Acta Scientiarum
http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v42i1.42458

Profitability of maize for silage fertigated with nitrogen doses in different crops in a semiarid region of Brazil

Ênio Gomes Flôr Souza[1,2*], Ellen Abreu da Cruz[1,3], Michelangelo de Oliveira Silva[1], Fabiano Barbosa de Souza Prates[1], Aurélio Paes Barros Júnior[2] and Francisco Bezerra Neto[2]

[1]Curso de Engenharia Agronômica, Instituto Federal de Educação, Ciência e Tecnologia de Alagoas, Av. Sergipe, s/n, 57460-000, Piranhas, Alagoas, Brazil. [2]Programa de Pós-Graduação em Fitotecnia, Universidade Federal Rural do Semi-Árido, Mossoró, Rio Grande do Norte, Brazil. [3]Programa de Pós-Graduação em Engenharia Industrial, Universidade Federal da Bahia, Salvador, Bahia, Brazil. *Author for correspondence. E-mail: enio.souza@ifal.edu.br

ABSTRACT. The objective of this work was to determine the adequate nitrogen (N) dose via fertigation associated with the maximum economic production of maize for silage, in two agricultural crops (summer and winter), in the municipality of Canindé de São Francisco-SE, Brazil. The experimental design was in randomized blocks, with four replicates. The treatments consisted of four doses of N (0, 80, 160, and 240 kg ha^{-1}) using urea. The cultivar planted was the hybrid Bt Feroz. The evaluated characteristics were as follows: shoot fresh and dry mass productivity, gross and net incomes, the rate of return and net profit margin. There was an interaction between N doses and agricultural crops for all variables. Higher agroeconomic efficiency in the production of maize for silage was obtained from the winter harvest. In the summer crop, the rate of return (1.82) and the net profit margin (45.52%) were highest when the plants were fertigated with 56.04 and 58.92 kg ha^{-1} of N, respectively. In winter, the yields of fresh mass, gross and net incomes increased linearly with increasing doses of N, with a profit proportional to the invested capital since nitrogen fertigation did not influence the rate of return (2.24) and the net profit margin (55.22%).

Keywords: *Zea mays* L.; forage storage; meteorological conditions; production costs; economic dose.

Received on April 19, 2018.
Accepted on July 5, 2018.

Introduction

The conservation of maize (*Zea mays* L.) from silage guarantees the achievement of an excellent feed for ruminants. Maize is a strategic species for meat and milk production, with products increasingly demanded by the world population (Yildiz, 2016). In the semiarid region of Brazil, rainfed maize crops, either for grain or for silage, are a challenge for farmers since there is usually low rainfall and irregular rains, where the occurrence of a water deficit can drastically reduce crop yield and, consequently, forage availability in the dry season (Santos et al., 2010). In semiarid areas, there is water available for irrigation. This water may reduce crop risks during drought periods and allow continuous use of the cultivated area.

In this context, the irrigated production of maize for silage has been growing, mainly seeking to meet the demands of cattle raising farmers in the rainfed areas, who have had agricultural crops and/or pastures damaged by recurrent drought. Generally, maize silage is stored in plastic bags of 30 to 50 kg in size, facilitating the transport of food between different locations. With the growing silage trade, farmers have invested in the use of drip irrigation and the use of soluble fertilizers via fertigation; however, information on the management of this type of fertilization in the cultivation of maize for silage is scarce in the literature (Gheysari, Mirlatifi, Bannayan, Homaee, & Hoogenboom, 2009a; Abbasi, Abbasi, Liaghat, & Alizadeh, 2011).

Among the nutrients demanded by maize, nitrogen (N) is the most important (Von Pinho, Borges, Pereira, & Reis, 2009), and its application affects the productivity and quality of this forage (Islam, Garcia, & Horadagoda, 2012; Fallah & Neisani, 2017). The lack of knowledge implied in the application of low or high doses of N promotes adverse effects on the yield of the crop, being fundamental to good nutrient management, in order to avoid losses by volatilization of ammonia (NH_3) or nitrate leaching (NO^-_3) to the water table (Gheysari, Mirlatifi, Homaee, Asadi, & Hoogenboom, 2009b; Wang, Li, & Li, 2014). Thus, the use of an ideal dose of N for maize crop needs can improve its efficiency of use (Cerný et al., 2012) and reduce the costs of nitrogen fertilizers (Neumann et al., 2005).

The use of nitrogen fertilizers in maize fertigation, especially with drip irrigation, can reduce fertilizer and labor costs, facilitating the splitting and reduction of N losses by NH_3 volatilization and leaching to NO^-_3 (Abbasi et al., 2011; He, Dukes, Hochmuth, Jones, & Graham, 2012). The maximum maize yields are generally higher than the economic ones (Neumann et al., 2005) since they are subject to the nutrient prices and other production costs. Several studies point out that one of the largest expenditures on maize for silage is fertilizer, recommending the search for strategies to reduce expenditures on these inputs (Tuvanç, & Dagdemir, 2009; Daniel, Zopollatto, & Nussio, 2011; Yildiz, 2016, Rabelo, Souza, & Oliveira, 2017; Santos, Moraes, & Nussio, 2017).

The objective of this study was to determine the adequate N dose for fertigated maize crops associated with the maximum economic production of silage, in two agricultural crops (summer and winter), in the municipality of Canindé de São Francisco, in the state of Sergipe, in the Brazilian semiarid region.

Material and methods

The experiments were conducted in the field using two agricultural crops. The first one was planted in the summer (January to April) and the second in the winter (June to September) of 2016 on a property located within an irrigated perimeter supplied with water of the São Francisco River, in the municipality of Canindé de São Francisco-SE, which is located in the Brazilian semiarid region (9°40'27"S, 37°45'45"W, 194 m altitude). The climate of the region, according to the classification of Köppen, is a Bssh', very hot, semiarid, steppe type, with a rainy season centered in the months of April, May and June (Sousa et al., 2010). The average meteorological data of the experiment period were obtained from an automatic meteorological station installed six kilometers from the experiment area (Figure 1).

