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Nitrogen Sources and Rates Effect on Yield, Nutritional Status, and Yield Components of Sunflower

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ABSTRACT

Due to the high levels of crude protein in the achene, sunflower (*Helianthus annuus* L.) is one of the main oilseeds grown worldwide, particularly for the oil and meal production for animal feed. Despite these advantages, there are few studies on nutrient use efficiency under tropical conditions, especially nitrogen (N). The experiment was conducted in greenhouse conditions to evaluate the effects of N sources and rates on sunflower achene yield (AY), yield and physiological components, and nutritional status of sunflower. The five N sources (calcium nitrate ($Ca(NO_3)_2$), potassium nitrate (KNO_3), ammonium nitrate (NO_3NH_4), ammonium sulfate ($(NH_4)_2SO_4$), and urea ($CO(NH_2)_2$)), and four N rates (0, 50, 100, and 200 mg kg^{-1}) were studied. AY was reduced with the ammonia sources application from the 100 mg N kg^{-1}. Plant height and capitulum dry weight (CDW), capitulum diameter, shoot dry weight (SDW), and chlorophyll content were significantly related with N sources and rates. Except for potassium (K), the N rates changed the N, P, Ca, Mg, and S concentration in the leaves and N concentration in achene. In the comparison of sources, on the average of N rates, urea application was more effective than the other N fertilizers in the AY.

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KEYWORDS
Achene yield; *Helianthus annuus*; N use efficiency; photosynthesis; yield components

Introduction

Nitrogen is very difficult to manage in agricultural systems due to the large number of reactions with the element, and also because of its high mobility in soil (Theago et al. 2014). Of all the nutrients, nitrogen (N) is usually at higher concentrations in plants and is quantitatively the most limiting nutrient of plant growth. The element is a constituent of protein and chlorophyll molecules and actively participates in ion uptake and in cell multiplication and differentiation (Engels and Marschner 1995; Fageria 2014a). Appropriate N supply to sunflower or other crops is essential for optimum crop yield (Kurvits and Kirkby 1980; Marschner 1995; Mengel and Kirkby 2001), since small N rates limit yield, and high N rates may result in excessive vegetative growth, predisposing the plants to diseases and yield loss (Fageria 2014a; Theago et al. 2014).

In the plant, N plays an important role in the metabolism and nutrition of sunflower crop. Nitrogen deficiency reduces achene yield (AY), while excess, the percentage oil content (Robinson 1978), considerably increases the incidence of pests and diseases, affecting sunflower AY (Vranceanu 1977). For greater nutrient-use efficiency, due to its low recovery efficiency (Fageria, Moreira, and Coelho 2011), the N source to be applied to sunflower should be carefully selected, since the plants can absorb N in the form of nitrate (NO_3^-) and/or ammonium (NH_4^+), but some plants may use one source or the other, depending on the species and the environment (Marschner 1995; Taiz and Zeiger 2015). The use of different N sources may influence the nutritional status of plants, due to changes in the rhizosphere, arising from alterations in the

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ion balance of this soil fraction (Crusciol et al. 2007). The characteristics and the amount of fertilizer will depend on the nutritional needs of the species used, soil fertility, type of reaction of the fertilizer, and economic factors (Fageria 2014a).

The present study aimed to assess and characterize the effects of different N sources and rates on AY, physiological components, yield components, and nutritional status of sunflower cultivated in organic soil with carbon (C) content higher than 25 g kg^{-1}.

Material and methods

The experiment was conducted in greenhouse conditions of Embrapa Soybean, located in the Londrina County, Paraná State, Brazil, under the geographic coordinates 23°11′39” LS and 51°10′40” LW. The organic soil used had the following chemical properties prior to the treatments application: pH in calcium chloride ($CaCl_2$) (0.01 mol L^{-1}) = 6.5, carbon (C) = 25.1 g kg^{-1} (Walkley–Black), organic matter (OM) = (C × 1.724 = 43.3 g kg^{-1}), calcium (Ca^{2+}) = 4.5 $cmol_c$ kg^{-1}, magnesium (Mg^{2+}) = 0.5, aluminum (Al^{3+}) = 0.0 $cmol_c$ kg^{-1}, potential acidity (H^{+}+Al^{3+}) = 4.0 $cmol_c$ kg^{-1}, potassium (K^{+}) = 0.3 $cmol_c$ kg^{-1}, cation exchange capacity (CEC) = 9.3 $cmol_c$ kg^{-1}, base saturation (V) = 56.8%, available boron (B) = 0.2 mg kg^{-1}, available copper (Cu) = 2.7 mg kg^{-1}, available iron (Fe) = 75.5 mg kg^{-1}, available manganese (Mn) = 130.0 mg kg^{-1}, and available zinc (Zn) = 21.9 mg kg^{-1}. The methods of soil analysis used in this experiment are described in EMBRAPA (1997).

