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CROP PRODUCTION

Economic nitrogen doses via fertigation for corn cultivation in a semiarid environment

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ABSTRACT. Producers in the northeastern semiarid region of Brazil have been cultivating irrigated corn. The commercialized product comprises mainly green ears and silage. However, the irrigation of crops for dry grain has been questioned regarding costs and price competitiveness in relation to the same non-irrigated product cultivated in other regions. In recent years, the use of drip tapes and fertigation has spread among corn producers in the region. The aim of this study was to determine the N dose, via fertigation, which provides the maximum economic production of corn for dry grain, in two crop seasons (summer and winter), in the semiarid region of Brazil. The experimental design was performed in randomized blocks, with four replications. In both crops, the treatments consisted of four doses of N (0, 80, 160, and 240 kg ha^{-1}) applied in the form of urea. In the hybrid corn (Bt Feroz), the N content was evaluated in terms of leaves, grain yield, gross and net incomes, the rate of return, and the profitability index. Independent of the crop season, the yield of dry grain (5,441.03 kg ha^{-1}) was highest when the corn was fertigated with a dose of 104.05 kg ha^{-1} N. The highest net incomes of the dry grain were obtained with 80 kg ha^{-1} N in summer (R$ 1,190.78 ha^{-1}) and 160 kg ha^{-1} N in winter (R$ 2,757.54 ha^{-1}). The winter crop was more favorable to the economic production of dry grain.

Keywords: *Zea mays* L.; planting date; production costs; profitability.

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Introduction

Corn is one of the main Brazilian agribusiness crops, and it has significant socioeconomic and nutritional importance. Brazil was the third-largest world producer in 2018, behind only China and the United States (Food and Agriculture Organization of the United Nations [FAO], 2020). In the 2018/19 harvest, the area planted with corn reached a record of 17.49 million hectares, producing 100.04 million tons of grain and average productivity of 5,719.00 kg ha^{-1} (Companhia Nacional de Abastecimento [CONAB], 2020).

Corn is a C4 plant, with a high photosynthetic rate and CO_2 fixation, which is responsible for a partial increase in maximum air temperature (up to 30.2°C during the post-silking stage) with high productivity (Zhou et al., 2017). Despite the water demand of corn being served through irrigation, its dry grain yield can be affected (Galindo et al., 2017) mainly as a result of the average air temperature under semiarid conditions, which in worse cases exceeds 35°C.

In addition to choosing the most appropriate planting season, fertilization plays an important role in soil fertility and corn mineral nutrition, especially in relation to N, the most required nutrient by the crop (Menezes, Berti, Vieira Junior, & Berti, 2018). Research on increasing N doses emphasizes a positive influence on the obtained grains yield. However, the recommended applications are highly variable owing to the particularities of edaphoclimatic conditions under which each study was carried out. The optimal doses ranged from 90 to 240 kg ha^{-1} (Farinelli & Lemos, 2010, 2012; Valderrama, Buzetti, Benett, Andreotti, & Teixeira Filho, 2011; Vilela et al., 2012; Lyra, Rocha, Lyra, Souza, & Teodoro, 2014; Oliveira et al., 2016).

In most studies on N fertilization in corn in Brazil, the fertilizers were distributed manually or mechanically. Under semiarid conditions, the risk of N loss due to the volatilization of NH_3 is relatively higher than that by NO_3^- leaching because certain edaphoclimatic factors and cultural practices contribute to this (Abbasi, Abbasi, Liaghat, & Alizadeh, 2011), for example, high doses of N and high temperatures (Ma et al., 2010; Tasca, Ernani, Rogeri, Gatiboni, & Cassol, 2011).

To reduce the costs of fertilizer and labor, to facilitate parceling and reduce the loss of N by the volatilization of NH_3 and leaching of NO_3^-, the use of nitrogen fertilizers in fertigation for corn nutritional management can be a viable alternative, especially when the irrigation is delivered specifically by dripping (Sampathkumar, & Pandian, 2010; Aubert, Roozeboom, Ruiz Diaz, Gipps, & Wolf, 2016; Kumar, Rajput, Kumar, & Patel, 2016; Souza et al., 2019; 2020).

The irrigated production of dry grain in the off-season can reach high productivity and promote greater profitability since the demand for such products is much greater than the supply, thus the price is relatively high. In addition to irrigation, the use of high doses of N for maximum productivity is generally greater than those considered economical, since they are subject to nutrient prices and other production costs (Souza, Buzetti, Tarsitano, & Valderrama, 2012; Kaneko et al., 2015; Souza, Buzetti, & Moreira, 2015; Galindo et al., 2017).