The soil of the experimental area was classified as *Luvissolo Crômico* (Santos et al., 2013), with wavy topography and clayey texture – granulometric values of 478.20 g kg^{-1} of sand, 98.00 g kg^{-1} of silt and 423.80 g kg^{-1} of clay (Donagema, Campos, Calderano, Teixeira, & Viana, 2011). The chemical characteristics (Silva, 2009) described in Table 1.

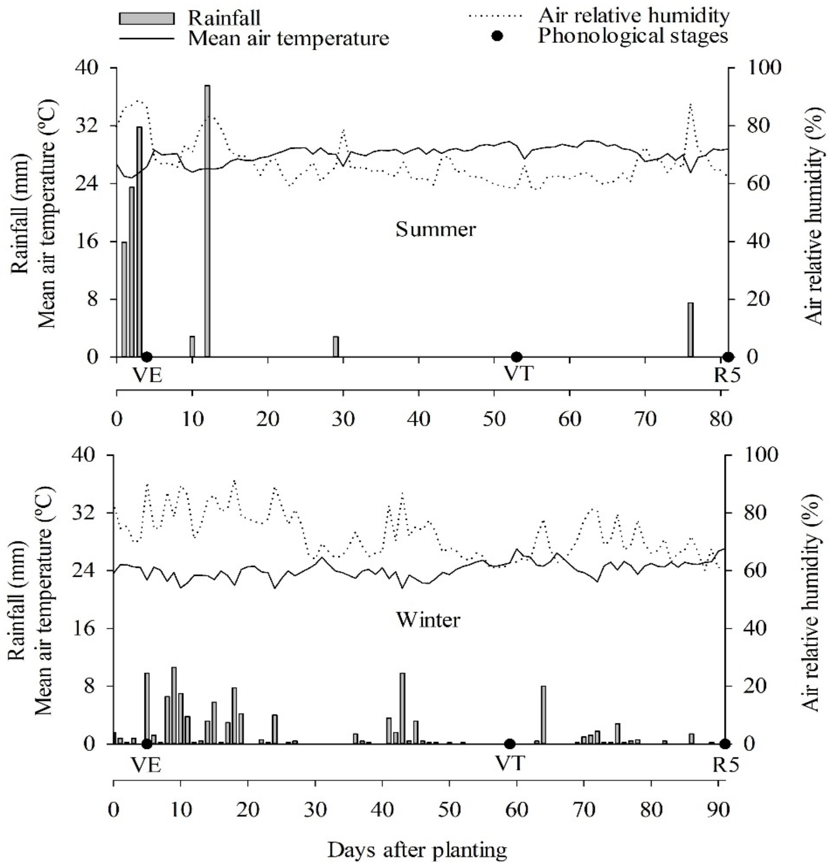

Figure 1. Rainfall, mean air temperature, relative air humidity and an indication of the stages of development (VE: emergence; VT: tasseling; R5: farinaceous grains) of maize for silage, in the summer and winter crops of 2016, in Canindé de São Francisco-Sergipe, Brazil.

Table 1. Soil chemical analyses of the experimental area (depth 0 to 20 cm) before planting maize in the summer and winter crops of 2016, in Canindé de São Francisco-Sergipe, Brazil.

Seasons	P mg dm^{-3}	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H+Al
		-----------------------------		$cmol_c\ dm^{-3}$			-----------------------------
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
Seasons	**pH H_2O**	**EC* dS m^{-1}**	**OM* g kg^{-1}**	**Cu**	**Fe**	**Mn**	**Zn**
				----------------	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.

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

Each plot consisted of six lines of 6.0 m in length, spaced at 1.0 m apart, totaling an area of 36.0 m^2 (6.0 x 6.0 m). The four central lines, discarding a plant at each end, were considered the useful area of the plot (22.4 m^2).

Soil preparation was performed with two cross harrowings at an average depth of 20 cm. Then, the parcels were demarcated and manual sowing of the hybrid maize Bt Feroz (Syngenta®) in the spacing of 1.0 m x 0.2 m (50 thousand plants ha^{-1}) was performed, with plantings carried out on 01/20/2016 (summer) and 06/17/2016 (winter). This cultivar is a double hybrid, early cycle plant with hard and orange grains and is intended for grain production and silage.

The experiment had a drip-irrigated irrigation system with a spacing of 0.2 m between emitters and an average flow of 1.2 L h^{-1}, the water slide being obtained by the water balance, considering precipitation and the evapotranspiration (Santos, Espínola Sobrinho, Medeiros, Moura, & Nunes, 2014). Approximately 122 mm of rainfall accumulated in the summer and 113 mm in the winter, while the gross irrigation slide totaled 233 and 149 mm in summer and winter, respectively.

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

The harvests were performed at phenological stage R5 (farinaceous grains), which corresponded to 77 DAE (summer) and 86 DAE (winter), that is, when the plants had a mean dry mass content of between 35 and 40%. The yield of the fresh maize mass (t ha^{-1}) was estimated from the green mass of 28 plants present in the harvest area of each plot. The dry mass yield (t ha^{-1}) was determined after drying three of these plants in a forced air circulation oven at a temperature set at 65°C, until reaching a constant mass.

Economic indicators were used to evaluate the efficiency of treatments. The costs of production of one hectare of maize for ensiling in 40 kg bags were estimated, which were calculated and analyzed at the end of each production process, adapting the methodology proposed by Conab (2010). No losses were recorded during the harvesting, storage and removal of silage.

The gross income (GI, US$ ha^{-1}) was measured as the value of maize silage in the months of April (US$ 98.87 per ton) and September 2016 (US$ 112.99 per ton), multiplied by the fresh mass yield of the plot (any losses that occurred during the harvesting, storage and removal of the ensiled material were not recorded). Between January and September 2018, the US dollar was quoted on average at R$ 3.54.