A completely randomized design with four replicates was used. The five N sources (potassium nitrate – KNO_3 (12% N), ammonium sulfate – $(NH_4)_2SO_4$ (21% of N), urea – $CO(NH_2)_2$ (44% N), calcium nitrate – $Ca(NO_3)_2$ (15% N), and ammonium nitrate – NH_4NO_3 (32% N)) and four N rates (0, 50, 100, and 200 mg kg^{-1} of soil) in clay pots with 3.2 kg of soil capacity were studied. Each N source was studied in different stands. Base saturation of soil in pots was raised to 70% (V_1) through the application of lime with 14% magnesium oxide (MgO), 33% calcium oxide, and a neutralizing power of 95%, using the following formula:

$$\text{Lime application}\left(\text{t ha}^{-1}\right) = \frac{V_1 - V_2}{NP} \times 100, \text{with } V_2 = \frac{\sum K^{+}, Ca^{2+}, Mg^{2+}}{CEC} \times 100$$

Ten seeds of sunflower, cultivar BRS 323, were sown per pot, and after pruning, two uniform plants were selected. The pots were watered daily to keep moisture close to 70% of field capacity, according to the methodology described by Cassel and Nielsen (1986). Throughout the sunflower cycle, senescent leaves were collected and with the stem, petals, capitulum and achene were dried in the oven to a constant weight to determine the total shoot dry weight (SDW), capitulum weight, and AY. Subsequently, urea equivalent (EqUrea) was calculated:

$$\text{EqUrea}(\%) = \frac{\text{AYurea}}{\text{AY}_n} \times 100$$

where n is AY obtained with the source at rate n; AY urea is the yield obtained with urea at rates (n), and achene yield index (AYI) is calculated with the following formula described in Fageria, Moreira, and Coelho (2011):

$$\text{AYI} = \frac{\text{Achene yield}}{\text{Achene yield} + \text{SDW}}$$

At the R1 growth stage, in the morning, on the third and fourth leaves from the apex, photosynthetic rate, A (μmol CO_2 m^{-2} s^{-1}), stomatal conductance, Gs (mol H_2O M^{-2} s^{-1}), transpiration, Trmmol (mmol H_2O m^{-2} s^{-1}), internal carbon dioxide (CO_2) concentration, Ci (μmol CO_2 mol^{-1}) were determined and the efficient use of water (H_2O) (A/Trmmol), EUH_2O (μmol CO_2 m^{-2} s^{-1}) were determined with a portable photosynthesis analyzer (LI-6400XT; LI-COR®, Lincoln, NE, USA). At the same growth stage, the SPAD unit was quantified (Konica Minolta Business Solutions, Tokyo, Japan), the value was converted to chlorophyll concentration using the formula $\hat{y} = 69.1 \times \exp0.^{0459 \times SPAD}$. On the same day, stem diameter at 10 cm above the ground (mm) and plant height (cm) were measured.

The results were subjected to analysis of variance (ANOVA), F-test, and regression at 5% of probability. The selection of the regression model was based on the R^2. Scott and Knott test ($P \leq 0.05$) for comparison of means was used in the assessment of EqUrea.

