*	r (IYxTP)	-0.60*	-0.61*	-0.66*	-0.30
	D: GY	-0.90	-0.72	-0.99	0.06	D: IY	-0.47	-0.35	-0.46	-0.95
	ID: TF	0.02	0.24	0.11	-0.02	ID: TF	-0.02	0.07	-0.41	-0.01
	ID: ST	0.07	-0.29	-0.20	-0.30	ID: ST	-0.20	0.48	-0.37	0.17
	ID: NDF	0.13	-0.03	0.17	-0.12	ID: NDF	-0.01	-0.26	-0.25	0.56
	ID: ASH	-0.05	0.03	0.56	-0.14	ID: ASH	-0.25	-0.66	0.38	0.00
	ID: EM	-0.15	0.13	-0.12	-0.11	ID: EN	0.37	0.11	-0.50	-0.03
TF	r (GYxTF)	0.54*	0.14	0.30	0.36	r (IYxTF)	-0.21	0.37*	0.67*	0.16
	D: GY	-0.04	0.65	-0.19	0.48	D: IY	0.04	0.45	0.47	0.19
	ID: TP	0.46	-0.26	0.92	0.00	ID: TP	0.24	-0.08	-0.39	0.03
	ID: ST	0.05	-0.50	0.05	-0.19	ID: ST	-0.14	0.83	0.22	0.11
	ID: NDF	-0.42	-0.07	-0.12	0.05	ID: NDF	0.03	-0.34	0.17	-0.23
	ID: ASH	0.11	0.05	-0.36	-0.15	ID: ASH	0.56	-0.93	-0.18	0.00
	ID: EN	0.38	0.25	0.01	0.15	ID: EN	-0.95	0.42	0.37	0.04
ST	r (GYxST)	-0.10	-0.13	0.26	-0.49*	r (IYxST)	-0.65*	-0.65*	-0.61*	0.22
	D: GY	0.17	-0.54	-0.10	-0.40	D: IY	-0.54	-0.92	-0.45	0.23
	ID: TP	-0.34	-0.39	-0.89	0.04	ID: TP	-0.18	-0.12	-0.39	-0.71
	ID: TF	-0.01	0.60	0.09	0.23	ID: TF	0.01	0.28	-0.23	0.09
	ID: NDF	-0.14	-0.06	0.19	-0.13	ID: NDF	0.01	-0.33	-0.28	0.60
	ID: ASH	0.08	0.04	0.99	-0.22	ID: ASH	0.40	0.84	0.51	0.01
	ID: EN	0.13	0.24	-0.02	0.00	ID: EN	-0.33	-0.40	-0.52	0.00
NDF	r (GYxNDF)	0.32*	0.02	-0.23	0.72*	r (IYxNDF)	-0.37*	0.30*	0.65*	-0.50*
	D: GY	-0.43	-0.07	-0.20	0.20	D: IY	0.04	-0.34	0.28	-0.94
	ID: TP	0.28	-0.34	0.95	-0.03	ID: TP	0.14	-0.11	-0.41	0.57
	ID: TF	-0.04	0.64	-0.11	0.12	ID: TF	0.04	0.45	0.28	0.05
	ID: ST	0.06	-0.51	0.10	0.26	ID: ST	-0.17	0.85	0.45	-0.14
	ID: ASH	0.11	0.05	-0.97	0.11	ID: ASH	0.53	-0.96	-0.49	0.00
	ID: EN	0.38	0.26	0.02	0.06	ID: EN	-0.95	0.42	0.53	0.02
ASH	r (GYxASH)	0.53*	-0.48*	-0.53*	-0.30	r (IYxASH)	-0.25	-0.23	-0.29	0.22
	D: GY	0.13	0.05	0.15	-0.22	D: IY	0.64	-0.99	0.55	0.01
	ID: TP	0.35	-0.52	-0.74	0.03	ID: TP	0.18	-0.15	0.32	-0.59
	ID: TF	-0.04	0.52	0.05	0.33	ID: TF	0.04	0.34	-0.13	0.13
	ID: ST	0.11	-0.61	-0.14	-0.39	ID: ST	-0.33	0.67	-0.38	0.22
	ID: NDF	-0.35	-0.07	0.17	-0.09	ID: NDF	0.03	-0.32	-0.22	0.45
	ID: EN	0.33	0.15	-0.02	0.05	ID: EN	-0.83	0.22	-0.45	0.01
EN	r (GYxEN)	-0.45*	-0.02	0.18	-0.54*	r (IYxEN)	0.35*	-0.33*	-0.67*	-0.40*
	D: GY	-0.38	-0.26	-0.03	-0.22	D: IY	0.97	-0.42	-0.54	-0.06
	ID: TP	-0.34	0.35	-0.99	0.03	ID: TP	-0.18	0.11	0.43	-0.47
	ID: TF	0.04	-0.64	0.13	-0.33	ID: TF	-0.04	-0.45	-0.32	-0.13
	ID: ST	-0.06	0.51	-0.10	0.00	ID: ST	0.18	-0.85	-0.43	0.00
	ID: NDF	0.42	0.07	0.19	-0.05	ID: NDF	-0.03	0.34	-0.28	0.26
	ID: CZ	-0.11	-0.05	0.98	0.05	ID: CZ	-0.55	0.96	0.50	0.00
	Value of k	4.9e-2	4.5e-2	5.4e-2	4.9e-2	Value of k	4.3e-2	5.1e-2	4.9e-2	4.9e-2
	R^2	0.89	0.66	0.72	0.67	R^2	0.82	0.45	0.62	0.85

