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The effect of different sources of N combined with marine algae on corn plant development

Rafaella Ferreira Batista Bernardes*, Atalita Francis Cardoso, Murilo Henrique de Deus Bernardes, Regina Maria Quintão Lana

Agrarian Science Institute, Post-Graduate Program in Agronomy, Universidade Federal de Uberlândia – UFU. St. Amazonas n/n, Umuarama Campus. Build 2E. ZIP 38400-902. Uberlândia, state of Minas Gerais, Brazil

***Corresponding author: rafaellaferreiraagro@gmail.com**

Abstract

The objective of this study was to evaluate the effect of different sources and doses of N combined with marine algae on the development of corn plants. Field experiments were conducted from December 2010 to February 2012 in Uberlândia, Minas Gerais. The experimental plots were laid out in a randomized block design with sub-subdivided plots. Different nitrogen sources in the form of immediate-release and controlled-release urea were evaluated on plots; rates of 0 (control), 60, 100 and 120 kg of N ha^{-1} were evaluated on subplots; and applications with or without marine algae were evaluated on sub-subplots. The dose of marine algae corresponded to 20% of the dose of urea. The study concluded that the application of marine algae in corn did not influence the efficiency of the different nitrogen sources. However, increasing nitrogen doses resulted in higher content of foliar N, thousand-grain weight and crop yield.

Keywords: Algea; controlled release; nitrogen; productivity; *Zea mays.*
Abbreviations: Ca_calcium; Cu_copper; Fe_iron; K_potassium; Mg_magnesium; Mn_manganese; N_nitrogen; NH_3_ammonia NT_number of tubers; P_phosphorus; S_sulfur; Zn_zinc.

Introduction

Corn (*Zea mays*) has a great importance worldwide due to its extensive use in animal feed, human consumption, oil production and ethanol production, with great incentives in Europe and the United States (Pavão and Filho, 2011). Brazil currently occupies the third place in corn production, with an output of 85 million tons from the last 2014/15 harvest. According to Conab (2015), corn production from the first harvest and an area of 6.156.100 hectares reached 30.244.100 tons. Minas Gerais was the second largest producer of corn during the first crop in 2015 in Brazil, with participation of 18%.

Several factors influence the attainment of high yields in corn as: corn hybrid, soil type, fertilization, climate, cultivation practices and the presence of pests and diseases (Fancelli and Dourado Neto, 2004; Galon et al., 2010). Among nutrients supplied via fertilizer applications, N stands out with its structural function and as a constituent of organic molecular compounds such as amino acids and proteins. In addition, N is involved in several vital processes in plants such as photosynthesis, respiration, multiplication and differentiation (Malavolta, 2006). This nutrient is absorbed in large quantities and by doing so it limits crop production the most (Perin et al., 2004). The management of N fertilization is one of the most studied agricultural practices aiming to improve its efficiency in crop production (Sangoi et al., 2007). The low uptake of N by plants delivered with fertilizers is a consequence of various processes of transformation and loss of N in the soil such as immobilization, denitrification, lixiviation and volatilization. Among N transformation mechanisms in soil, NH_3 volatilization has de highest impact on low recovery of N by crops, especially when the source is urea applied on straw (Vitti et al., 2005). Among various sources of N used in corn, urea is the most popular in Brazil. This is due to its high solubility in water, a proper assimilation of hydrolysis products by plants and high content of N in the fertilizer (45% of N) (Prando et al., 2012; Vitti et al., 2007). In order to reduce N losses in soil, alternative sources of fertilizers may be used, as slow-release or controlled-release fertilizers. These fertilizers present low water solubility, which allows a gradual release of N into the soil solution for a specified period of time (Chien et al., 2009). These types of fertilizers have obvious advantages over conventional ones in various crops such as rice, vegetables and ornamental plants (Hefner and Tracy, 1991; Csizinszky, 1994), on different types of soils and with different climates and management systems. Another promising alternative to improve fertilization efficiency is the use of algae. Several studies have demonstrated the potential use of algae extracts to increase plant growth, sometimes with consequent increases in production (Bardiviesso et al., 2011). Studies have shown that the application of rock dust, molybdenum and algae extract could be beneficial to beans, increasing biological N fixation, productivity, stress tolerance, chlorophyll content and photosynthetic ability (Bertoldo et al., 2015).