The net income (NI, US$ ha^{-1}) was calculated by the difference between the gross income (GI) and the total costs (TC, US$ ha^{-1}) involved in obtaining the fresh mass productivity. The rate of return (RR) was determined from the relation between GI and TC, corresponding to the capital obtained for each dollar applied in the cultivation of maize for silage. The net profit margin (NPM) consisted of the ratio between NI and GI, expressed as a percentage (Beltrão, Nóbrega, Azevedo, & Vieira, 1984; Martin, Serra, Oliveira, Ângelo, & Okawa, 1998).

For each crop season (summer and winter), analysis of variance of the characteristics was performed using the Sisvar application, version 5.6 (Ferreira, 2011). Subsequently, a joint analysis was performed for the characteristics with a homogeneity of variances between the harvests. The regression equations for the N doses were chosen based on the following criteria: biological explanation of the phenomenon, simplicity of the equation and test of the parameters of the equation by Student's t test, at 5% probability.

Results and discussion

The joint analysis of the experiments showed an interaction between N doses and crop seasons for all characteristics evaluated in the maize production for silage (Table 2).

In summer, the productivity of fresh maize mass for silage increased up to 26.92 t ha^{-1} at a dose of 87.62 kg ha^{-1} N and then decreased (Figure 2A). The winter crop increased in green mass from 28.54 t ha^{-1} (absence of nitrogen fertilization) to 38.14 t ha^{-1} (240 kg ha^{-1} of N), that is, an increase of 40 kg of forage per kg of N employed via fertigation. For all N doses studied, the winter crop yielded higher productivity than the summer maize crops for silage (Table 3). In relation to dry matter yield, the results showed that there were larger accumulations of phytomass at doses of 80 kg ha^{-1} of N (summer) and 240 kg ha^{-1} of N (winter), giving values of 10.91 and 13.54 t ha^{-1}, respectively (Figure 2B and Table 3).

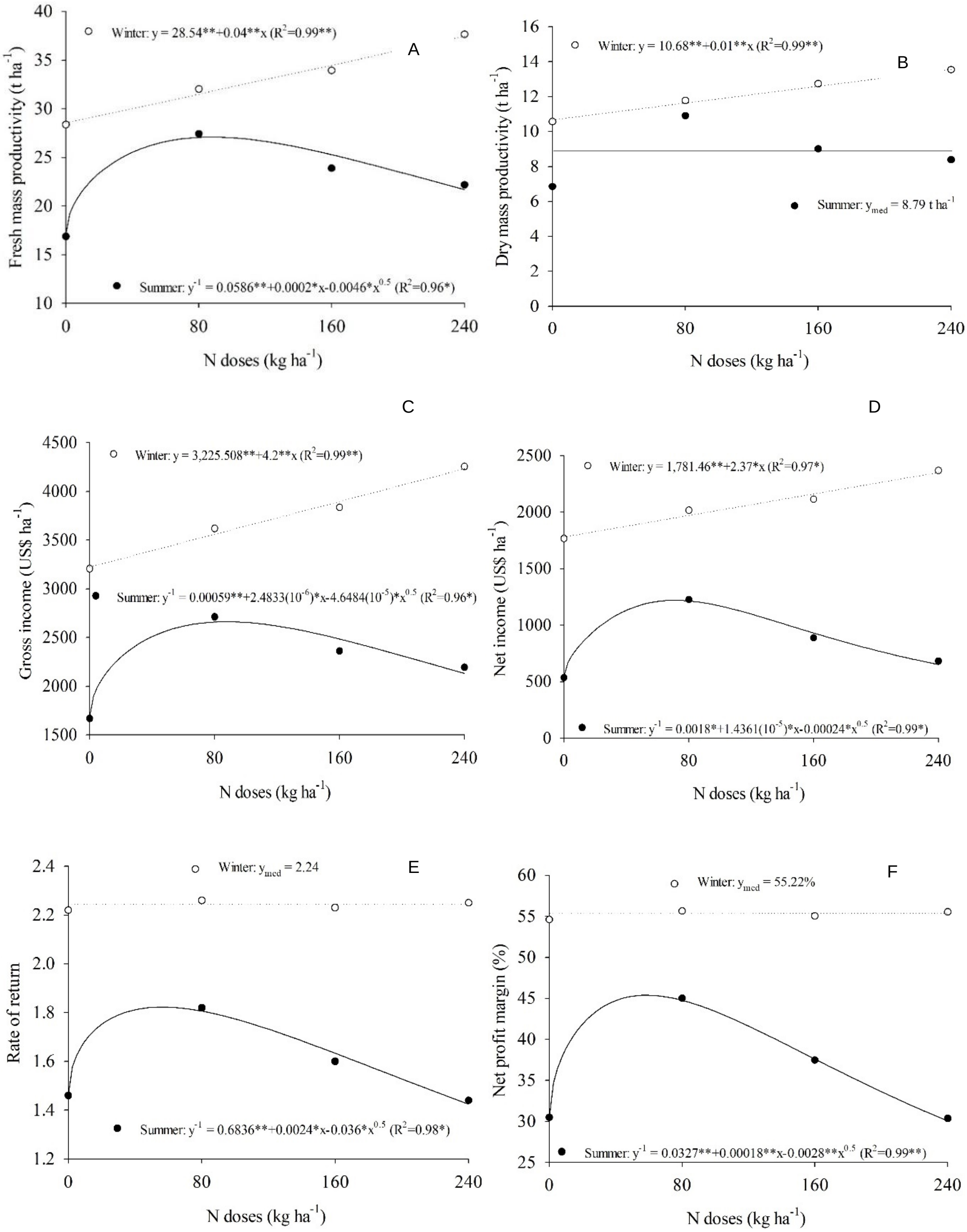

Figure 2. Fresh (A) and dry (B) mass productivity, gross income (C), net income (D), rate of return (E) and net profit margin (F) of maize for silage, fertigated with nitrogen doses in two agricultural crops in the Brazilian semiarid region.