In Table 4, of the correlation and path in corn / oat system of grain and industry yield on indicators of chemical grain quality in nitrogen use, the correlation of grain yield with total protein was negative in all conditions, mainly via direct grain yield. The positive correlation of grain yield with total fiber was also observed, however, its direct and indirect effects do not maintain a pattern by fertilization conditions, showing the complexity of action of the variables by nutrient use. In the correlation analysis of industry yield with chemical quality components, the negative correction between industry yield and total protein is verified, mainly by the negative direct effect of industry yield. The correlation between industrial yield and total fiber content was positive from 60 kg.ha^{-1} nitrogen. The industrial yield showed a positive relationship with the ashes, only at the dose 0 kg.ha^{-1} and 30 kg.ha^{-1}, however, from a higher nutrient availability (60 kg.ha^{-1}) the correlation was negative. The correlation between industrial yield and energy was significant at intermediate nutrient doses. In corn / oat system (Table 4), significant correlations of industrial yield with chemical quality components showed an instability of direct and indirect effects given by nitrogen fertilization conditions, evidencing the complexity of nutrient action on these system variables. Under these conditions, high nitrogen doses increased the protein content of oat grains, reducing grain and industry yield. On the other hand, high nitrogen doses reduce grain fiber content, increasing grain and industry yield.

Table 4. Correlation and path of grain nutritional quality indicators on grain and industry yield in nitrogen use in the corn / oat system.