In this sense, the aim of the present work was to determine the dose of N, via fertigation, that would provide the maximum economic production of dry corn grain, using two crop seasons (summer and winter).

Material and methods

The experiments were conducted in the field, using two crop seasons, one in summer (January to May) and the other in winter (June to October) of 2016. The property was located inside an irrigated perimeter supplied with water from the São Francisco River, in the municipality of Canindé de São Francisco, Sergipe State, in the semiarid region of Brazil (9°40'27" S, 37°45'45" W, 194 m altitude). The climate of the region, according to the classification of Köppen, is BSsh, which is very hot, semiarid, steppe-like, with a rainy season centered around the months of April, May, and June (Sousa et al., 2010). The average meteorological data for the experimental period were obtained from an automatic meteorological station installed 6 km from the experiment area (Figure 1).

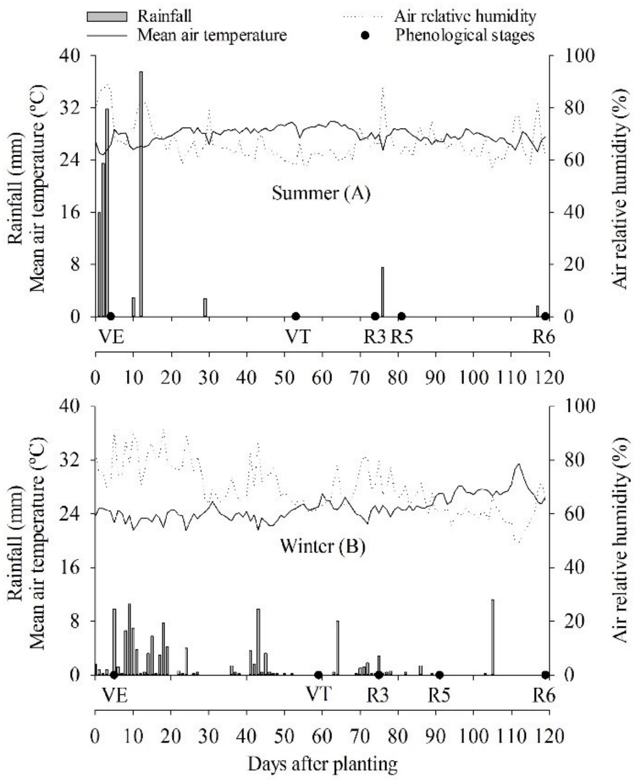

Figure 1. Values of accumulated rainfall, mean air temperature, and relative air humidity and an indication of the phenological stage (VE – emergence, VT – flowering male, R3 – milky grains, R5 – farinaceous grains, R6 – physiological maturity) of corn fertigated with doses of nitrogen in the summer (A) and winter (B) crops.

The soil of the experimental area was classified as *Luvissolo Crômico*, with wavy topography and a clayey texture. It has grain-size values of 478.20 g kg^{-1} sand, 198.00 g kg^{-1} silt, and 423.80 g kg^{-1} clay, with the chemical characteristics (Silva, 2009) described in Table 1.

The experimental design was a randomized block, with four replications. The treatments consisted of four doses of N (0, 80, 160, and 240 kg ha^{-1}). The doses were divided, with 15% applied at 15 days after emergence (DAE), 50% at 20 DAE, and 35% at 40 DAE, through a Venturi-type fertilizer injector. A Zn dose (2.0 kg ha^{-1}) was applied via fertigation to all treatments (Sobral, Carvalho, Barreto, & Anjos, 2007). The N and Zn doses were supplied by urea and Zn sulfate, respectively.

Table 1. Soil chemical analyses of the experimental areas cultivated with corn (0 to 20 cm depth), in the summer and winter crops.

	P	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H+Al
Crop seasons	mg dm^{-3}			-----cmol$_c$ dm^{-3}-----			
Summer	24.00	0.37	16.30	10.10	0.12	0.00	3.20
Winter	26.00	0.43	18.60	8.20	0.27	0.00	0.00
	pH	EC*	OM*	Cu	Fe	Mn	Zn
	H_2O	dS m^{-1}	g kg^{-1}		-----mg dm^{-3}-----		
Summer	6.60	0.34	25.80	0.10	42.90	76.60	2.00
Winter	7.10	0.57	34.70	0.60	41.80	103.00	2.50

*EC – electrical conductivity, OM – organic matter, P, K^+, and Na^+: Mehlich ($HCl+H_2SO_4$), Ca^{2+}, Mg^{2+}, and Al^{3+} – KCl 1M.

Each plot consisted of six lines of 6 m in length, spaced 1 m apart, in a total area of 36 m^2 (6 x 6 m). The four central lines, discarding a plant at each end, were considered the harvest area of the plot (22.4 m^2).

