Article

Influence of fertilization on yield and quality of rye grain in the arid zone of Sonoran, Mexico

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Abstract

In the arid zone of northwestern Mexico, rye cultivation is not established, and it is necessary to generate their knowledge in agronomic matters. The objective of the present study was to determine the feasibility of rye cultivation considering nitrogen fertilization doses evaluating the yield and its grain quality components. The research work was carried out in the municipality of Hermosillo, Sonora. The sowing date established was December 15, 2016 using a drip irrigation system. The evaluated rye variety is called Criollo Tlaxcala. Fertilization treatments consisted of 1) control without aggregate of N (N 0); and 2) 80 kg N ha^{-1} and 3) 150 kg N ha^{-1}. The results indicate that as the fertilization dose increases, it significantly influences the yield and quality of grain. Likewise, the results show that the protein content exceeds those reported in different countries in rye by 11%.

Keywords: grain, protein, secondary grains.

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Introduction

In developing countries, the demand for cereals has grown much faster than production and this dependence on imports is likely to increase (FAO, 2015). In 2030, developing countries could import 265 million tons of cereals annually; that is, 14% of its use. The consumption of secondary grains has grown rapidly, driven above all by the increasing use as food in developing countries. In the future, it can increase its consumption faster than traditional crops such as rice, wheat and corn, depending on the growth of the food and livestock sector (FAO, 2015).

Mexico stands out in the global forecasts on imports of secondary grains, mainly rye; its imports will increase by 15%, which means 23.8 million tons, between 2015 and 2025 (USDA, 2015). Arid areas are one of the most important areas of agricultural production worldwide. The most important characteristics of these areas are the unavailability of the water resource, high and low temperatures and saline intrusion, among others (Mazuela Aguilar, 2013; Andrade *et al*., 2017). 60% of food worldwide is produced in arid areas.

In the Mexican Republic, one of the areas of relevance in food production is the northwest of Mexico, consisting of the states of Baja California, Baja California Sur, Sonora, Sinaloa and Chihuahua (Martínez *et al*., 2016; Andrade *et al*., 2017). Among the main crops with commercial export interest are the following: wheat, sesame, safflower, chickpea, sorghum, corn, cotton, vine, walnut, watermelon, tomato, among other products. In Sonora the area destined for these crops is 614 606 ha.

Nitrogen fertilization is one of the most important factors in the growth and development of cereal crops. The availability of N for the plant is indispensable because it is a basic component of the organic molecules involved in plant growth and development (Salas, 2003). The search for alternative secondary grains with beneficial nutritional properties for human consumption such as rye, is of paramount importance especially when it comes to producing them in arid environments in which there are adverse factors such as edaphic and climatic conditions that reduce crop productivity (Murillo *et al*., 2001; Liukkonen *et al*., 2003; Bushuk, 2004).

The protein content of rye grain is in the range of 6.5 to 14.5% and is dependent on the conditions of agronomic management of the crop, although the protein content of the grain has been reported to be influenced primarily by genotype (Hansen *et al.*, 2004; Arendt and Zannini, 2013). From a nutritional point of view, rye proteins are recognized to be superior to those of wheat and other cereal grains due to the better balance of essential amino acids (Arendt and Zannini, 2013). In the arid zone of northwestern Mexico, there is the interest of establishing rye cultivation.

However, it is necessary to expand knowledge in agronomic matters. The objective of this study was to determine the feasibility of rye cultivation considering different doses of nitrogen fertilization in relation to yield and its grain quality components.

Materials and methods

Description of the experimental site or area of study

The research work was carried out in the experimental field of the Department of Agriculture and Livestock (DAG) of the University of Sonora which is located with the coordinates 29° 00’ 46.2’’ north latitude, 111° 08’ 03.1’’ west latitude to 146 masl. A semi-warm arid subtropical climate predominates, with precipitation and average annual temperature of 320.8 mm and 23.1 °C, respectively (INIFAP, 2010). The experimental area was established in a soil with sandy loam texture, characterized by a content of 49.08% sand, 32.12% silt and 18.8% clays. The sowing date established was in the autumn-winter cycle December 15, 2016-2017. A drip irrigation system was used.