VAR	**EF**	**Doses of N (kg.ha^{-1})**				**EF**	**Doses of N (kg.ha^{-1})**			
		0	**30**	**60**	**120**		**0**	**30**	**60**	**120**
	(2011+2012+2013+2014+2015+2016)									
TP	r (GYxTP)	-0.87*	-0.58*	-0.44*	-0.62*	r (IYxTP)	-0.47*	-0.42*	-0.89*	-0.41*
	D: GY	-0.71	-0.69	-0.98	-0.37	D: IY	-0.88	-0.13	-0.62	-0.99
	ID: TF	-0.20	0.03	-0.16	0.00	ID: TF	0.04	-0.17	0.08	0.00
	ID: ST	-0.08	0.37	0.41	0.04	ID: ST	-0.27	-0.16	-0.09	0.04
	ID: NDF	0.44	-0.09	-0.12	0.07	ID: NDF	0.31	0.11	0.23	0.29
	ID: ASH	0.04	-0.13	-0.10	0.29	ID: ASH	-0.02	-0.16	-0.16	0.01
	ID: EM	-0.36	-0.07	0.51	-0.65	ID: EN	0.39	0.01	-0.13	0.24
TF	r (GYxTF)	0.67*	0.45*	0.40*	0.47*	r (IYxTF)	-0.05	0.26	0.71*	0.40*
	D: GY	0.27	0.21	0.07	-0.27	D: IY	-0.05	-0.98	0.09	0.18
	ID: TP	0.54	-0.09	0.83	-0.01	ID: TP	0.65	-0.04	0.52	-0.02
	ID: ST	0.08	0.35	-0.23	0.05	ID: ST	0.28	-0.12	0.05	0.05
	ID: NDF	-0.64	-0.12	0.03	0.05	ID: NDF	-0.46	0.28	-0.07	0.24
	ID: ASH	-0.03	0.58	0.02	0.47	ID: ASH	0.01	0.51	0.03	0.03
	ID: EN	0.45	-0.48	-0.32	0.18	ID: EN	-0.49	0.60	0.08	-0.09
ST	r (GYxST)	-0.48*	-0.03	0.26	-0.18	r (IYxST)	-0.56*	-0.19	-0.68*	0.26
	D: GY	-0.16	0.47	0.60	0.08	D: IY	-0.56	-0.20	-0.13	0.08
	ID: TP	-0.34	-0.55	-0.72	-0.25	ID: TP	-0.41	-0.11	-0.45	-0.73
	ID: TF	-0.13	0.11	-0.03	-0.17	ID: TF	0.02	-0.66	-0.03	0.11
	ID: NDF	0.33	-0.11	-0.18	0.11	ID: NDF	0.23	0.25	0.40	0.50
	ID: ASH	0.02	0.21	-0.14	0.56	ID: ASH	-0.01	0.25	-0.28	0.03
	ID: EN	-0.18	-0.20	0.66	-0.51	ID: EN	0.20	0.28	-0.17	0.25
NDF	r (GYxNDF)	0.52*	0.14	-0.07	0.22	r (IYxNDF)	-0.18	0.24	0.10	-0.48*
	D: GY	-0.67	-0.14	0.25	-0.13	D: IY	-0.47	0.33	-0.55	-0.59
	ID: TP	0.46	-0.23	0.40	0.21	ID: TP	0.56	-0.04	0.25	0.60
	ID: TF	0.26	0.16	0.01	0.11	ID: TF	-0.05	-1.01	0.01	-0.07
	ID: ST	0.08	0.36	-0.43	-0.07	ID: ST	0.27	-0.16	0.09	-0.07
	ID: ASH	-0.02	0.43	0.11	-0.47	ID: ASH	0.01	0.51	0.21	0.03
	ID: EN	0.45	-0.42	-0.43	0.57	ID: EN	-0.48	0.60	0.11	-0.28
ASH	r (GYxASH)	0.55*	0.71*	0.28	0.13	r (IYxASH)	0.46*	0.42*	-0.53*	0.34
	D: GY	-0.11	0.56	-0.16	0.59	D: IY	0.03	0.67	-0.30	0.04
	ID: TP	0.53	0.17	-0.52	-0.18	ID: TP	0.65	0.03	-0.33	0.53
	ID: TF	0.07	0.13	-0.01	-0.22	ID: TF	-0.01	-0.85	-0.01	0.14
	ID: ST	0.03	0.18	0.55	0.08	ID: ST	0.10	-0.07	-0.12	0.08
	ID: NDF	-0.15	-0.11	-0.18	0.10	ID: NDF	-0.10	0.25	0.39	0.47
	ID: EN	0.18	-0.26	0.60	-0.27	ID: EN	-0.20	0.37	-0.15	0.13
EN	r (GYxEN)	-0.67*	0.15	0.23	-0.83*	r (IYxEN)	0.13	-0.40*	-0.75*	0.07
	D: GY	-0.46	0.52	0.67	-0.88	D: IY	0.52	-0.73	-0.17	0.44
	ID: TP	-0.55	0.09	-0.77	-0.27	ID: TP	-0.68	0.02	-0.49	-0.79
	ID: TF	-0.26	-0.14	-0.03	0.06	ID: TF	0.05	0.88	-0.04	-0.04
	ID: ST	-0.06	-0.18	0.60	0.05	ID: ST	-0.22	0.08	-0.13	0.05
	ID: NDF	0.65	0.11	-0.16	0.08	ID: NDF	0.45	-0.27	0.35	0.38
	ID: CZ	0.04	-0.28	-0.14	0.18	ID: CZ	-0.01	-0.33	-0.27	0.01
	Value of k	4.9e-2	5.2e-2	6.4e-2	5.6e-2	Value of k	4.6e-2	4.3e-2	5.4 e-2	6.2e-2
	R²	0.78	0.88	0.68	0.86	R²	0.90	0.49	0.94	0.87