Lithothamnium is a genus of calcareous marine algae cosmopolitan in the oceans (Hafle et al., 2009). It is used in various sectors of industry, such as plant nutrition and animal nutrition. The main consumer countries are: Brazil, France, England, Ireland, Holland, Italy, Germany and Japan, among others (Melo and Neto, 2003). The calcareous algae are composed of Ca and Mg carbonates containing more than 20 trace elements such as Fe, Mn, B Ni, Cu, Mo, and Se present in various amounts (Dias, 2000).

The Lithothamnium is derived from calcareous marine algae for acid soil correction. In Brazil, these deposits are found in Amazon region and south of Rio de Janeiro, a distance of about 4,000 km, with not yet known reserves . The product is removed from the seabed , the marine sediment on the continental shelf of the Espirito Santo state and stored in the factory yard for a variable period . After the first milling, it is dried in the hot air and cold micro-powder. Due to the porosity of the body seaweed, the product shows an intense activity in the soil due to the high specific surface material (Melo and Neto, 2003).

By absorbing minerals from the environment, *Lithothamnium* transform the chemicals into compounds which are easily absorbed by plants. The main function of these minerals is the formation of enzymes which act as organic catalysts of chemical exchanges in cells. *Lithothamnium* also increase pH, availability of essential nutrients, biological activity, and cation exchange capacity (CEC) of soil, as a result promoting availability and absorption of other nutrients by plants (Mendonça et al., 2006; Moreira et al., 2011).

In this context, the objective of this study was to evaluate the efficiency of different N sources at various doses in corn production.

Results and Discussion

There was no significant relationship between the immediate-release and controlled-release urea, the doses and the use of *Lithothamniumn* for all the traits assessed in this experiment.

Foliar nutrients

The treatments with different N sources and N doses in this experiment showed interaction. The evaluation of foliar N, P, K, Ca and Fe contents showed no significant differences caused by different N sources (Tables 3 and 4). However, significant differences were found in foliar levels of Cu, Mn and Zn of corn plants (Table 4). With the exception of foliar levels of S, Mg and Cu, which were less than optimal, other elements were suitable for corn according to (Faquin, 2012). The range of nutrient concentration in leaves best defines nutritional status of plants (Silva and Monteiro, 2010).

Foliar S

The content of S found in corn leaves was below the optimal level (Table 3). The equilibrium between the amounts of N and S in the soil and plants is important because it reflects nutritional status of the plants (Mattos and Monteiro, 2003). Possibly, the high doses of N used in this experiment influenced the absorption of S, thus reducing its content in leaves.

The availability of nutrients for plants is affected by various physical, chemical and biological reactions. The competition between nutrients may be synergistic, when an ion assists another one, or antagonistic when an ion absorption is impaired by the presence of another ion. There is also a non-competitive inhibition when the ions do not compete for the same site of the carrier. An example of this interaction is the effect of K^+ and Ca^{2+} cations on Mg^{2+}, which often induce deficiency in plants (Silva and Trevisam 2015; Moreira et al., 2000) (Table 3).

Foliar Cu

Low Cu content found in corn leaves may be due to its interaction with N. Cu deficiency is often a result of negative interaction with other nutrients in soil or a fertilizer. As a result, high levels of N aggravate the deficiency. Cu is strongly adsorbed to inorganic soil colloids and forms complexes with organic matter which are unavailable for plants. Another factor that interferes with the uptake of Cu is pH, since increasing pH decreases the availability of Cu cations (Giracca and Nunes, 2016).