Soil preparation was done mechanically with a fallow and a subsequent dredge pass. The rye variety evaluated was ‘Criollo Tlaxcala’ donated by the Agricultural Association of Tlaxcala, Mexico. The method of sowing manually double-row squirt, with a dose of 120 kg ha^{-1}. At the time of planting, 80 kg ha^{-1} of phosphorus (P) was applied using mono ammonium phosphate (12N-61P-0K). The fertilization treatments consisted of: 1) control without N (N 0), 2) 80 kg N ha^{-1} and 3) 150 kg N ha^{-1}, the fertilizers were applied fractionally in the physiological stage of embuche (70%) and flowering-anthesis (30%), the source used was that of ammonium nitrate (33N-03P-00K).

A manual weed control of the crop was carried out to avoid competition for the N used. There was no presence of pests and diseases during the entire period of the vegetative cycle.

Design and statistical analysis

The experiment was established with a randomized block design; 3 nitrogen fertilizations (0 80 and 150 kg ha^{-1}) were implemented, 4 repetitions were performed on the plot for later analysis. The experimental plot consisted of an area of 30 m^2. The data obtained were analyzed by means of an analysis of variance (Anova). The Tukey test was used to analyze the differences between the specific treatment means. The statistical software InfoStat (Di Rienzo *et al*., 2015) for Windows was used.

Phenological stages, performance variables and their components

The physiological stages evaluated in the present study were recorded in days after sowing (DDS), consisted of emergency, amacollamiento, embuche, spiking, anthesis and physiological maturity. The description of the stages is detailed in (Table 1) according to Solis-Moya *et al*. (2004) using the scale Zadoks *et al*. (1974).

At the end of the experiment, the number of spikes per m^2 was measured and the biomass and grain harvest were performed. The variables evaluated were total biomass, hectolitic weight, thousand grain weight and grain protein. The grain yield (RG) was determined with the weight of the seed harvested in grams, dividing it by the harvested area (m^2) and expressed in tons per hectare (t ha^{-1}).

Table 1. Description of the phenological stages evaluated.

Variable	Measurement
Amacollo	Emergence of the first amacollo 50% of the seedlings
Embuche	When 50% of plant pods are thickened or swollen
Spiking	When 50% of the spikes were exposed
Anthesis	When the anthers of the middle part of the spike were exposed in 50%
Physiological maturity	When 50% of the plants lost the characteristic green color 80% of their leaves, stems and spike.

The total biomass (BIO) was obtained in the vegetative stage of physiological maturity manually for this using a brush, the cut of the plant was made approximately at a height of 5 cm above the soil surface, calculating the yield in tons per hectare (t ha^{-1}). For the determination of hectolitic weight (PHL) a homogenizer (model Boerner 34, Seedburo) was used after the sample was weighed on an analytical balance (model 8850, Seedburo) determining the value in (kg hl^{-1}) following the methodology of the (AACC, 2000).

For the variable weight of one thousand grains (PMG), 4 replicates were considered, which were weighed on an analytical balance (OHAUS, model AR No. 2140), being recorded in grams (gr). On the other hand, grain protein (PRO) was identified according to method 46-13.01 of (AACC, 2000) using a nitrogen determiner (LECO FP-528. Leco Corporation) by applying a conversion factor of (N x 6.25) (Wrigley *et al*., 2010).

The degrees of growth days (GDC) occurred from sowing to commercial maturity were calculated. To estimate the duration of the different phenological stages, the proposal by Ma and Smith (1992) was used, considering the following equation:

$$GD=\sum_{i=1}^{n}(T_{ai} - T_{b})$$

Where: T_{ai} represents the average of the maximum and minimum daily air temperatures, T_b at the base temperature where the plant stops growing, which usually most cereals consider a value of 0 °C (Cao and Moss, 1989; Kernich and Halloran, 1996).

The rainfall data, maximum and minimum air temperatures during the development of the experiment, were taken from a VAISALA model (WXT510) automatic station, located approximately 20 m away from the place where the experimental planting is located.

Results and discussion

Phenology and climatic conditions

In relation to the heat days (GDC), the representations of the phenological phases in general until commercial maturity are represented in (Figure 1), the analysis of variance does not show a significant difference. This reflects little variation in the phenology of rye in the three nitrogen fertilization treatments. The total demand of the thermal period of the crop at physiological maturity was 2 384 GDC in 128 days after sowing. In (Figure 2), it is observed that the first stages of the cultivation took place in an environment between 7 and 30 °C with rainfall not exceeding 10 mm on a monthly average.