VAR = variable; EF = effect; GY = grain yield (kg.ha^{-1}); IY = industrial yield (kg.ha^{-1}); TP = total protein (g.kg^{-1}); TF = total fiber (g.kg^{-1}); ST = starch (g.kg $^{-1}$); NDF = neutral detergent fiber (g.kg^{-1}); ASH = ashes (g.kg^{-1}); EN = energy (MJ.kg^{-1}); r = correlation value; D = direct contribution; ID = indirect contribution; R² = coefficient of determination; k = linearization coefficient; * = Significant at 5% probability of error, respectively, by F test.

Increased nitrogen fertilization has a positive response to protein concentration in oat grains (Sterna et al., 2016; Yan et al., 2017), however, research shows a negative correlation between grain yield and total protein (Martinez et al., 2010; Hawerroth et al., 2015). According to Kelling and Fixen (1992), when the need for nitrogen for plant growth and grain production is satisfied, nutrient addition is then used to increase protein concentration in the grain, which explains the high protein content in the soybean / oat system compared to the corn / oat system. Research by Sterna et al. (2016) showed that the use of nitrogen has no significant influence on fiber content, but it increases the amount of starch. However, Sharma et al. (2018) by evaluating the effect of nitrogen on yield and quality of oat cultivars, determined a decreasing effect of crude fiber content by increasing nitrogen, a fact also observed in our study.

CONCLUSIONS

The increase of nitrogen fertilization for topdressing promoted increase of the total protein of oat grains and reduction of the total fiber in the soybean / oat and corn / oat system. Higher levels of grain protein by nitrogen fertilization implies reduction of grain and industry yield, regardless of the cropping system.

ACKNOWLEGDMENTS

We thank CAPES, CNPq, FAPERGS the UNIJUI for the financial support and the Scientific and Technological Initiation Scholarship, Postgraduate Scholarship and Research Productivity Grant. We also thank the Graduate Program in Mathematical Modeling at UNIJUÍ for the resources available in the development of this research, which was part of the doctoral thesis of the first author.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Arenhardt EG, Silva JAG and Gewehr E (2015). The Nitrogen Supply in Wheat Cultivation Dependent on Weather Conditions and Succession System in Southern Brazil. *Afr. J. Agric. Res.* 10: 4322-4330. doi:10.5897/AJAR2015.10038.

Aseeva TA and Melnichuk B (2018). Dependence of Various Oat Ecotypes' Yield Capacity on Climatic Factors in the Middle Amur Region. *Russ. Agric. Sci*. 44: 5-8. doi:10.3103/S1068367418010056.

Castro GSA, da Costa CHM and Neto JF (2012). Ecofisiologia da Aveia Branca. *Sci. Agrar. Paran*. 11: 1-15.

Crestani M, Silveira SFS, Tessmann EW, Mezzalira I, et al. (2012). Combining Ability for Grain Chemistry Quality Traits in a White Oat Diallelic Cross. *Euphytica*. 185: 139-156. doi:10.1007/s10681-012-0641-0.