Foliar N

According to foliar levels verified in this study, an important aspect to be considered is the responsiveness of corn to N provided with different sources, raising the concentration of N in the leaves to amounts considered sufficient for the development of plants.

Significant differences ($p < 0.05$) regarding N content in the leaves were observed as a function of N doses (Fig. 1).

Increasing N doses elevated N content in leaves, reaching maximum level of 29.79 g kg^{-1} at a dose of 120 kg h^{-1}. There was an increase in foliar N by 0.0736 g kg^{-1} per each kilogram of added urea, reaching a predictive capacity of 94% with linear relationship. This increase was observed with two evaluated sources, probably due to rainfall events during the period of this experiment at a level which promoted efficient absorption of conventional urea and reduced its volatilization. Rainwater or irrigation water can promote incorporation of urea into soil, consequently reducing the difference between N sources (urea and polymerized conventional urea) (Cantarella et al., 2008).

Similar results were observed by Valderrama et al. (2011) who, in an experiment carried out with different N sources, immediate-release and modified urea in corn, found an increase in foliar N as a result of different N doses, regardless of the sources. Furthermore, Valderrama et al. (2011) and Silva et al. (2012) did not find significant differences in foliar N content in corn plants caused by immediate-release and modified urea.

Foliar Ca and P

Regarding the amount of Ca present in corn leaves, its levels decreased as N doses increased, until the dose of 61 kg ha^{-1} of N was reached (Fig. 2). Although there was a quadratic adjustment of this characteristic, this behavior cannot be explained from a physiological point of view of plants. Usually increased N doses decrease foliar Ca levels caused by antagonism between N and Ca.

Regarding P content in leaves, differences caused by different doses were detected. The dose of 120 kg of N ha^{-1} resulted in the highest levels of foliar P (approximately 3.2 g kg^{-1}) (Fig. 3). A positive interaction between N and P has already been verified in literature (Iqbal and Iqbal, 2001). P and N interact synergistically - at appropriate doses the combined effect on plant production is better than when applied separately. Plants which depend on the fixation of atmospheric N_2 present greater need for P, increasing its absorption (Silva and Trevisam, 2015).

Table 1. Chemical soil characterization of the experimental area at depth of 0-20cm.

P	K	SO_4^-	Al	Ca	Mg	H+Al	SB	T	V	MO
--------mg dm^{-3}-----			------------------cmol$_c$ dm^{-3}------					--%--		dag kg^{-1}
9.5	34	4	0.4	0.4	0.1	4.30	0.59	4.9	12	2.6
pH H_2O	B		Cu		Fe		Mn		Zn	
	--mg dm^{-3}---------------------------									
5.2	0.12		1.2		66		1.2		0.4	

P, K = (HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) avaliable P (extrator Mehlich-1); Ca, Mg, Al, (KCl 1 mol L^{-1}); H+Al = (Buffer – SMP at pH 7.5) pH H_2O (1:2.5); SB = sum of bases; T = CEC at pH 7.0; V = base saturation; OM = organic matter OM = colorimetric method (Embrapa, 2009).

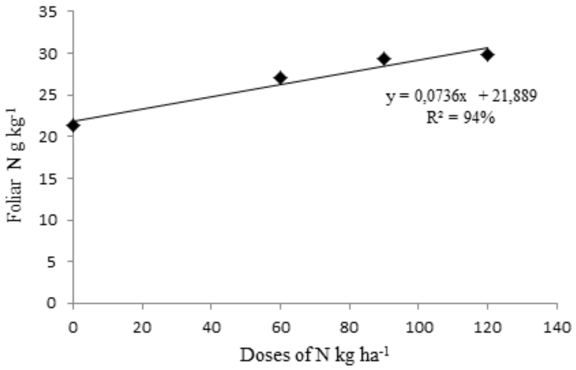

Fig 1. Foliar N in corn as a function of different doses of N, regardless of its source.