Soil preparation was performed, with two cross harrowings to an average depth of 20 cm. Then, the plots were demarcated and sown manually with Bt Feroz (Syngenta®) corn at a spacing of 1.0 m x 0.2 m (50,000 plants ha^{-1}), with the plantations effected on 01/20/2016 (summer) and 06/17/2016 (winter). This cultivar is a double hybrid, with an early cycle, which produces hard and orange grains.

The experiment had a drip-irrigated irrigation system, with a spacing of 0.2 m between the emitters and an average flow of 1.2 L h^{-1}, the amount of water being obtained from the water balance, considering precipitation and crop evapotranspiration (Santos, Espínola Sobrinho, Medeiros, Moura, & Nunes, 2014). The amounts applied were 254 mm (summer) and 179 mm (winter) via the irrigation system.

The cultural procedures adopted during the experiments followed the standards used by the producers of the region. Weed control was performed using herbicide (500 g L^{-1} of the atrazine active ingredient) applied at 23 DAE.

At 49 DAE (summer) and 54 DAE (winter), on the occasion of the appearance of female inflorescence, the basal third of the opposite leaf and below the first spike were randomly collected from 10 plants from the harvest area of each plot, excluding the central row (Malavolta, 2006), to determine the N content in the diagnostic leaf (Silva, 2009).

A single harvest was conducted at 115 DAE (summer) and 114 DAE (winter). Dry grain yield (kg ha^{-1}) was estimated from the ears harvested of 28 plants in the harvest area, and the values were corrected for a moisture content of 13% (wet basis).

Economic indicators were used to evaluate the efficiency of the treatments. The total costs of producing 1 ha of corn for dry grain were estimated as a function of N dose and cropping season, which were calculated and analyzed at the end of each production process, adapting the methodology proposed by Companhia Nacional de Abastecimento (Conab, 2010).

The gross income (R\$ ha^{-1}) for the dry grain was equivalent to the production of the 60-kg sack value (R\$ 66.00 $sack^{-1}$ for both crops) for dry grain yield. Between January and October 2018, US\$1 was quoted, on average, as being R\$ 3.51 (Brazilian currency is the Real (R\$)). The net income (R\$ ha^{-1}) was calculated by the difference between the gross income and the total costs (R\$ ha^{-1}) involved in obtaining the dry grain. The rate of return was determined from the relation between the gross income and total costs, which corresponded to the capital obtained for each real applied in the corn cultivation. The profitability index (%) consisted of the relation between the net income and gross income, expressed as a percentage.

For each crop season (summer and winter), analyses of variance of the characteristics were conducted using Sisvar version 5.6 (Ferreira, 2011). Subsequently, a joint analysis was performed on the characteristics using homogeneity of variance between the harvests.

The regression equations for the N doses were chosen based on the following criteria: the biological explanation of phenomenon; simplicity of equation; and test of parameters of the equation using the Student's t-test, at 5% probability.

Results and discussion

There were isolated effects of N dose and crop season on the characteristics evaluated (Table 2). For N content in the diagnostic leaf, there was an increase with increasing N dose up to an estimated maximum value of 29.4 g kg^{-1}, when the corn plants were fertigated with 173.58 kg ha^{-1} N, with the values then decreasing up to the highest dose assessed (Figure 2A).

Table 2. Summary of the joint analysis of variance (F values) for N content in the diagnostic leaf (DL, g kg^{-1}), grain yield (GY, kg ha^{-1}), gross income (GI, R\$ ha^{-1}), and rate of return (RR) of corn fertigated with N doses in two crop seasons.

Sources of variation	DF	F values			
		DL	GY	GI	RR
Blocks (Crops)	6	0.91 ns	0.88 ns	0.88 ns	0.86 ns
Doses (D)	3	37.63**	8.11**	8.11**	5.27**
Crops (C)	1	54.85**	56.59**	56.59**	68.95**
D x C	3	1.08 ns	1.53 ns	1.53 ns	2.45 ns
CV (%)		6.03	15.47	15.47	14.14
		Means			
		26.5	4,883.31	5,371.64	1.31

ns – not significant at 5% probability using the F test; ** – significant at 1% probability using the F test; DF – degrees of freedom; CV – coefficient of variation.