Results and discussion

Achene yield

The N sources and rates showed significant interaction for AY, indicating variability between these two variables (Figure 1). Based on regression equations, KNO_3 and $Ca(NO_3)_2$ had linear effect, and the highest yields estimated for these sources were obtained with the 200 mg N kg^{-1} application, while

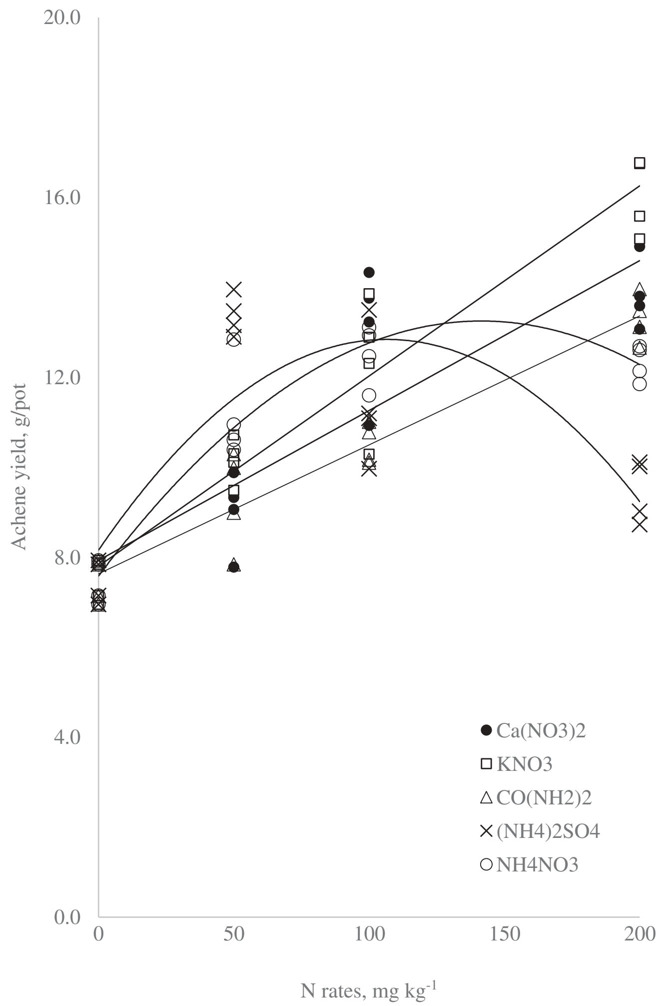

Figure 1. Relationship between N application by five sources (calcium nitrate, potassium nitrate, urea, ammonium sulfate, and ammonium nitrate) and achene yield (AY) of sunflower. *Significant at the 5.0% probability.

$Ca(NO_3)_2$ (calcum nitrate) – $\hat{y} = 7.930 + 0.033x$, $R^2 = 0.77$*; KNO_3 (potassium nitrate) – $\hat{y} = 7.801 + 0.042x$, $R^2 = 0.93$*; $CO(NH_2)_2$ (urea) – $\hat{y} = 7.64 + 0.029x$, $R^2 = 0.92$*; $(NH_4)_2SO_4$ (ammonium sulfate) – $\hat{y} = 8.160 + 0.088x - 0.0004x^2$, $R^2 = 0.62$*; NH_4NO_3 (ammonium nitrate) – $\hat{y} = 7.586 + 0.080x - 0.0003x^2$, $R^2 = 0.90$*.

NH_4NO_3 and ammonium sulfate $(NH_4)_2SO_4$ presented quadratic effects, with the highest estimated rates of 133.3 and 110.0 mg N kg^{-1}, respectively. In the comparison of sources, the highest AY values were obtained with the KNO_3 and $Ca(NO_3)_2$ at 200 mg N kg^{-1} (Figure 1). Linear and quadratic effects on AY at high N rates, depending on the form of N used, was probably caused by the high soil OM content (43.3 g kg^{-1}), which is equivalent to 2.2 g N kg^{-1} of soil. This is consistent with the findings of Xu, Tsai, and Tsai (1992), which found that N-NH_4^+ and N-NO_3^- use efficiencies vary according to the total amount of N in the environment; when there is low availability of N, plant growth is favored; when there is a higher N concentration in the ammonium form, while in soils with high N levels, the application of N-NO_3^- is more efficient. Sharma and Gaur (1988) and Biscaro et al. (2008) in a study with N rates in sunflower crop also obtained significant responses for AY with the use of all N rates. Zubillaga, Aristi, and Lavado (2002) reported positive N rates effect in sunflower with significant increase in the AY per plant.