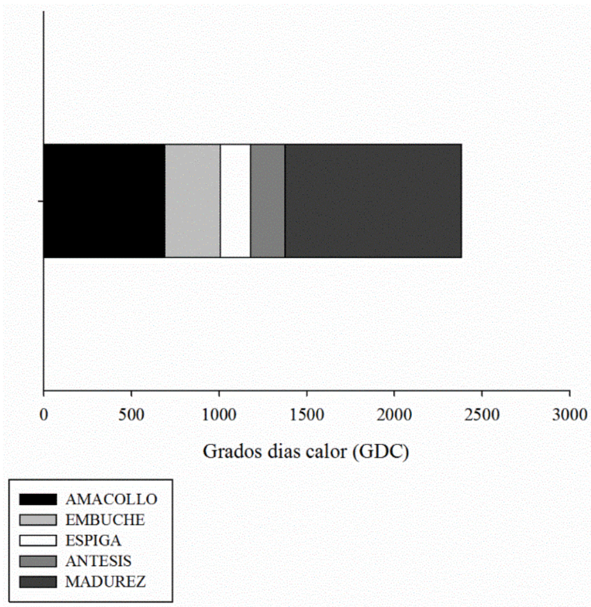

Figure 1. Duration of the main stages in terms of degrees hot days (GDC), for the 2016-2017 winter-spring agricultural cycle.

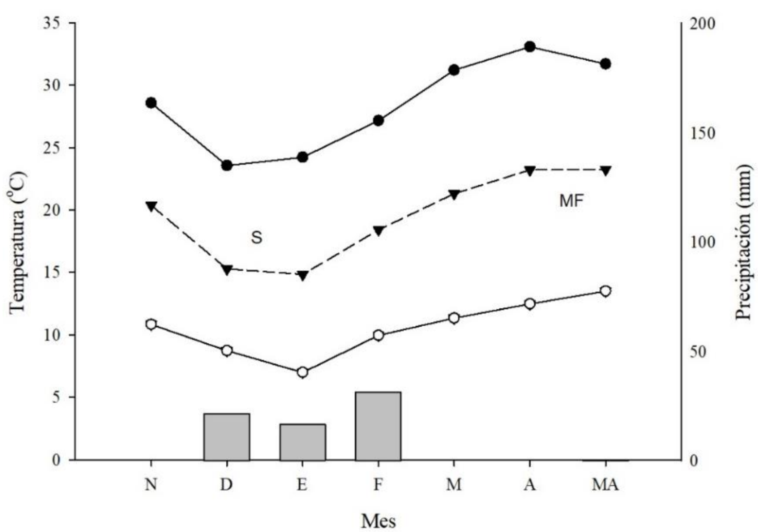

Figure 2. Precipitation (■) and temperatures (°C) maximum (●), minimum (○), monthly average (▼). S= sowing, December 15, 2016; MF= physiological maturity, April 20, 2017.

The behavior of this cultivar in GDC is similar to those of Ballesteros *et al*. (2015) in triticale, where 2137 GDC and 2307 GDC resulted in two experimental cycles (Ballesteros *et al*., 2015). On the other hand, López *et al*. (2018) reported a job with rye in the winter-spring season in the town of Hermosillo, Son. With results not similar to those obtained in this study, obtaining 2274 GDC and 112 DDS until physiological maturity. The greater number of GDC and DDS in this work is attributed to the establishment of the crop on dates where air temperatures and incidence of solar radiation are predominantly lower.

Performance of grains and components

The treatments (T) with doses of 0, 80 and 150 kg ha^{-1}, developed statistical differences in all the variables except PH observing differences in the RG, PRO, NGE, BIO and at $p\leq 0.05$ in the (NEPM) and (PMG), fertilization (N) is an important factor to increase yield and its components (Table 2).

Table 2. F values in the combined variance analysis for rye yield in three fertilization treatments.

Source of variation	BIO	NEPM	PMG	PHL	PRO	RG
Repetition	0.6	0.26	1.34	0.28	1.44	0.13
Fertilization	17.9*	4.59*	10.3*	0.58 ns	17.15**	27.06**
Error (CM)	456394	343.47	0.95	0.19	0.06	17256.07
CV (%)	6.12	9.7	2	0.6	1.51	6.33

BIO= biomass; NGE= number of grains per spike; NEPM= number of spikes per square meter; PMG= thousand grain weight; PH = hectolitic weight; PRO= total protein; RG= grain yield; *= $p\leq 0.05$; **= $p\leq 0.01$; ns= not significant; CV= coefficient of variation.