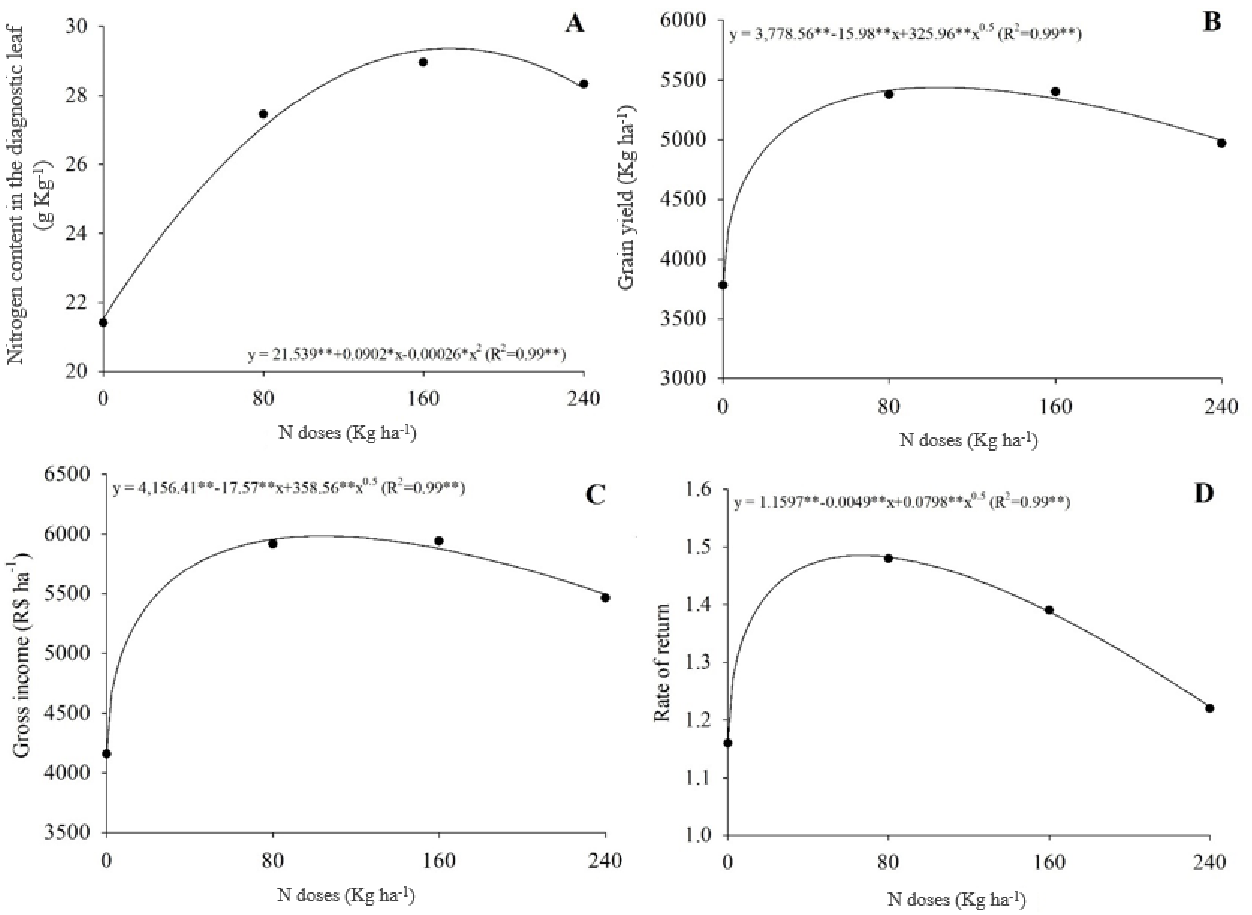

Figure 2. N content in the diagnostic leaf (A), grain yield (B), gross income (C), and rate of return (D) of corn fertigated with N doses.

The reduction in N content in the diagnostic leaf at the highest dose (240 kg ha^{-1}) may have been caused by the excess of N in the soil that reduced the efficacy of other nutrients by the increase in pH, consequently decreasing the crop yield. In addition, fertigation with a high N dose in soil with a pH of over 6.5 may have promoted higher volatilization of NH_3 from the urea application (Ma et al., 2010; Tasca et al., 2011).

For good corn development and yield, the N content in the diagnostic leaf should be between 28 and 35 g kg^{-1} (Malavolta, 2006). Visually, plants without N fertigation showed early yellowing of the older leaves. Thus, using the minimum N content in the diagnostic leaf suggested by Malavolta (2006), a minimum dose of 103.50

kg ha^{-1} N was estimated, using the regression equation of the present study, to meet the needs of the nutrient by culture (Figure 2A).

A winter corn cultivation of 28.6 g kg^{-1} (Table 3) yielded an average N content in the diagnostic leaf superior to that of the summer planting (24.5 g kg^{-1}). In the summer crop, high temperatures and low humidity (Figure 1A) may have contributed to higher volatilization of NH_3 from urea (Tasca et al., 2011), causing possible negative effects on these variables.