EqUrea showed that only ammoniacal sources (NH_4NO_3 and $(NH_4)_2SO_4$) at the dose 200 mg N kg^{-1} were more effective than amide N, $CO(NH_2)_2$ (Figure 2). In the comparison of sources for each N rates, Ca $(NO_3)_2$ was more efficient than KNO_3, NH_4NO_3, and $(NH_4)_2SO_4$ at the 50 mg N kg^{-1}; at the 100 mg N kg^{-1}, KNO_3 and $(NH_4)_2SO_4$ were similar and differed from $Ca(NO_3)_2$ and NH_4NO_3, while at the 200 mg N kg^{-1}, $(NH_4)_2SO_4$ was statistically more efficient than the other sources (Figure 2). These results differ from the findings of Fageria et al. (2011; 2014), who reported the higher efficiency of ammoniacal N ($(NH_4)_2SO_4$) compared with amide N ($CO(NH_2)_2$) form in the rice (*Oryza sativa* L.) cultivation. In sunflower, on the average of rates and sources, the N fertilizers application in amide form (urea) showed the highest potential of use with the higher AY (Figure 2).

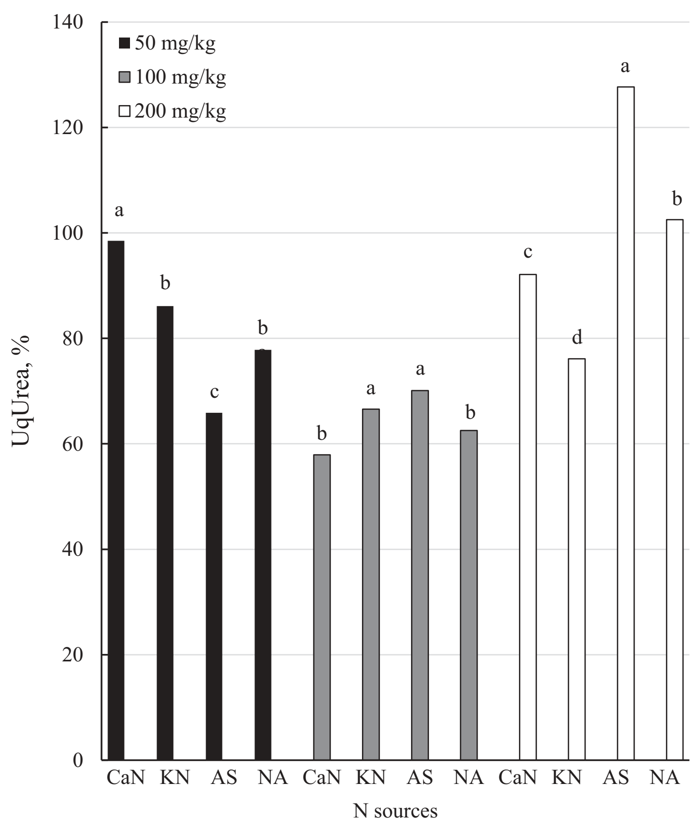

Figure 2. Urea equivalent (EqUrea%) in sunflower through calcium nitrate (CaN), potassium nitrate (KN), ammonium sulfate (AS), and ammonium nitrate (AN) application in three N rates (50, 100, and 200 mg kg^{-1}). Means followed by different letters differ at 5% probability by Scott and Knott test.

Yield components

For the N sources, there was a significant effect for stem height, plant height, capitulum dry weight (CDW), and SDW yield with significant interaction between N sources × N rates for these variables. The highest values for stem diameter (8.0 mm) at the 100 mg N kg^{-1} was applied as $(NH_4)_2SO_4$; for plant height (0.95 m), the greatest effect was observed with the 50 mg N kg^{-1} application using KNO_3, while for the CDW (41.3 g/pot) and SDW (61.9 g/pot), the highest values were obtained with the 200 mg N kg^{-1} application using NH_4NO_3 (Table 1). Regarding the rates, there was also a significant effect ($P \leq 0.05$) on these growth components, regardless of the N source used. Based on regression equations, there was differentiation between the sources and all yield variables studied (Table 1). The largest stem diameter was obtained at the estimated rates of 200.0, 95.8, 98.5, 116.0, and 425 mg N kg^{-1} for the sources $Ca(NO_3)_2$, KNO_3, $(NH_4)_2SO_4$, NH_4NO_3, and $CO(NH_2)_2$, respectively. Concerning plant height, the values obtained were 92.9 mg N kg^{-1} for KNO_3 and 200 mg N kg^{-1} for the other N sources. Regarding CDW and SDW, the highest estimated values were obtained at 200 mg N kg^{-1} for sources $Ca(NO_3)_2$, NH_4NO_3, and $CO(NH_2)_2$, while with the use of KNO_3 and $(NH_4)_2SO_4$, the highest weight values were observed at the estimated rates of 124.5 and 200 and of 147.3 and 129.5 mg N kg^{-1}. The different N sources effects on growth components were also observed by Fagundes et al. (2007) and Guedes Filho et al. (2013) in sunflower crop.