Yield

The comparison of means between treatments for the grain yield variable (kg ha^{-1}) using the Tukey test ($p\leq 0.05$) in (Figure 3), indicates that a significant difference $p\leq 0.01$ was obtained between the three levels of fertilization Therefore, the grain yield increased as the amount of nitrogen increased from the control to 150 kg ha^{-1}. The treatment with 150 kg ha^{-1} N obtained an average of 2 385 kg ha^{-1} presenting the maximum yield, in contrast to the average absolute control of 1 965 kg ha^{-1}, low doses of nitrogen can affect or induce the phenological state in the culture, affecting in turn, the onset of anthesis and flowering (Fois *et al*., 2009).

The results obtained in the present study agree with Bakhsh *et al*. (1999) and Rustam and Yasin (1991), where they reported that an increase in nitrogen dosages has a positive impact on grain yield behavior. On the other hand, the yields obtained in all the treatments evaluated were higher than the average reported by López *et al*. (2018), where this author worked with rye, obtaining a general average of 1 965 kg ha^{-1}. This effect indicates that as the sowing date warms up, the environmental conditions are less favorable for the production of this grain.

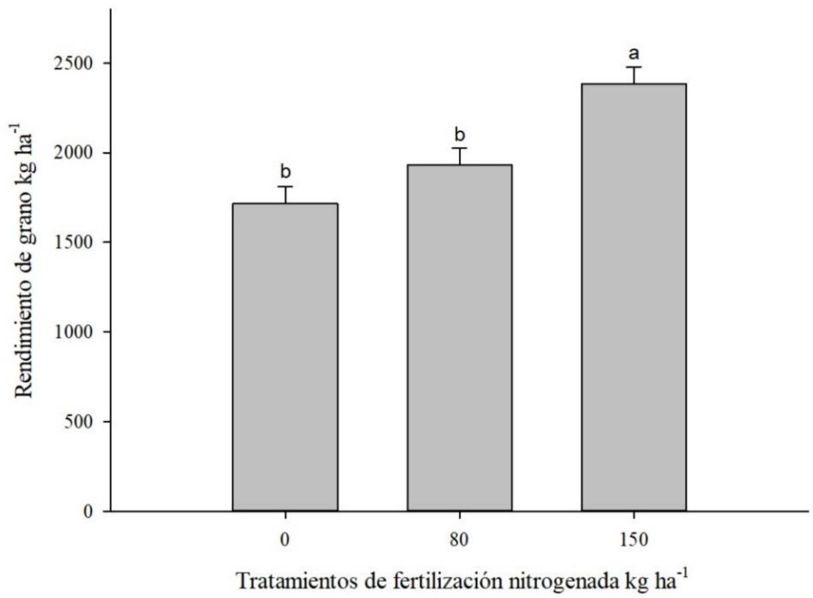

Figure 3. Effect of nitrogen dosing on grain yield components.

The number of spikes per square meter and the weight of one thousand grains maintained a positive linear effect as the dosages of the nitrogen fertilizer increased. Langer and Liew (1973), evaluating the effects of the variation in the nitrogen supplementation applied to different stages of the wheat crop, revealed that the number of spikelets increases with the increase of nitrogen applied to the crop, producing in turn a number larger leaves and therefore, affecting performance. In addition, Ali *et al*. (2003) evaluating nitrogen doses on grain yield, they found that grain yield depends mostly on grain weight and also on the number of spikes per square meter (Figure 4).