Table 3. N content in the diagnostic leaf, grained yield, gross income, and rate of return of corn in two crop seasons.

Crop seasons	N content in the diagnostic leaf (g kg^{-1})	Grain yield (kg ha^{-1})	Gross income (R$ ha^{-1})	Rate of return
Summer	24.5	3,878.80	4,266.68	1.04
Winter	28.6	5,887.82	6,476.60	1.59

The estimated dose of 104.05 kg ha^{-1} N promoted a maximum grain yield of 5,441.03 kg ha^{-1} (Figure 2B), which then decreased to the highest dose (a reduction of 7.19%). The plants that did not receive N fertilization presented lower productivity (3,778.56 kg ha^{-1}), with a decrease of 44% in relation to the plants that received the estimated dose.

The productivity decrease can be attributed to the fact that the efficiency of the N dose decreased as a function of increasing dose (Farinelli & Lemos, 2010; 2012; Mota et al., 2015; Sangoi et al., 2015) because excess N can exceed the needs of the crop, in line with the Law of the Maximum (the excess of a nutrient limits or harms the productivity of a plant), as well as favoring loss via NH_3. In relation to the production of dry grain, higher N doses also caused superfluous consumption by the plant (Melo, Corá, & Cardoso, 2011), that is, the plant increased the N content in the diagnostic leaf up to a dose of 173.58 kg ha^{-1} N (Figure 2A), while the grain yield decreased from 104.05 kg ha^{-1} N (Figure 2B).

In several studies carried out under the most diverse environmental conditions in Brazil (conventional fertilization, rainfed or irrigated), the authors obtained quadratic responses for grain physical productivity, with estimated optimal N doses of 92 kg ha^{-1} (Farinelli & Lemos, 2010), 120 kg ha^{-1} (Melo et al., 2011), 150 kg ha^{-1} (Farinelli & Lemos, 2012), and 188 kg ha^{-1} (Lyra et al., 2014), with increasing doses reducing productivity. In addition, certain studies found positive linear effects of N dose on grain yield up to 120 kg ha^{-1} (Valderrama et al., 2011), 160 kg ha^{-1} (Vilela et al., 2012), and 240 kg ha^{-1} (Oliveira et al., 2016) of N.

In a study using irrigated corn in Mossoró, Rio Grande do Norte State, Brazil, Silva et al. (2014) obtained a maximum estimated grain yield (7,480.00 kg ha^{-1}) at the recommended dose of 88 kg ha^{-1} N for the production of hybrid AG 1051. In the same edaphoclimatic conditions and using the hybrid AG 1051, Silva, Braga, Ribeiro, Oliveira, and Santos (2010), Silva, Oliveira, Silva, Chicas, and Tomaz (2015), and Monteiro, Silva, Tavella, Oliveira, and Silva (2016) reached average grain yields of 5,094.00; 6,264.00; and 6,332.00 kg ha^{-1}, respectively, with a dose of 120 kg ha^{-1} N. These productivities were superior to the present research and can be justified by the use of NH_3 sulfate instead of urea (Barros, Santos, Pacheco, Procópio, & Souza, 2016), reducing possible N loss by NH_3 volatilization and sulfur availability, in addition to the use of phosphate fertilization (60 to 120 kg ha^{-1} P_2O_5) and potassium (30 to 50 kg ha^{-1} K_2O) in the foundation.

Corn cultivation in winter (Table 3) yielded an average result (5,887.82 kg ha^{-1}) that was higher than the average summer crop (3,878.80 kg ha^{-1}). The highest mean air temperatures in summer (Figure 1A) may have contributed to a decrease in N accumulation (Table 3), causing a detrimental effect on the agronomic performance of the corn (Table 3), as the weather conditions of the period reduced the vegetative cycle of the crop to only 53 days (planting to male flowering). Conversely, in winter, the male flowering occurred 59 days after sowing (Figure 1B). The occurrence of average night temperatures below 24°C contributes to decreased cellular respiration. When this occurs during the grain filling stage (i.e., from female flowering [R1] to physiological maturity [R6]), the mild temperatures promote greater accumulation and translocation of photoassimilation and, consequently, enable a greater deposition of dry matter in the grains (Zhou et al., 2017), as verified by the conditions of the winter crop (Figure 1B).

In terms of the agronomic performance results, it was verified that the productive potential of corn for dry grain can be increased by the use of ideal doses of N and the planting of cultivars improved for meteorological conditions and beneficial to the efficient N utilization. Although increasing the dose of N promotes higher grain yields in corn, especially in winter, this may be not economically viable (Souza et al., 2015).