According to analysis of variance, the capitulum diameter and AY/SDW ratio were influenced only by N rates, with no effect of N sources and interaction N sources × N rates (Table 1). Regarding N rates, on the average of the five sources, on the capitulum diameter, regression equation ($\hat{y} = 8.491 + 0.019x - 0.000005x^2$, $R^2 = 0.61$, $P \leq 0.05$) indicated the best estimated rate of 161.7 mg N kg^{-1}, while for the CDW/SDW ratio there was no significant effect of the N rates applied, with values ranging from 0.40 to 0.44. Increase in capitulum diameter depending on N rates was found to be directly related to achene weight ($\hat{y} = 1.809 + 3.393x$, $r = 0.68$, $P \leq 0.05$) (Fagundes et al. 2007; Zagonel and Mundstock 1991).

Table 1. Yield components of sunflower as influenced by N sources and rates.

Treatments	Diameter of stem	Height of plants	Diameter of capitulum	Capitulum dry weight	SDW	
mg N kg^{-1}	(mm)	(m)	(cm)	(g/plot)	(g/plot)	CDW/SDW
Control (0)	7.1	1.17	8.3	29.1	68.1	0.43
$Ca(NO_3)_2$						
50	7.2	1.21	9.1	28.4	70.4	0.40
100	7.2	1.20	8.8	35.9	85.4	0.42
200	7.3	1.20	9.8	36.1	86.7	0.42
KNO_3						
50	7.6	1.19	9.8	35.8	83.0	0.43
100	7.6	1.23	9.1	37.5	91.5	0.41
200	7.0	1.13	9.9	40.2	95,7	0.42
$(NH_4)_2SO_4$						
50	7.8	1.19	10.0	33.0	75.7	0.44
100	8.0	1.21	9.9	35.9	85.8	0.42
200	6.1	1.23	9.6	35.2	84.4	0.42
NH_4NO_3						
50	7.6	1.20	10.3	32.5	73.8	0.44
100	6.9	1.20	10.0	33.9	78.6	0.43
200	6.2	1.25	10.0	41.3	103.2	0.40
$CO(NH_2)_2$						
50	7.3	1,18	9.6	29.6	70.1	0.41
100	7.8	1,17	9.5	32.7	76.5	0.43
200	5.5	1,31	10.0	37.2	92.1	0.40
LSD (0.05)						
N source	3.55*	5.11*	1.09^{NS}	6.17*	8.25*	2.41^{NS}
N rate	31.31*	12.46*	12.06*	56.40*	119.52*	4.99*
N source × N rate	5.52*	5.43*	0.43^{NS}	2.75*	11.72*	2.07^{NS}
CV%	5.60	6.89	9.72	6.86	5.48	11.49

*Significant at the 5.0% level.
^{NS}Non-significant.
CV, coefficient of variation; CDW, capitulum dry weight; SDW, shoot dry weight.

Physiological components

Photosynthetic rate (A), Ci, GS, Trmmol, and EUH_2O were not influenced by N sources and rates, ranging from 25.54 to 28.44 µmol CO_2 m^{-2} s^{-1}, 256.50 to 284.25 mol H_2O m^{-2} s^{-1} and 1.22 to 2.68 µmol CO_2 mol^{-1}, 4.06 to 5.58 mmol H_2O m^{-2} s^{-1}, and 4.81 to 7.01 µmol CO_2 m^{-2} s^{-1}, on average 26.87 µmol CO_2 m^{-2} s^{-1}, 274.62 mol H_2O m^{-2} s^{-1}, 1.98 µmol CO_2 mol^{-1}, 4.79 mmol H_2O m^{-2} $s^{-1,}$ and 5.66 µmol CO_2 m^{-2} s^{-1}, respectively (Table 2). This result contradicts an initial expectation, since the N metabolism in the plants is directly related to the components that participate in photosynthesis and respiration, among other metabolites (Fageria 2014b; Marschner 1995). The high OM content in the soil (43.3 g kg^{-1}) have probably supplied nutritional requirements in the vegetative stage of plant growth, masking the direct N sources and rate effects on these physiological components in sunflower.