Table 2. Summary of the joint analysis of variance (F values) for fresh (FMP) and dry mass productivity (DMP), gross income (GI), net income (NI), the rate of return (RR) and net profit margin (NPM) of maize for silage, fertigated with doses of nitrogen in two agricultural crops in the Brazilian semiarid region.

Sources of Variation	df	F values					
		FMP	DMP	GI	NI	RR	NPM
Blocks (Seasons)	6	1.11 ns	0.64 ns	1.08 ns	1.07 ns	1.31 ns	1.36 ns
Doses (D)	3	10.99**	9.22**	10.73*	5.87**	5.01*	5.64**
Seasons (S)	1	98.58**	73.56**	178.79**	210.52**	248.34**	162.28**
D x S	3	4.60*	5.23**	4.46*	4.64*	4.04*	4.91*
CV (%)		10.67	10.60	10.61	16.59	6.16	9.45
Overall mean		27.80	10.47	2,981.72	1,449.56	1.91	45.53

ns, ** and *: not significant, significant at 1% and 5% probability, by the F test, respectively.

Table 3. Mean values of fresh and dry mass productivities, gross and net incomes, the rate of return and net profit margin of the interaction between agricultural crops and nitrogen doses via fertigation in maize production for silage in the Brazilian semiarid region.

Seasons	N Doses (kg ha^{-1})			
	0	80	160	240
	Fresh mass productivity (t ha^{-1})			
Summer	16.87	27.43	23.89	22.18
Winter	28.38	32.04	33.95	37.66
	Dry mass productivity (t ha^{-1})			
Summer	6.85	10.91	9.01	8.39
Winter	10.57	11.78	12.74	13.54
	Gross income (US$ ha^{-1})			
Summer	1,667.94	2,712.50	2,361.76	2,192.94
Winter	3,207.06	3,620.06	3,836.16	4,255.37
	Net income (US$ ha^{-1})			
Summer	534.37	1,227.52	887.45	682.09
Winter	1,767.21	2,016.49	2,113.65	2,367.72
	Rate of return			
Summer	1.46	1.82	1.60	1.44
Winter	2.22	2.26	2.23	2.25
	Net profit margin (%)			
Summer	30.51	45.03	37.48	30.36
Winter	54.61	55.64	55.06	55.55

In the summer crop, the reduction in productivity from the dose of 80 kg ha^{-1} of N may have been caused by the low recovery efficiencies and the utilization of N applied (Menezes et al., 2013). According to Figure 1, conditions of high temperature (averages above 28°C) and low relative humidity of the air (averages lower than 67%) were observed in the summer crop, which may intensify the volatilization process of NH_3 from the application of urea (Tasca, Ernani, Rogeri, Gatiboni, & Cassol, 2011). In addition, the nitrogen fertilizer also decreases its efficiency when used in high doses and in soils with a pH above 6.5 (Ma et al., 2010; Tasca et al., 2011), as was the case in this experiment.

On the other hand, in the winter, forage productivity increased linearly with increasing doses of N via fertigation, probably due to meteorological conditions more favorable to nitrogen fertilization and maize development, with temperatures below 24°C and a better distribution of rainfall (Figure 1). Linear increases in maize production for silage have been reported up to doses of 165.4 (Martins et al., 2014) and 163 kg ha^{-1} N (Neumann et al., 2005), with yields estimated at 44.05 and 55.23 t ha^{-1}, respectively. It should be noted that the average temperatures in the regions of these surveys were lower than 21°C.

In relation to plant physiology, the highest summer air temperatures (Figure 1) contributed to accelerating the maize cycle (81 days from planting to harvest) when compared to the winter crop (91 days), thus influencing a decrease in crop productivity (Table 3). In evaluating the response of maize to silage at two growing seasons in Iran, Gheysari et al. (2009a) observed that the crop cycle ranged from 87 (year 2004) to 100 days (year 2003), justifying this difference by the occurrence of lower average temperatures in 2003 (22.9°C from planting to VT and 17.8°C from VT to R5). However, due to this reduction in air temperature in 2003, especially at the end of the cycle (mean of 13.8°C), the authors reported fresh mass productivity lower than the 2004 harvest.

At 85 days after planting, Santos et al. (2010) harvested six maize varieties in the farinaceous-hard stage that were cultivated between April and August in the municipality of Petrolina, a semiarid region of Pernambuco. The mean temperatures varied between 24.1 and 26.9°C and the average productivities were 33.80 t ha^{-1} (fresh mass) and 13.7 t ha^{-1} (dry mass). In the city of Crato, a semiarid region of Ceará, Soares, Pinto, Camara, and Santana (2017) also reached an average yield of 33.44 t ha^{-1} of Bt Feroz maize green forage at 90 days after planting and under average temperatures of 24.6 to 26.5°C. Therefore, both papers presented data similar to those observed in the winter season in Canindé de São Francisco-SE.

Based on the results of these studies, it is possible that the productive potential of maize for silage varies greatly with the cultivation conditions (meteorology, nitrogen fertilization management, cultivars, etc.). Although the application of high doses of N can cause high yields of fresh mass, especially in winter, there is the possibility of not being economically viable. In this sense, it was necessary to perform an economic analysis of maize production for silage under the experimental conditions of the present work.

For the gross income, the N doses estimated at 87.60 kg ha^{-1} (summer) and 240.00 kg ha^{-1} (winter) reached maximum values of US$ 2,662.27 ha^{-1} and US$ 4,233.81 ha^{-1}, respectively (Figure 2C). Winter planting was more favorable to gross income (Table 3) due to the higher productivity of fresh mass and product remuneration, which increased by an average of 48.98 and 14.28%, respectively, in relation to the results of the summer crop. In the autumn-winter of 2016, the maize planting season in Sergipe, rainfed crops obtained low productivities due to the scarcity of rainfall in this period (CONAB, 2017), causing a lack of forage for animals in the off-season and increasing the value of the silage.