According to the joint analysis of the gross income variables of dry corn grain production, we observed the isolated effects of N dose and crop season (Table 2).

The gross income from the production of 1 ha of corn for dry grain showed similar statistical behavior to grain yield (Table 2). That is, there was an increase in income up to a dose of 104.05 kg ha^{-1} N (R$ 5,985.13 ha^{-1}), with a subsequent reduction up to a dose of 240 kg ha^{-1} N. In the winter crop (R$ 6,476.60 ha^{-1}), there was a gross grain value higher than the summer planting (R$ 4,266.68 ha^{-1}) (Figure 2C and Table 3, respectively).

The fall in productivity of the second crop of corn in 2015/16, was caused by the irregular rainfall over the large producing centers, which considerably increased the price of corn in the northeastern semiarid region, such as in the Alto Sertão of Sergipe, where the per-bag price for 60 kg was R$ 66.00 in the experimental summer and winter harvests, reflecting positively on the gross income of the crop. Even in regions where producers obtain good corn prices, if productivity is low, profitability will be compromised. Thus, investment in management practices, such as balanced N fertilization, improves the grain yield and corn crop gross margin, regardless of location (Galindo et al., 2017).

Table 4 shows the total costs of production of 1 ha of corn for dry grain as a function of N rate via fertigation and season cropping in Canindé de São Francisco, Sergipe State, Brazil. The variable, fixed and factored income (opportunity) costs for producing 1 ha of the average treatments of corn for dry grain corresponded, respectively, to R$ 2,408.07, R$ 542.37, and R$ 1,108.22 ha^{-1} (Table 4). The inputs (seeds, fertilizers, herbicides, and raffia bags) represented an average of 33.69% (summer) and 31.07% (winter) of the operational costs of the crop (Table 4). These results highlight that the inputs (mainly fertilizer and seed) should be prioritized in decisions aimed at reducing costs in the production of corn grain, as market research anticipates, although strategies that reduce other expenses should also be considered.

Regarding the specific expenditure on N fertilization in the operational costs, the values of 9.30% (80 kg ha^{-1}), 17.06% (160 kg ha^{-1}), and 23.69% (240 kg ha^{-1}) in the summer crop, and 8.06% (80 kg ha^{-1}), 14.68% (160 kg ha^{-1}), and 20.73% (240 kg ha^{-1}) in the winter crop (Table 4) were obtained. A decrease in the price of urea (source of N) from R$ 1.50 kg^{-1} (summer) to R$ 1.30 kg^{-1} (winter) was the main reason for the cost reduction.

The choice of another soluble source of N may be an option for the farmer. According to Barros et al. (2016), the use of 119 kg ha^{-1} N in the form of NH_3 sulfate provided higher yields and incomes for the corn harvest at a lower dose than urea (190 kg ha^{-1} N). Thus, it compensated for its higher cost, in the 2014 and 2015 harvests in Umbaúba, in the Coastal Tablelands region of Sergipe State, Brazil.

Labor costs corresponded, on average, to 25.67 and 25.30% of the operational costs of the summer and winter crops, respectively (Table 4). Although similar, the labor costs differed according to the irrigation time required, with the water requirement being higher for the summer crop (42.33h) than the winter (29.83h), particularly, in times of high temperatures and lack of rainfall (Figure 1), and with the demand for workers to pack the grains, with the winter harvest (4.91 workers per day) being superior to the summer crop (3.23 workers per day) due to the high grain yield obtained in this harvest (Table 3).

The values of the operating costs are similar to those found by Galindo et al. (2017), who studied the economic viability of corn produced in Selvíria, Mato Grosso do Sul State, Brazil, in the 2013/14 and 2014/15 crop seasons, under fertilization with 0 to 200 kg ha^{-1} N. They calculated operating expenses between R$ 2,549.63 and R$ 3,533.30 ha^{-1}, with the highest expenses being from fertilizer and mechanized operations, corresponding to 31.30 and 28.90% of the variable costs, respectively. The highest cost for fertilizer was due to the use of 400 kg ha^{-1} at formula NPK 08-28-16 in the foundation, together with increased doses of N-urea. Conversely, the expenses for the mechanized operations were lower than the equivalent activities in this experiment (machine rent and labor).

Because the irrigation used was the drip type, the farmer should also consider the lifespan of the drip tapes (two years, on average), making it necessary to save R$ 520.68 ha^{-1} per corn crop for dry grain (Table 4) to account for replacement of hoses and to avoid clogging of the emitters or leakage that impairs the application efficiency of water and fertilizer. When economically analyzing corn crops irrigated by a central pivot, Kaneko et al. (2015) reported a depreciation in the equipment of only R$ 44.58 ha^{-1} (1.83% of the total operational cost), are possibly due to the fact that they considered a lower cost for the irrigation system per unit area, associated with a longer useful life relative to drip irrigation.