Table 2. Treatments of N and *Lithothamnium.*

Treatments (ha^{-1})	Subplots	Sub-subplots
0 kg and N	0 kg and Immediate – release urea	0 kg and *Lithothamnium*
		0 kg and *Lithothamnium*
60 kg and N	133,3 kg and Immediate – release urea	0 kg de *Lithothamnium*
		26,6 kg and *Lithothamnium*
100 kg and N	222,2 kg and Immediate – release urea	0 kg and *Lithothamnium*
		44,5 kg and *Lithothamnium*
120 kg and N	266,6 kg and Immediate – release urea	0 kg and *Lithothamnium*
		53,33 kg and *Lithothamnium*
0 kg and N	0 kg and Controlled – release urea	0 kg and *Lithothamnium*
		0 kg and *Lithothamnium*
60 kg and N	133,3 kg and Controlled – release urea	0 kg and *Lithothamnium*
		26,6 kg and *Lithothamnium*
100 kg and N	222,2 kg and Controlled – release urea	0 kg and *Lithothamnium*
		44,5 kg and *Lithothamnium*
120 kg and N	266,6 kg and Controlled – release urea	0 kg and *Lithothamnium*
		53,33 kg and *Lithothamnium*

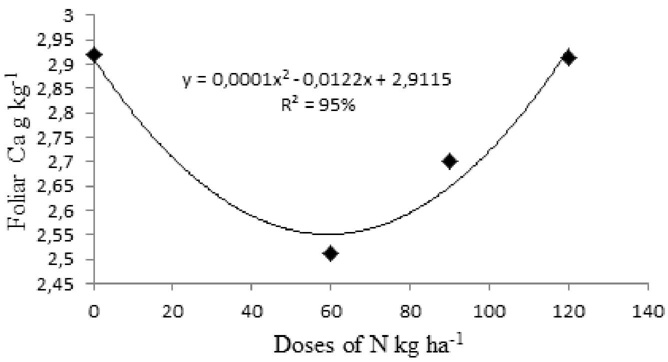

Fig 2. Foliar Ca in corn at different doses of N, regardless of the source of N.

Table 3. Corn foliar macronutrients as a function of different nitrogen sources and doses.

Urea	NO_3^-	$H_2PO_4^-$	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}
			g kg $^{-1}$			
Conventional	27.15 A	3.1 A	22.57 A	2.76 A	1.5 A	1.49A
Polymerized	28.3 A	3.1 A	22.5 A	2.85 A	1.48 A	1.46A
MAD	1.24	0.158	0.22	0.22	0.132	0.07
CV %	8.23	9.3	1.8	14.59	16.19	9.34

*Means followed by the same capital letter in the column do not differ by Tukey test at 5% probability. MAD: mean absolute deviation. CV: coefficient of variation.

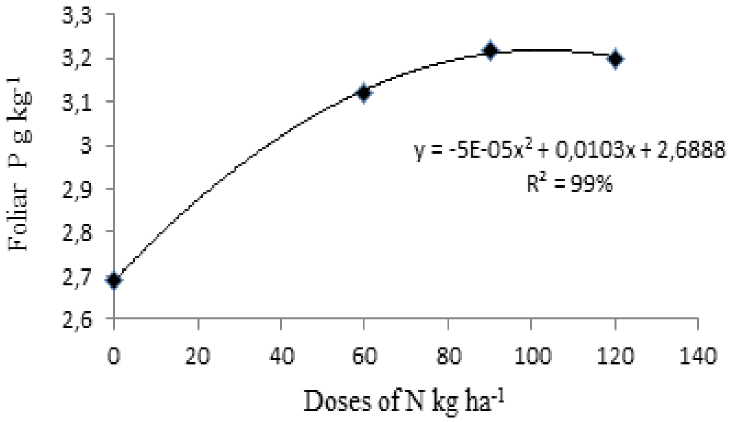

Fig 3. Foliar P (g kg^{-1}) in corn at different doses of N, regardless of N source.