Daou C and Zhang H (2012). Oat beta-glucan: its role in health promotion and prevention of diseases. *Compr. Rev. Food Sci. F.* 11: 355-365. https://doi.org/10.1111/j.1541-4337.2012.00189.x.

Englyst HN, Bingham SA, Runswick SA, Collinson E, et al. (1989). Dietary Fibre (Non-starch Polysaccharides) in Cereal Products. *J. Hum. Nutr. Diet.* 2: 253-271. doi:10.1111/j.1365-277X.1989.tb00028.x.

Forsberg RA and Reeves DL (1995). Agronomy of oats. P. 223-251 *in* R. W. Welch, ed. *The oat crop: Production and utilization*. Chapman & Hall, New York, NY

Gutkoski LC and Pedó I (2000). Aveia: Composição Química, Valor Nutricional e Processamento. 1 ed. Varela, São Paulo.

Hawerroth MC, da Silva JAG, Woyabb LG, Zimmer CM, et al. (2015). Correlations Among Industrial Traits in Oat Cultivars Grown in Different Locations of Brazil. *Aust. J. Crop Sci*. 9: 1182-1189.

Humphreys DG, Smith DL and Mather DE (1994). Nitrogen Fertilizer and Seeding Date Induced Changes in Protein, Oil and β-Glucan Contents of Four Oat Cultivar. *J. Cereal Sci.* 20: 283-290. doi:10.1006/jcrs.1994.1068.

Kelling KA and Fixen PE (1992). *Oat Science and Technology*. Madison: Sorrelis ME (Eds). 6, Soil and Nutrient Requeriments for Oat Production. p. 165-190.

Krüger CAMB, da Silva JAG, Medeiros SLP, Dalmago GA, et al. (2012). Herdabilidade e Correlação Fenotípica de Caracteres Relacionados à Produtividade de Grãos e à Morfologia da Canola. *Pesq. Agropec. Bras*. 46: 1625-1632.

Kumar A, Jaiswal RS, Verma ML, Joshi YP, et al. (2001). Effect Of Nitrogen Levels And Cutting Management On Yield And Quality Of Different Varieties Of Oats Fodder. *Indian J. Anim. Nut*. 18(3): 262-266. https://doi.org/10.20546/ijcmas.2017.603.245.

Leonard KJ and Martinelli JA (2005). Virulence of Oat Crown Rust in Brazil and Uruguay. *Plant Dis*. 89: 802-808. doi:10.1094/PD-89-0802.

Lima KR, Carvalho CAB, Azevedo FHV and Malafaia PAM (2017). Sward Structure and Nutritive Value of Urochloa Ruziziensis Under Nitrogen and Potassium Fertilisation. *Rev. Caatinga*, 30: 220-229. doi:10.1590/1983-21252017v30n124rc.

Ma BL, Biswas DK, Zhou QP and Ren CZ (2012). Comparisons among cultivars of wheat, hulled and hulless oats: Effects of N fertilization on growth and yield. *Can. J. Plant Sci.* 92: 1213-1222. doi:10.4141/cjps2011-167.

Marolli A, da Silva JAG, Romitti MV, Mantai RD, et al. (2017). Contributive Effect of Growth Regulator Trinexapac-Ethyl to Oats Yield in Brazil. *Afri. J. Agric. Res.* 12: 795-804. doi:10.5897/AJAR2016.11784.

Marolli A, da Silva JAG, Sawicki S, Binelo MO, et al. (2018). A Simulação da Biomassa de Aveia por Elementos Climáticos, Nitrogênio e Regulador de Crescimento. *Arq. Bras. Med. Vet. Zoot.* 70: 535-544. doi:10.1590/1678-4162-9504.

Martinez MF, Arelovich HM and Wehrhahne LN (2010). Grain Yield, Nutrient Content And Lipid Profile Of Oat Genotypes Grown In A Semiarid Environment. *Field Crops Res.* 116: 92-100. https://doi.org/10.1016/j.fcr.2009.11.018.