Table 4 shows the components of total costs in the production of one hectare of maize for silage as a function of N doses via fertigation and agricultural crops. The total costs were estimated as US$ 1,133.56 ha^{-1} (absence of nitrogen fertilization); US$ 1,484.85 ha^{-1} (80 kg ha^{-1} of N); US$ 1,474.37 ha^{-1} (160 kg ha^{-1} of N) and US$ 1,510.87 ha^{-1} (240 kg ha^{-1} of N) for the summer harvest; and US$ 1,439.78 ha^{-1} (absence of nitrogen fertilization); US$ 1,603.64 ha^{-1} (80 kg ha^{-1} of N); US$ 1,722.51 ha^{-1} (160 kg ha^{-1} of N) and US$ 1,887.64 ha^{-1} (240 kg ha^{-1} of N) for the winter harvest.

In summer, variable, fixed and factor income (opportunity) costs for the production of one hectare of maize for silage corresponded, respectively, to US$ 1,083.53 ha^{-1} (average of treatments), US$ 104.29 ha^{-1} and US$ 213.09 ha^{-1}. In the winter harvest, the specific costs were, on average, US$ 1,306.83 ha^{-1} (variable), US$ 117.16 ha^{-1} (fixed) and US$ 239.39 ha^{-1} (factor income).

After accounting for the cost of producing maize silage in the 2015/2016 harvest, Santos et al. (2017) obtained total costs of US$ 1,301.31 ha^{-1} in São Paulo and US$ 1,389.96 ha^{-1} in Minas Gerais (US$ quoted on average at R$ 3.82 between October 2015 and April 2016), 85.47% of which refers to variable costs, 5.98% to fixed cost (depreciation) and 8.55% to opportunity cost (lease). These values are relatively similar to the production of irrigated maize in semiarid regions, although they differ in relation to the cultivation system in the Southeast (rainfed planting and use of outsourced sowing mechanization to silage compaction).

On the other hand, Yildiz (2016) observed that 40.10% of the total costs of maize cultivation for silage were related to variable expenses (mainly fertilizers), 35.20% for fixed costs (mainly depreciation/maintenance of own machinery) and 24.70% for land leasing in Turkey. In another study conducted in this country, Tuvanç and Dagdemir (2009) reported variable costs of 78.58% of total maize silage production costs since the rental of machinery and implements for harvesting was considered a variable expense. Therefore, in the economic analysis of maize cultivation for silage, the cost-benefit analysis should be evaluated between the use of machinery owned or the contracting of third-party services.

According to Table 4, the most important expenses for the cost of maize for silage were related to the inputs (seeds, fertilizers, pesticides, bags and clips for storage of forage), which represented on average 46.87% of this component of the production costs, while the harvesting operations corresponded to 34.31% (summer) and 40.87% (winter). Similar results were found by Daniel et al. (2011) and Santos et al. (2017), whose results highlight that these two components should be prioritized in decisions aimed at reducing maize silage production costs, although strategies to reduce all other expenses should also be analyzed.

In relation to the total costs, the expenses with nitrogen fertilization corresponded to 5.07% (80 kg ha^{-1}), 10.22% (160 kg ha^{-1}) and 14.96% (240 kg ha^{-1}) in summer crop and 4.07% (80 kg ha^{-1}), 7.58% (160 kg ha^{-1}) and 10.38% (240 kg ha^{-1}) in the winter season (Table 4). The main reason for reducing this relative cost between the seasons was the decrease in the urea price from US$ 0.42 kg^{-1} in the summer crop to US$ 0.37 kg^{-1} in winter cultivation, in addition to the increase in expenses with silage (forage harvesting and bagging). This information emphasizes the importance of conducting market research to obtain a lower cost with the main item of the inputs (fertilizers), seeking the anticipated purchase, avoiding problems of product delivery and increasing the unit cost (supply and demand curve).

Table 4. Mean values of the variable, fixed, operational and total costs in the production of one hectare of maize for silage, fertigated with doses of nitrogen in two agricultural crops in the Brazilian semiarid region.

Discrimination		Summer		Winter	
I – Expenditure on crop costs	Unity	Amount	US$	Amount	US$
1 – Machine rental					
Tractor with plow grid	h	2.00	62.15	2.00	62.15
Tractor-mounted forage harvester	h	5.55	187.97	9.42	319.15
2 – Labor					
Distribution of drip tapes	daily	2.00	22.60	2.00	22.60
Manual planting with rattle	daily	1.00	11.30	1.00	11.30
Irrigation or fertigation	h	38.83	54.84	24.83	35.07
Spraying (herbicide)	daily	1.00	11.30	1.00	11.30
Dismantling of the irrigation system	daily	2.00	22.60	2.00	22.60
Bagging of fodder	daily	11.62	131.28	19.73	222.90
3 – Seeds					
Hybrid maize Bt Feroz	kg	15.00	117.91	15.00	110.56
4 – Fertilizers					
Urea (45% N) - 240 kg ha^{-1} of N	kg	533.34	225.99	533.34	195.86
Zinc sulphate (21% Zn)	kg	9.53	9.80	9.53	9.80
5 – Pesticides					
Atrazine (herbicide)	L	4.00	31.64	4.00	28.25
6 – Others					
Soil analysis	unity	1.00	14.69	1.00	16.67
Silage bag (40 kg)	unity	554.50	203.63	941.50	345.75
Silage bag clamp	unity	554.50	10.65	941.50	18.08
Subtotal (A)			1,118.35		1,432.04
II – Other expenses					
7 – Administrative expenses (3% of the cost of the crop)			33.55		42.96
8 – Technical assistance (2% of the cost of the crop)			22.37		28.64
9 – Rural territorial tax (US$ 2.82 year^{-1})			0.63		0.70
Subtotal (B)			56.55		72.30
III – Financial expenses					
10 – Interest on financing (7.49% year^{-1})			18.59		26.74
Subtotal (C)			18.59		26.74
Variable cost (A+B+C=D)			1,193.49		1,531.08
IV – Depreciation					
11 – Depreciation of facilities*			100.12		112.48
Subtotal (E)			100.12		112.48
V – Other fixed costs					
12 – Maintenance of facilities (1% year^{-1})			4.17		4.68
Subtotal (F)			4.17		4.68
Fixed cost (E+F=G)			104.29		117.16
Operational cost (D+G=H)			1,297.78		1,648.24
VI – Income from factors					
13 – Remuneration on fixed capital (6% year^{-1})			25.02		28.11
14 – Rent (US$ 847.46 ha^{-1} year^{-1})			188.07		211.29
Subtotal (I)			213.09		239.40
Total cost (H+I=J)			Summer		Winter
240 kg ha^{-1} of N			1,510.87		1,887.64
160 kg ha^{-1} of N			1,474.37		1,722.51
80 kg ha^{-1} of N			1,484.85		1,603.64
0 kg ha^{-1} of N			1,133.56		1,439.78