Table 4. Foliar micronutrients in corn as a function of different nitrogen sources and doses.

Urea	H_3BO_3	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{++}
		mg kg $^{-1}$			
Conventional	5.4 A	15.88 A	112.4 A	77.64 B	26.4 B
Polymerized	4.82 A	12.73 B	127.29 A	91.5 A	30.38 A
MAD	0.7	1.35	44.83	4.37	1.39
CV %	24.88	17.02	69.1	9.58	9.07

*Means followed by the same capital letter in the column do not differ by Tukey test at 5% probability. MAD: mean absolute deviation. CV: coefficient of variation.

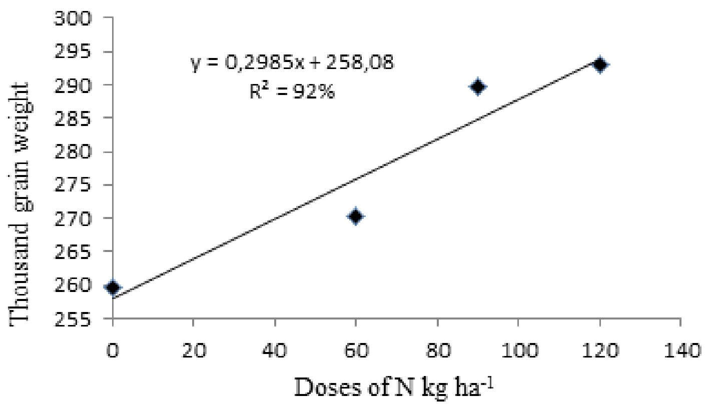

Fig 4. Thousand-grain weight of corn at different doses of N, regardless of the source of N.

Thousand-grain weight

Regarding the weight of a thousand grains of corn, different doses and sources of N did not cause a statistical difference ($p < 0.05$) (Table 5 and Fig. 4). It was observed that with increasing N doses there was a linear increase in the weight of a thousand grains of corn. This can be explained by the fact that N is an active part in many vital processes in plants, such as protein synthesis, ion absorption, photosynthesis, respiration, proliferation and differentiation, causing a greater accumulation of photoassimilates in plants, converting them into heavier grains (Malavolta, 2006). According to Ulger et al. (1995), the thousand-grain weight is directly related to grain yield. It is probably associated with the concentration of N in the leaves, which may explain the results of this work.

Grain yield

Regarding grain yield, no statistical differences ($p < 0.05$) among urea sources and different N rates were observed (Fig. 5). However, higher doses of N increased productivity, reaching the highest level (9.000 kg ha^{-1}) at the highest

Table 5. Thousand-grain weight of corn (g) as a function of different sources of N.

Urea	Average
Polymerized	8317.625 a
Conventional	7194.372 b

*Means followed by the same capital letter in the column do not differ by Tukey test at 5% probability.

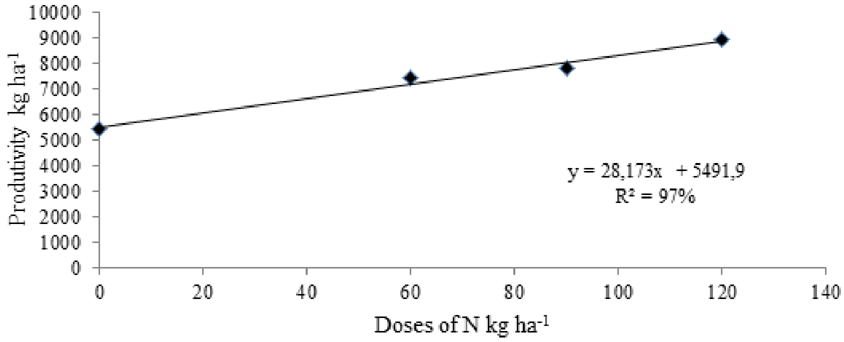

Fig 5. Corn productivity at different doses of N, regardless of the source of N.

applied dose of N (120 kg N ha^{-1}). In the absence of topdressing with N, productivity was approximately 5500 kg ha^{-1}. In an experiment conducted by Pavinato et al. (2008), increased productivity of corn was observed with increasing levels of N. Barbosa et. al. (2010) stated that there was no significant correlation between the sources (polymerized and conventional) at doses of 120 and 150 kg of N and the productivity of corn. Also, a dose of 180 kg of N showed no significant difference.