The opportunity cost related to property rental was also significant, and corresponded on average, to 24.29% (R$ 978.08 ha^{-1}) of the total costs in both the summer and winter harvests (Table 4). The corn cycle for dry grain extended up to 119 DAP (Figure 1), thus occupying the crop area for longer when compared to corn harvests for green grain (70 to 75 DAP) or silage (81 to 91 DAP).

Table 4. Components of total costs in the production of 1 ha of corn for dry grain, fertigated with doses of N in two crop seasons.

Discrimination		Summer		Winter	
I – Cost expenditure of crop cultivation	Unity	Amount	R$	Amount	R$
1 – Machine rental					
Tractor with disk harrow	h	2.00	220.00	2.00	220.00
Tractor-mounted corn-thresher	bag	67.87	203.61	97.70	293.10
2 – Labor					
Distribution of drip tapes	daily	2.00	80.00	2.00	80.00
Manual planting with rattle	daily	1.00	40.00	1.00	40.00
Irrigation or fertigation	h	42.33	211.65	29.83	149.15
Spraying (herbicide)	daily	1.00	40.00	1.00	40.00
Manual harvesting of cobs	daily	6.00	240.00	6.00	240.00
Bagging of grains	daily	3.39	135.74	4.88	195.40
3 – Seeds: Hybrid corn Bt Feroz	kg	15.00	417.40	15.00	391.40
4 – Fertilizers:					
Urea (45% N) – 240 kg ha^{-1} N	kg	533.34	800.01	533.34	693.34
Zn sulfate (21% Zn)	kg	9.53	34.69	9.53	34.69
5 – Pesticide: Atrazine (herbicide)	L	4.00	112.00	4.00	100.00
6 – Other items					
Soil analysis	Unity	1.00	52.00	1.00	59.00
Raffia bags (60 kg)	Unity	67.87	47.51	97.70	68.39
Subtotal (A)			2,634.61		2,604.47
II – Other expenses					
7 – Administrative expenses (3% of the cost of the crop)			79.04		78.13
8 – Technical assistance (2% of the cost of the crop)			52.69		52.09
9 – Rural territorial tax (R$ 10.00 per year)			3.26		3.26
Subtotal (B)			134.99		133.48
III – Financial expenses					
10 – Interest on financing (7.49% per year)			64.34		63.60
Subtotal (C)			64.34		63.60
Variable cost (A+B+C=D)			2,833.94		2,801.55
IV – Depreciation					
11 – Depreciation of facilities*			520.68		520.68
Subtotal (E)			520.68		520.68
V – Other fixed costs					
12 – Maintenance of facilities (1% per year)			21.69		21.69
Subtotal (F)			21.69		21.69
Fixed cost (E+F=G)			542.37		542.37
Operational cost (D+G=H)			3,376.31		3,343.92
VI – Income from factors					
13 – Remuneration on fixed capital (6% per year)			130.14		130.14
14 – Rental (R$ 3,000.00 ha^{-1} per year)			978.08		978.08
Subtotal (I)			1,108.22		1,108.22
Total costs (H+I=J)			Summer		Winter
240 kg ha^{-1} N			4,484.53		4,452.14
160 kg ha^{-1} N			4,234.45		4,256.32
80 kg ha^{-1} N			3,975.20		3,976.22
0 kg ha^{-1} N			3,445.88		3,644.59

*10,000 m of low-density polyethylene drip tape, with emitters spaced 0.20 m and a nominal diameter of 16 mm (useful life = 2 years; value of the new good = R$ 0.27 m^{-1}); PVC pipes and connections (useful life = 16 years, value of the new good = R$ 3,952.80 ha^{-1}).

The importance of this information is that it assists the farmer in decision-making regarding the rotation planning and/or succession of crops in irrigated areas, and the need to amortize the investment since a longer cultivation cycle will extend the term for the remuneration of the activity. A significant number of studies on the economic analysis of corn cultivation, however, have not described the income of factors (remuneration over fixed capital and lease) in the production costs (Kaneko et al., 2010; Garcia et al., 2012; Souza et al., 2012; Kaneko et al., 2015; Kappes, Gitti, Arf, Andrade, & Tarsitano, 2015; Galindo et al., 2017).