*10,000 m of low-density polyethylene drip tapes with emitters spaced 0.20 m and nominal diameter 16 mm (useful life = 2 years, well new value = US$ 0.08 m^{-1}); pipes and connections in PVC (lifespan = 16 years, value of the new good = US$ 1,116.61 ha^{-1}).

Analyzing the costs of maize silage production in Montes Claros-MG (harvest 2016), Rabelo et al. (2017) reported that urea (350 kg ha^{-1}) had a 17.27% participation in total expenditure (US$ 1,106.04 ha^{-1} - US$ quoted on average at R$ 3.48 in 2016), in that this nitrogen fertilizer and other fertilizers accounted for US$ 531.61 ha^{-1}

(48.06%). Possibly, the soil in question had fertility far below that of the *Luvissolo* de Canindé de São Francisco-SE, demanding a higher fertilization in order to guarantee the expected productivity of 40 t ha^{-1}.

In general, the costs of renting machinery for tillage and forage harvest were the most onerous for the farmer (Table 4). This cost averaged 18.11% (summer) and 20.58% (winter) of the total costs. This increase in winter expenditures was justified by the increase in fresh maize mass yield (Table 3), thus prolonging the harvest time. As the services with machinery were outsourced, there was no incidence of tractor-driver salary expenses and depreciation/maintenance of machines and implements.

With expenses similar for the rental of machinery, labor also showed a significant increase in production costs (16.81 to 19.63% of total expenses), mainly because the manual bagging process was considered (Table 4). The practice of placing silage in plastic bags has been prominent in recent years in the Northeast region, mainly due to the long periods of drought, which encouraged farmers to conserve green fodder in a way that facilitates transportation between the producing and consuming regions of this animal food.

Another important point in the cost of the crop was the soil analysis, which represented only 1.43% of the total costs, i.e., a very small expense in relation to the potential agronomic, economic and environmental benefits derived from the collection of this information for recommendations for the use of correctives and fertilizers.

The depreciation of the irrigation system also burdened the total costs since it was considered to have a two-year useful life due to the drip tapes (Cunha, Pordeus, Silva Júnior, Pontes, & Azevedo, 2012). It is fundamental that the farmer save US$ 100.12 ha^{-1} in the summer and US$ 112.48 ha^{-1} in winter in order to maximize the amount necessary to replenish this material at the appropriate time, avoiding problems such as clogging of emitters or leaks, the consequence of which is the low efficiency water and nutrient applications to the crop.

The opportunity cost related to the rental of the property was also significant, as it corresponded to US$ 188.07 ha^{-1} and US$ 211.29 ha^{-1}, respectively, in summer and winter crops (Table 4). This expenditure was higher in the winter because the maize cycle lasted from 81 (summer) to 91 days (winter) from the planting to the forage harvest at the ideal silage point.

By subtracting the production costs from the gross income, the profit of the investment is calculated. In the summer crop, increasing values of net income can be estimated up to a dose of 71.14 kg ha^{-1} of N (US$ 1,220.04 ha^{-1}), whereas in winter, there was a linear increase between fertigations with 0 and 240 kg ha^{-1} of N, reaching a maximum income of US$ 2,351.07 ha^{-1} (Figure 2D). Along with the fresh mass productivity and gross income, for all N doses studied, the net income for winter planting of maize for silage was significantly higher than the summer crop (Table 3).

In general, an average of US$ 62.79 per ton (summer) and US$ 50.41 per ton (winter) of forage from bagged maize were spent. When 80 kg ha^{-1} of N was applied via fertigation in the summer harvest, the cost of the ton reduced to US$ 54.13, that is, close to the winter average, which, in turn, did not vary between treatments. All costs related to the production of green mass were lower than the selling prices practiced in the region: US$ 98.87 per ton (summer) and US$ 112.99 per ton (winter), demonstrating that the net income of the activity was always positive, but most profitable in winter farming.

For maize silage production in the summer, the rate of return (1.82) and the net profit margin (45.52%) were highest when the plants were fertigated with 56.04 and 58.92 kg ha^{-1} of N, respectively (Figure 2E and 2F). On the other hand, in the winter crop, nitrogen fertilization did not influence the rate of return (average of 2.24) and the net profit margin (mean of 55.22%) since productivity and incomes (gross and net) increased linearly with increasing doses of N (Figure 2A, 2C and 2D), with profit proportional to invested capital (same cost per ton). Evaluating the seasons as a function of the N doses, it was possible to observe that the rates of return and the net profit margins obtained in the winter were higher than those found in the summer maize crop (Table 3).

At three levels of maize cultivation for silage production in Tehran, Iran, Komleh, Keyhani, Rafiee, and Sefeedpary (2011) verified averages of the rate of return and profit margin of 1.57 and 36.13% for small, medium and large farms. The authors stated that better management of inputs, such as fertilizers and seeds, could increase the cost-benefit ratio of the activity.