Civardi (2011), evaluated coated urea by spreading conventional urea incorporated into soil, and found no significant correlation with plant height, height of the first ear insertion, stem diameter, prolificacy of corn, average cob diameter and number of rows per ear. However, the same author observed differences in productivity and thousand-grain weight. Conventional urea without coating incorporated into soil produced better results comparing to polymerized sources, providing better grain filling and increase of density. Urea application form may be more relevant than its coating. According to Civardi (2011), the investment to apply conventional urea incorporated into soil is smaller than the investment to apply coated urea, resulting in lower costs.

Materials and Methods

Site description and soil characteristics

The experiment was conducted in Uberlândia, MG, at the Federal Institute of Triângulo Mineiro - Uberlândia Campus located in Uberlândia, Minas Gerais, from December 2010 to February 2011. The headquarters of the institute is located at geographic coordinates of 18º 46" 12' south latitude and 48º 17" 17' west longitude. Soil sampling was conducted in the experimental area at a depth of 20 cm for chemical and physical characterization (Table 1). The soil was classified as clayey red latosol, (121 g kg^{-1} of coarse sand, 69 g kg^{-1} of fine sand, 24 g kg^{-1} of silt and 806 g kg^{-1} of clay).

Experimental setup

Randomized blocks design was used with four replications, in sub-split plots. N sources, immediate-release and controlled-release urea, were evaluated on plots, doses of 0 (control), 60, 100 and 120 kg N ha^{-1} were evaluated on subplots, and applications with or without *Lithothamnium* were evaluated on sub-subplots, totaling 8 treatments, 32 plots and 64 subplots. Each plot consisted of 16 lines 3.5m in length and the subplots were composed of 8 lines each 3.5m long. The experimental area occupied 6.75 m^2.

Plant materials and treatments

A simple corn hybrid "impact" by Syngenta was used, planted with spacing of 90 cm and an average population of 60.000 plants per hectare. A 08-28-16 fertilizer was used at planting at a dose of 350 kg per hectare, using urea, triple superphosphate and K chloride as sources. Topdressing fertilization was carried out 35 days after planting using immediate-release and controlled-release urea, along with the application of *Lithothamnium* at a dose corresponding to 20% of urea (Table 2).

Measured plant traits

To evaluate the uptake of nutrients by corn, 15 leaves per plot were removed. The first leaf above the insertion of the female inflorescence in R2 was extracted during flowering and pollination, which is a correct time to perform leaf analysis in corn (Faquin, 2002). The evaluation of thousand-grain weight was carried out using methodology described in the Rules for Seed Analysis (Brazil, 2009).

Productivity was assessed using the mass of grains of corn from the two central rows. Ears were harvested manually from two meters in each row and weighted. Later, the data were used to estimate the productivity in kilograms per hectare.

Statistical analysis

The results were submitted to analysis of variance which was done by F test at 5% probability. Subsequently, the averages were compared by Tukey's test ($p \leq 0.05$) to evaluate qualitative variables (N sources and presence or absence of

Lithothamnium) and by regression analysis to assess the quantitative variables (N levels).

Conclusion

No effect of *Lithothamnium* on improving the efficiency of urea applied via topdressing in corn crop was observed. There was no difference between N sources (immediate-release and controlled-release urea) for the studied variables. There was increased N uptake, yield and thousand grain weight in corn crop with increasing doses of N. *Lithothamnium* did not significantly alter foliar Ca^{2+} and Mg^{2+} levels in corn.

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