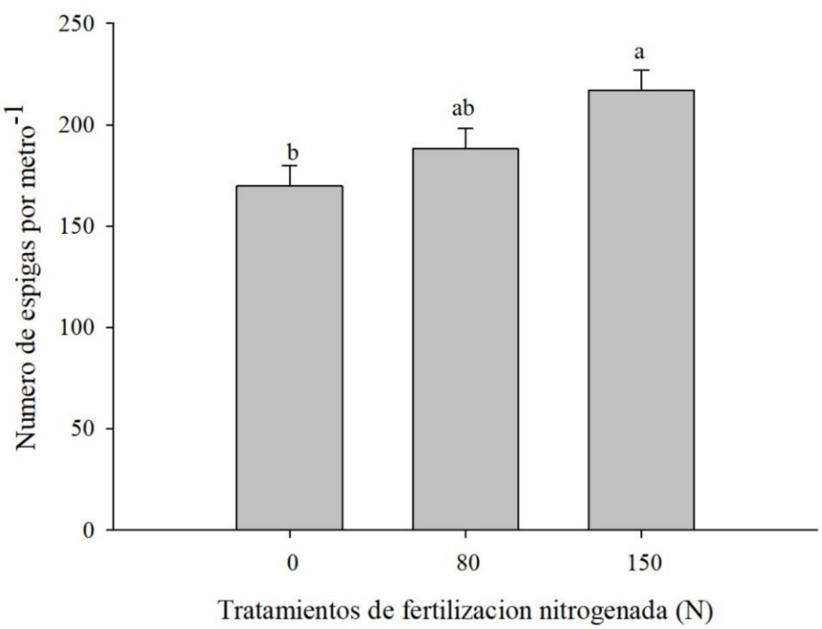

Figure 4. Effect of the dosage of nitrogen on the number of spikes per meter.

The results also reveal that for treatments with a dosage of 150 kg ha^{-1} (N) (Figure 5) the biomass production at physiological maturity was the highest ($p \leq 0.05$) with 12 513 kg ha^{-1}.

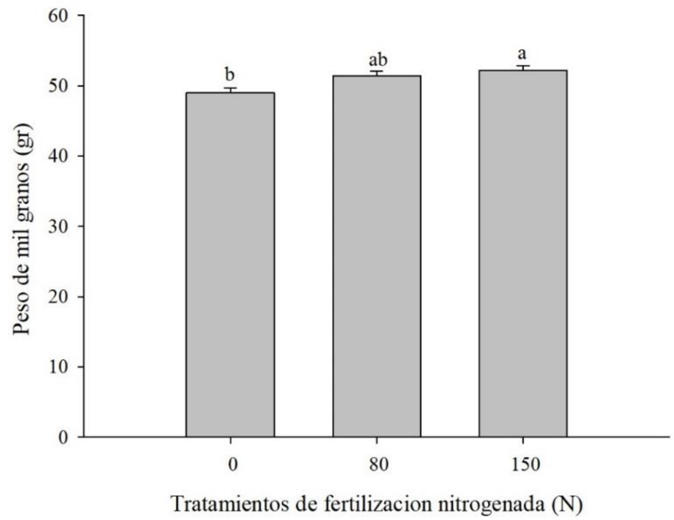

Figure 5. Effect of the dosage of nitrogen on the weight of one thousand grains.

The increase in the production of biomass in rye and wheat cultivars has been observed during various investigations that corresponds to an increase in the levels of the inorganic nitrogen nutrient present in the edaphological properties (Balkcom *et al*., 2011) (Figure 6).

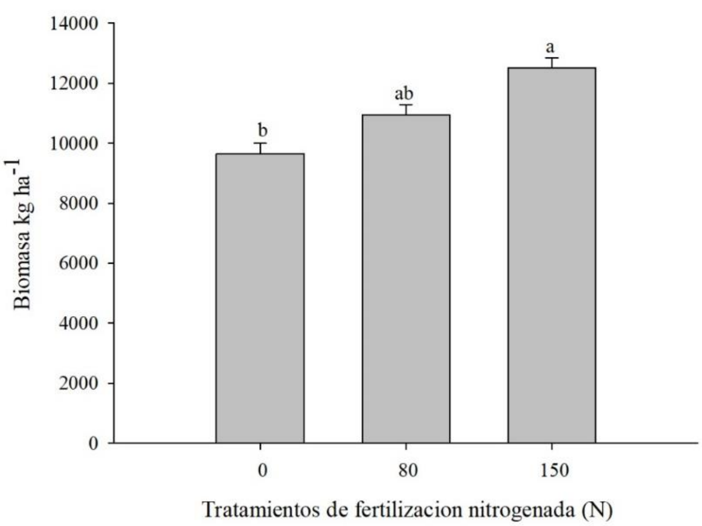

Figure 6. Effect of the dosage of nitrogen on the biomass component kg ha^{-1}.

In the Table 2 describes the relationship between hectolitic weight and nitrogen fertilization. This factor did not have a significance of $p \leq 0.05$; therefore, there was no effect on the three levels of fertilization, which indicates the phenotypic stability for these characteristics. These results reaffirm the explanation of Mellado *et al*. (2008), where it indicates that the application of nitrogen with only 50 kg ha^{-1} improves the hectolitre weight of rye by 1 kg hL^{-1} and higher doses to this nutrient did not significantly change this characteristic.