The rate of return and the net profit margin consisted of equations that associate production costs, gross income, and profit, thus being variables that can assist the farmer in making decisions about the need for investment capital, allowing for a similar possibility of economic return. While production costs varied little between growing seasons (Table 4), gross income was much higher in winter, as a consequence of high fresh mass productivities (Table 3). This ratio made profitability more attractive for maize production in the period of lower temperatures.

In this sense, a lower N dose would be recommended in the summer harvest (56 kg ha^{-1}), considering that the high temperatures in the period possibly reduced the nitrogen fertilization efficiency (volatilization of NH_3), in addition to having affected the productive potential of maize due to more precocious tasseling (Figure 1). Winter weather conditions favored higher N doses via fertigation, with positive responses in maize shoot development and in the profitability of silage production (Figure 2 and Table 3).

The reduction in corn productivity for silage with higher N rates in the summer reinforces the need to study conditions similar to this one (average temperatures equal to or greater than 28°C, clay soils and pH above 7.0), focusing on the effects of increasing the frequency (splitting) of fertigation, reducing the dose of N by application or the use of other nitrogen sources such as ammonium sulfate or ammonium nitrate.

Conclusion

In the summer harvest, a nitrogen dose via fertigation of 56 kg ha^{-1} promoted maximum economic efficiency in maize production for silage.

In winter, fresh mass productivity and gross and net incomes of maize for silage increased linearly with increasing doses of nitrogen and with rate of return and profitability proportional to invested capital.

The winter season allowed higher productivity and profitability for maize cultivation for silage in the semiarid region of Sergipe, Brazil.

Acknowledgements

Special thanks are due to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) by the grant of doctoral scholarship and to the Instituto Federal de Alagoas (IFAL), Campus Piranhas, for the availability of laboratory infrastructure.

References

Abbasi, Y., Abbasi, F., Liaghat, A., & Alizadeh, H. (2011). Evaluation of furrow fertigation and model validation on maize field. *Irrigation and Drainage Systems, 25*(4), 279-291. DOI: 10.1007/s10795-012-9124-7

Beltrão, N. E. M., Nóbrega, L. B., Azevedo, D. M. P., & Vieira, D. J. (1984). *Comparison between agroeconomic indicators for the evaluation of sole and intercropping systems involving cotton upland and cowpea*. Campina Grande, PB: Embrapa Algodão.

Cerný, J., Balík, J., Kulhánek, M., Vasák, F., Peklová, L., & Sedlár, O. (2012). The effect of mineral N fertiliser and sewage sludge on yield and nitrogen efficiency of silage maize. *Plant Soil and Environment, 58*(2), 76-83. DOI: 10.17221/538/2011-PSE

Companhia Nacional de Abastecimento [CONAB]. (2017). *Follow-up of the Brazilian grain crop – v. 4 – crop 2016/17 – n. 12*. Brasília, DF: CONAB.

Companhia Nacional de Abastecimento [CONAB]. (2010). *Agricultural production costs: the methodology of CONAB*. Brasília, DF: CONAB.

Cunha, J. L. O., Pordeus, R. V., Silva Júnior, M. J., Pontes, F. S. T., & Azevedo, C. A. V. (2012). Economic impacts of depreciation of drip irrigation systems in agricultural production cost. *Enciclopédia Biosfera, 8*(15), 1008-1020.

Daniel, J. L. P., Zopollatto, M., & Nussio, L. G. (2011). A escolha do volumoso suplementar na dieta de ruminantes. *Revista Brasileira de Zootecnia*, *40*(supl. especial), 261-269.

Donagema, G. K., Campos, D. V. B., Calderano, S. B., Teixeira, W. G. & Viana, J. H. M. (2011). *Manual of methods of soil analysis* (2nd ed.). Rio de Janeiro, RJ: Embrapa Solos.

Fallah, S., & Neisani, S. (2017). The effects of nitrogen source on nutritive value of irrigated silage corn. *Notulae Scientia Biologicae, 9*(1), 116-123. DOI: 10.15835/nsb9110010

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia, 35*(6), 1039-1042. DOI: 10.1590/S1413-70542011000600001

Gheysari, M., Mirlatifi, S. M., Bannayan, M., Homaee, M. & Hoogenboom, G. (2009a). Interaction of water and nitrogen on maize grown for silage. *Agricultural Water Management, 96*(5), 809-821. DOI: 10.1016/j.agwat.2008.11.003

Gheysari, M., Mirlatifi, S. M., Homaee, M., Asadi, M. E., & Hoogenboom, G. (2009b). Nitrate leaching in a silage maize field under different irrigation and nitrogen fertilizer rates. *Agricultural Water Management, 96*(6), 946-954. DOI: 10.1016/j.agwat.2009.01.005

He, J., Dukes, M. D., Hochmuth, G. J., Jones, J. W., & Graham, W. D. (2012). Identifying irrigation and nitrogen best management practices for sweet corn production on sandy soils using CERES-Maize model. *Agricultural Water Management, 109*, 61-70. DOI: 10.1016/j.agwat.2012.02.007

Islam, M. R., Garcia, S. C., & Horadagoda, A. (2012). Effects of irrigation and rates and timing of nitrogen fertilizer on dry matter yield, proportions of plant fractions of maize and nutritive value and *in vitro* gas production characteristics of whole crop maize silage. *Animal Feed Science and Technology, 172*(3-4), 125-135. DOI: 10.1016/j.anifeedsci.2011.11.013

Komleh, S. H. P., Keyhani, A., Rafiee, S. H., & Sefeedpary, P. (2011). Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran. *Energy, 36*(5), 3335-3341. DOI: 10.1016/j.energy.2011.03.029

Ma, B. L., Wu, T. Y., Tremblay, N., Deen, W., McLaughlin, N. B., Morrison, M. J., & Stewart, G. (2010). On-farm assessment of the amount and timing of nitrogen fertilizer on ammonia volatilization. *Agronomy Journal, 102*(1), 134-144. DOI: 10.2134/agronj2009.0021

Martin, N. B., Serra, R., Oliveira, M. D. M., Ângelo, J. A., & Okawa, H. (1998). Integrated farm costs system - CUSTAGRI. *Informações Econômicas, 28*(1), 7-28.