Chlorophyll content was affected by N sources and rates, with significant interaction between N sources × N rates (Table 2). Regarding regression equations, a positive linear effect occurred with the $Ca(NO_3)_2$ application; the highest content was obtained at the 200 mg N kg^{-1} and quadratic effect for sources KNO_3, $(NH_4)_2SO_4$, NH_4NO_3, and $CO(NH_2)_2$, with the highest contents estimated at rates of 132.95, 91.88, 71.20, and 78.43 mg N kg^{-1}, respectively (Table 2). The high chlorophyll levels, however, did not correspond to the photosynthetic rates, which (as previously mentioned) were not influenced by the treatments (Table 2). This happened because in many cases the light uptake capacity of chlorophyll in plants may exceed the metabolic capacity under high light intensities, generating photo-inhibition. In this case, reduced chlorophyll synthesis would be a strategy to obtain maximum photosynthetic efficiency (Maurino and Weber 2013).

Table 2. Influence of N sources and rates on photosynthesis rates (A), stomatal conductance (gs) intercellular CO_2 concentration (Ci), transpiration rate (Trmmol), intrinsic water use efficiency (IWUE), and chlorophyll in sunflower.

Treatments	A	gs	Ci	Trmmol	IWUE	Chlorophyll
mg N kg^{-1}	(µmol CO_2 m^{-2} s^{-1})	(mol H_2O m^{-2} s^{-1})	(µmol CO_2 mol^{-1})	(mmol H_2O m^{-2} s^{-1})	(µmol CO_2 m^{-2} s^{-1})	(mg m^{-2})
Control (0)	26.87	273.50	1.99	4.42	6.09	340.92
$Ca(NO_3)_2$						
50	26.82	279.75	2.44	4.26	6.29	351.21
100	28.44	277.00	2.68	4.06	7.01	355.37
200	27.25	270.75	1.93	4.67	5.83	393.10
KNO_3						
50	26.95	256.50	1.22	4.92	5.47	366.21
100	26.71	272.50	1.51	5.04	5.30	392.19
200	26.57	277.50	1.85	5.28	5.03	376.28
$(NH_4)_2SO_4$						
50	26.81	275.25	1.61	5.58	4.81	359.37
100	26.89	273.00	2.47	5.18	5.20	364.97
200	25.54	276.75	1.79	5.24	4.87	277.42
NH_4NO_3						
50	26.06	284.25	2.29	5.13	5.08	360.44
100	27.28	282.75	1.71	4.82	5.66	365.09
200	27.54	277.50	1.70	4.43	6.21	305.41
$CO(NH_2)_2$						
50	27.19	268.75	1.90	5.14	5.29	379.67
100	25.65	281.25	2.66	5.37	4.77	385.98
200	27.38	275.25	2.16	4.58	5.98	325.80
LSD (0.05)						
N source	0.72^{NS}	2.92^{NS}	2.95^{NS}	2.19^{NS}	0.29^{NS}	5.65*
N rate	0.57^{NS}	1.30^{NS}	1.42^{NS}	2.02^{NS}	2.39^{NS}	11.64*
N source × N rate	0.72^{NS}	1.99^{NS}	1.49^{NS}	1.79^{NS}	1.44^{NS}	5.20*
CV (%)	5.23	8.87	18.18	9.26	8.20	6.44

*Significant at the 5.0% level.

^{NS}Non-significant.

CV, coefficient of variation.