The amount of nitrogen also significantly affected the quality of grain protein. The interaction between the three doses of nitrogen and the protein content was significant $p \leq 0.05$. Obviously, protein content was increased with fertilizer dosages. A maximum content (16.5%) of protein was observed with the dose of 150 kg ha^{-1}, the minimum content of grain protein (14.78%) was presented with the dose of 0 kg ha^{-1}. This can be explained by the greater availability of nitrogen for amino acid synthesis (Figure 7) and in turn in subsequent protein synthesis.

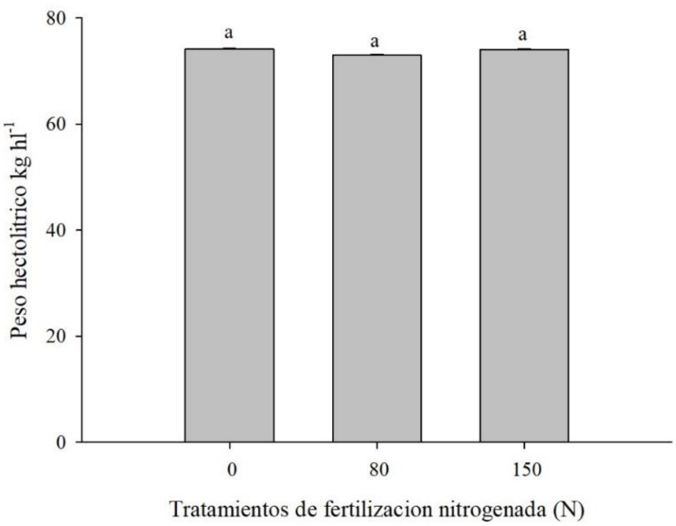

Figure 7. Effect of nitrogen dosing on hectolitic weight (kg hL^{-1}).

A linear increase in the percentage of protein has been observed as the nitrogen range in baker wheat was extended (Figure 8).

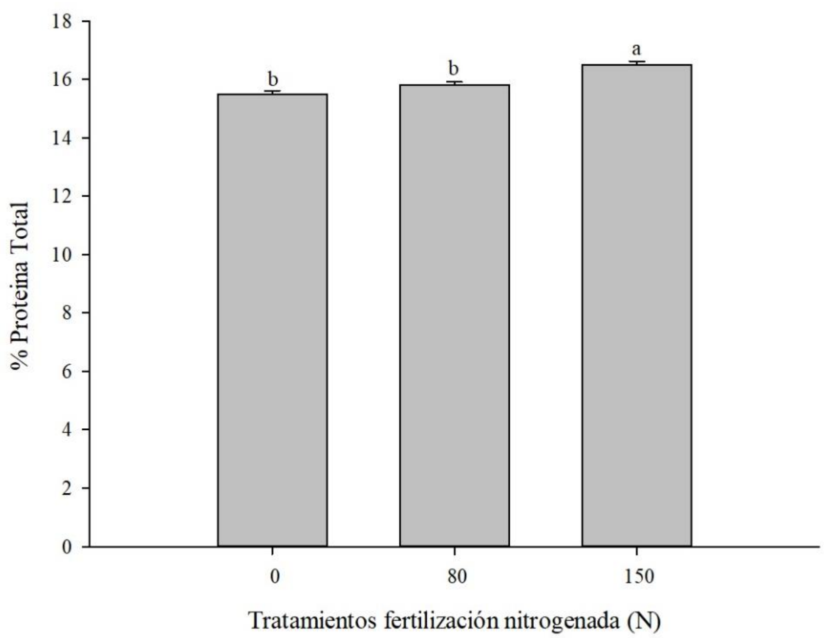

Figure 8. Effect of the dosage of nitrogen on the protein component.

Conclusions

With the completion of this study, it was possible to broaden the knowledge of agronomic behavior and quality in rye cultivation, under the influence of three doses of nitrogen fertilization, under arid areas in northwestern Mexico. The results showed that the rye variety evaluated as Criollo Tlaxcala on the sowing date of December 15, 2016-2017, with a drip irrigation system, by increasing the fertilization dose from 0 to 150 kg ha^{-1}, present significant positive values in the variable of yield, quality of grain and biomass.

Similarly, it is concluded that the protein content obtained under the proposed conditions, exceeds those reported in different countries where they are dedicated to the production of rye. It is recommended that in subsequent studies, factors related to planting dates, limiting conditions of the water and salinity resource should be taken into account.

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