Martins, C. M. M. R., Bermudes, R. F., Cerutti, W. G., Viegas, J., Correa, M. N., Muller, R. C., ... Santos, M. V. (2014). Morphological characteristics of maize plants in estimate the silage chemical composition. *Brazilian Journal of Veterinary Research and Animal Science, 51*(3), 233-241. DOI: 10.11606/issn.1678-4456.v51i3p233-241

Menezes, L. F. G., Ronsani, R., Pavinato, P. S., Biesek, R. R., Silva, C. E. K., Martinello, C., ... Silveira, M. F. (2013). Production, nutritional value and recovery efficiencies and nitrogen utilization of corn silage under different doses of nitrogen fertilizer. *Semina: Ciências Agrárias, 34*(3), 1353-1362. DOI: 10.5433/1679-0359.2013v34n3p1353

Neumann, M., Sandini, I. E., Lustosa, S. B. C., Ost, P. R., Romano, M. A., Falbo, M. K., & Pansera, E. R. (2005). Yield and production components of corn (*Zea mays* L.) for silage as a result of nitrogen fertilization. *Revista Brasileira de Milho e Sorgo, 4*(3), 418-427. DOI: 10.18512/1980-6477/rbms.v4n3p418-427

Rabelo, C. G., Souza, L. H., & Oliveira, F. G. (2017). Analysis of the costs of corn silage production - case study. *Caderno de Ciências Agrárias, 9*(2), 8-15.

Santos, G., Moraes, J. M. M., & Nussio, L. G. (2017). Cost and sensitivity analysis in the production of silage. *Revista iPecege, 3*(1), 39-48. DOI: 10.22167/r.ipecege.2017.1.39

Santos, H. G., Jacomine, P. K. T, Anjos, L. H. C., Oliveira, V. Á., Lumbreras, J. F., Coelho, M. R., ... Oliveira, J. B. (2013). *Brazilian system of soil classification* (3rd ed. rev. amp.). Brasília, DF: Embrapa.

Santos, R. D., Pereira, L. G. R., Neves, A. L. A., Azevêdo, J. A. G., Moraes, S. A., & Costa, C. T. F. (2010). Agronomic characteristics of maize varieties for silage production in the submédio São Francisco river valley. *Acta Scientiarum: Animal Sciences, 32*(4), 367-373. DOI: 10.4025/actascianimsci.v32i4.9299

Santos, W. O., Espínola Sobrinho, J., Medeiros, J. F., Moura, M. S. B., & Nunes, R. L. C. (2014). Crop coefficient and water requirement of green maize in Brazilian semi-arid conditions. *Irriga, 19*(4), 559-572. DOI: 10.15809/irriga.2014v19n4p559

Silva, F. C. (2009). *Manual of chemical analyzes of soils, plants and fertilizers* (2nd ed. rev. amp.). Brasília, DF: Embrapa Informação Tecnológica.

Soares, R. J. S., Pinto, A. A., Camara, F. T, & Santana, L. D. (2017). Productivity of transgenic corn green mass in the function of the population arrangement in the Cariri, CE region. *Interações, 18*(2), 117-127. DOI: 10.20435/inter.v18i2.1444

Sobral, L. F., Carvalho, H. W. L., Barreto, A. C., & Anjos, J. L. (2007). Maize. In L. F. Sobral, P. R. A. Viegas, O. J. W. Siqueira, J. L. Anjos, M. C. V. Barreto, & J. B. V. Gomes. (Ed.). *Recommendations for the use of correctives and fertilizers in the State of Sergipe* (p. 201-203). Aracaju, SE: Embrapa Tabuleiros Costeiros.

Sousa, I. F., Silva, V. P. R., Sabino, F. G., Netto, A. O. A., Silva, B. K. N., & Azevedo, P V. (2010). Reference evapotranspiration in the irrigated perimeters of the State of Sergipe. *Revista Brasileira de Engenharia Agrícola e Ambiental, 14*(6), 633-644. DOI: 10.1590/S1415-43662010000600010

Tasca, F. A., Ernani, P. R., Rogeri, D. A., Gatiboni, L. C., & Cassol, P. C. (2011). Ammonia volatilization following soil application of conventional urea or urea with urease inhibitor. *Revista Brasileira de Ciência do Solo, 35*(2), 493-502. DOI: 10.1590/S0100-06832011000200018

Tuvanç, İ. A., & Dagdemir, V. (2009). A study on determining production cost of corn silage in the Pasinler Province of Erzurum. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi, 40*(1), 61-69.

Von Pinho, R. G., Borges, I. D., Pereira, J. L. A. R., & Reis, M. C. (2009). Macronutrients absorption and dry matter accumulation in maize. *Revista Brasileira de Milho e Sorgo, 8*(2), 157-173. DOI: 10.18512/1980-6477/rbms.v8n2p157-173

Wang, Z., Li, J., & Li, Y. (2014). Effects of drip irrigation system uniformity and nitrogen applied on deep percolation and nitrate leaching during growing seasons of spring maize in semi-humid region. *Irrigation Science, 32*(3), 221-236. DOI: 10.1007/s00271-013-0425-x

Yildiz, T. (2016). Determination of total costs, labour requirements and work efficiencies in second fodder corn silage production at Bafra Town of Samsun. *Turkish Journal of Agriculture - Food Science and Technology, 4*(12), 1149-1156. DOI: 10.24925/turjaf.v4i12.1149-1156.967