Mohr RM, Grant CA, May WE and Stevenson FC (2007). The influence of nitrogen, phosphorus and potash fertilizer application on oat yield and quality. *Can. J. Soil Sci*. 87: 459-468.

Obur A, Holman JD and Schlegel A (2018). Seeding Rate and Nitrogen Application Effects on Spring Oat and Triticale Forage. *Kansas Agric. Experiment Station R. R.* 4: 1-8. doi:10.4148/2378-5977.7587.

Peltonen-Sainio P, Kontturi M, Laine A, Niskanen M, et al. (2017). Characterizing an Outperforming Pea Cultivar for Intercropping With Oat at High Latitudes. *Agric. Food Sci.* 26: 138-147. doi:10.23986/afsci.61076.

Penning de Vries EWT, Jansen DM, Tem Berge HFM and Bakema AH (1989). Simulation of ecophysiological processes in several annual crops. PUDOC, Wageningen.

Prando AM, Zucareli C, Fronza V, de Oliveira FA, et al. (2013). Características Produtivas do Trigo em Função de Fontes e Doses de Nitrogênio. *Pesqui. Agropecu. Trop.* 43: 34-41. doi:10.1590/S1983-40632013000100009.

Rawat A, Agrawal SB and Patle N (2010). Effect of Soil Enrichment in Conjunction With Bio-organics and Chemical Fertilizers on Yield and Quality of Fodder Oat (*Avena sativa* L.). *Forage Res.* 35: 190-192.

Redaelli R, Scalfati G, Ciccoritti R, Stefani E, et al. (2015). Effects of Genetic and Agronomic Factors on Grain Composition in Oats. *Cereal Res. Commun.* 43: 144-154. doi:10.1556/CRC.2014.0019.

Sharma V, Kumar K and Sharma S (2018). Effect of Different Varieties and Nitrogen on Yield and Quality of Oat (*Avena sativa* L.). *I. J. Sci. Environ. Tec.* 7: 1366-1369.

Silva JAG, Goi Neto CJ, Fernandes SB, Mantai RD, et al. (2016). Nitrogen efficiency in oats on grain yield with stability. *Rev. Bras. Eng. Agrí. Ambient.* 20: 1095-1100. doi:10.1590/1807 1929/agriambi.v20n12p1095-1100.

Silva JAG, Mamann ATW, Scremin OB, Carvalho IR, et al. (2020). Biostimulants in the Indicators of Yield and Industrial and Chemical Quality of Oat Grains. *J. Agric. Stud.* 8: 68-87. doi:10.5296/jas.v8i2.15728.

Silveira SFS, Hawerroth MC, Oliveira DCS, Woyann LG, et al. (2016). Heterosis and Genetic Parameters for Grain Quality in Oat Segregating Populations. *Sci. Agric.* 73: 471-477. doi:10.1590/0103-9016-2015-0129.

Sterna V, Zute S and Brunava L (2016). Oat Grain Composition and its Nutrition Benefice. *Agric. Agric. Sci. Procedia*. 8: 252-256. doi:10.1016/j.aaspro.2016.02.100.

Tang PC, Xu B, Gao ZY, Li HP, et al. (2018). Relationship Between Physiological Indicators of Oat and Meteorological Factors in Tibet's Alpine Pastoral Areas. *Appl. Ecol. Env. Res.* 16: 2741-2754.

Weber FH, Gutkoski LC and Elias MC (2002). Caracterização Química de Cariopses de Aveia (*Avena sativa* L.) da Cultivar UPF 18. *Ciên. Tecnol. Aliment.* 22: 39-44. doi:10.1590/S0101-20612002000100007.

Yan W, Fregeau-Reid J, Ma B, Pageau D, et al. (2017). Nitrogen Fertilizer Complements Breeding in Improving Yield and Quality of Milling Oat. *Crop Sci.* 57: 3291-3302. doi:10.2135/cropsci2017.05.0290.