Regarding the net income and profitability index of the summer crop, Table 5 shows that the coefficients of variation of the F test were not acceptable (above 30%). In the summer crop, the profit was negative with treatments of 0 and 240 kg ha^{-1} N (Table 6). In winter, the N doses did not influence the net income and profitability index, with averages equal to R$ 2,394.29 ha^{-1} and 36.52%, respectively, and with positive values regardless of dose (Table 6).

Table 5. Summary of individual variance analysis (F values) for the net income (NI, R$ ha^{-1}) and profitability index (PI, %) of dry corn grain fertigated with N doses in summer and winter crops.

Sources of variation	DF	F values			
		Summer		Winter	
		NI	PI	NI	PI
Blocks	3	1.06 ns	0.90 ns	0.49 ns	0.56 ns
Doses	3	4.07*	3.22 ns	1.74 ns	2.11 ns
CV (%)		383.83	-623.08	24.56	15.16
		Means			
		231.67	-5.62	2,394.29	36.52

ns – not significant at 5% probability using the F test; * – significant at 5% probability using the F test, DF – degrees of freedom, CV – coefficient of variation.

Table 6. Mean values of grain yield (GY), gross income (GI), total costs (TCs), net income (NI), rate of return (RR), and profitability index (PI) in the production of 1 ha of corn for dry grain, fertigated with doses of N in two crop seasons.

N Doses kg ha^{-1}	Crop seasons	GY kg ha^{-1}	GI	TCs	NI	RR	PI %
			--------------R$ ha^{-1}--------------				
0	Summer	2,317.49	2,549.24	3,445.88	-896.64	0.74	-50.70
	Winter	5,248.37	5,773.20	3,644.59	2,128.61	1.58	36.43
80	Summer	4,696.34	5,165.98	3,975.20	1,190.78	1.30	20.96
	Winter	6,064.74	6,671.21	3,976.22	2,694.99	1.68	39.98
160	Summer	4,429.14	4,872.05	4,234.45	637,60	1.15	8.74
	Winter	6,376.23	7,013.86	4,256.32	2,757.54	1.65	38.77
240	Summer	4,072.23	4,479.45	4,484.53	-5.08	1.00	-1.47
	Winter	5,861.95	6,448.14	4,452.14	1,996.00	1.45	30.91

Galindo et al. (2017) achieved positive profits in the crop year 2013/14, but negative in the 2014/15 harvest. Thus, it justifies the different functions of the meteorological factors in the growing seasons (high temperatures and low precipitation), even with irrigation, and emphases that corn productivity is influenced by various meteorological factors, such as adequate water supply.

According to Table 6, in the summer and winter crops, the net income and profitability index were higher when using 80 kg ha^{-1} N. In the winter crop, even without N fertilization in the cover, there was high productivity with the low financial cost (R$ 2,128.61 ha^{-1} and 36.43%). In winter, beneficial weather conditions (Figure 1) and higher natural fertility of the soil (Table 1) achieved the corn requirements for high productivity expression (5,228.37 kg ha^{-1}), even without fertilization with NPK. Similar results were obtained by Kaneko et al. (2015), where the profitability index ranged from 39.23 to 42.36% in two corn crops (2011/12), in the absence of N-ureacovering. However, there was fertilization of the planting, with 32 and 24 kg ha^{-1} N used in the first and second crops, respectively, in the formula NPK 08-28-16.

For the rate of return (i.e., the relationship between gross income and total production costs), there were isolated effects of N dose and crop season (Table 2), with a maximum value of R$ 1.48 per invested real, when the corn plants were fertigated with 66.49 kg ha^{-1} N (Figure 2D). In Table 3, the rate of return obtained for the winter crop (R$ 1.59) was higher than for the summer crop (R$ 1.04).

In presenting the cost-benefit of the activity, the rate of return expresses information about gross income and its relation to the expenses, allowing the rural producer to choose more cost-effective cultural practices that often promote a lower environmental impact. The economic results show that a reduction in N fertilizer use in corn crops results in lower capital investment, and it is associated with higher economic returns and lower leaching risks (Wang, Li, & Li, 2014) and volatilization of NH_3 (Tasca et al., 2011). In irrigated corn crops and under fertilization with 0 to 200 kg ha^{-1} N, Souza et al. (2012) also obtained maximum rates of return with reduced dose (50 kg ha^{-1} N, with urea covering), giving R$ 1.37 in the 2007/08 crop and R$ 1.08 in 2008/09.

Conclusion

Regardless of the crop season, the dry grain yield (5,441.03 kg ha^{-1}) was highest when the corn was fertigated with a dose of 104.05 kg ha^{-1} N. The highest net incomes were observed at 80 kg ha^{-1} N in summer (R$ 1,190.78 ha^{-1}) and 160 kg ha^{-1} N in winter (R$ 2,757.54 ha^{-1}).

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