Nutrient concentration

Although the N fertilizers included Ca (19% of $Ca(NO_3)_2$), K (45% of potassium oxide (K_2O) of KNO_3), and S (24% of S of $(NH_4)_2SO_4$) in their composition, the foliar N, P, K, Ca, Mg, and S concentrations and N concentration in achene were not affected by the N sources and the interaction N sources × N rates (Table 3). Concerning the rates, except for the foliar K concentration, N rates had a significant effect on the foliar concentration of the other nutrients in this study. On the average of N sources, the effect of the rates was linear and significant ($P \leq 0.05$) for the foliar N concentration ($\hat{y} = 43.860 + 0.0099x$, $R^2 = 0.91$), P ($\hat{y} = 4.131 + 0.0016x$, $R^2 = 0.68$), Ca ($\hat{y} = 11.899 + 0.0012x$, $R^2 = 0.89$), Mg ($\hat{y} = 4.964 + 0.0013x$, $R^2 = 0.65$), and S ($\hat{y} = 1.641 + 0.0009x$, $R^2 = 0.80$) and of N concentration in the achene ($\hat{y} = 14.389 + 0.114x$, $R^2 = 0.83$). Fageria (2014b) reported the positive effects of N on the uptake of these nutrients, since N, P, Mg, Ca, and S act directly or indirectly in various physiological processes in the plant, such as ion uptake and photosynthesis (Marschner 1995, Fageria 2014a). The foliar N, P, K, Ca, Mg, and S concentrations were close to or above 45–50 g N kg^{-1}, 3.1–3.3 g P kg^{-1}, 11–24 g K kg^{-1}, 3.0 g Ca kg^{-1}, 1.1 g Mg kg^{-1}, and 2.9 g S kg^{-1} indicated as appropriate by Reuter, Edwards, and Wilhelm (1997) for sunflower crop, and in the average of the treatments, the macronutrients concentration in the leaves in vegetative R1 growth stage was N > K > Ca > Mg > P > S. Zobiole et al. (2010), in a study with sunflower, and Fageria et al. (2013), with soybean (*Glycine max* (L.) Merr) reported a similar sequence of foliar accumulation of these macronutrients in the same vegetative stage (R1).

The nitrogen to sulfur (N/S) ratio in the leaves ranged from 24.5 to 27.5 for N sources and rates. Since these nutrients are components of some essential amino acids (cysteine and methionine), this ratio can be considered a reliable index in the assessment of the nutritional status of plants, and its value was on average 25.5 in this study, above 19.3, a value indicated as appropriate by Moreira, Carvalho, and Evangelista (1999). Jamal, Moon, and Abdin (2010) report that a low N/S ratio reduces seed yield. Among the sources

Table 3. Foliar N, P, K, Ca, Mg, and S concentration, and achene N concentration of sunflower under different N sources and rates.

Treatments	N – Leaf	P – Leaf	K – Leaf	Ca – Leaf	Mg – Leaf	S – Leaf	N (Achene)
mg N kg^{-1}	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})
Control (0)	44.0	4.1	34.9	11.9	5.0	1.6	11.5
$Ca(NO_3)_2$							
50	44.5	4.3	35.0	12.0	5.0	1.7	21.8
100	44.6	4.5	35.1	12.0	5.0	1.7	27.1
200	45.7	4.4	32.7	12.2	5.1	1.8	39.4
KNO_3							
50	44.2	4.3	34.9	12.0	5.0	1.8	20.1
100	44.6	4.4	35.2	11.9	5.1	1.8	28.4
200	45.9	4.4	35.1	12.1	5.0	1.8	38.1
$(NH_4)_2SO_4$							
50	44.3	4.2	35.0	12.0	5.2	1.7	21.0
100	44.7	4.3	35.0	12.1	5.4	1.8	22.1
200	46.5	4.3	35.1	12.2	5.4	1.9	37.8
NH_4NO_3							
50	44.3	4.2	36.5	12.0	5.1	1.7	27.2
100	44.5	4.4	35.1	12.1	5.1	1.8	30.3
200	45.6	4.5	35.3	12.1	5.1	1.8	28.9
$CO(NH_2)_2$							
50	44.3	4.2	34.9	12.0	5.0	1.7	26.2
100	44.9	4.5	35.1	12.0	5.1	1.8	23.9
200	46.2	4.5	35.3	12.1	5.2	1.8	33.1
LSD (0.05)							
N source	2.41^{NS}	1.46^{NS}	1.37^{NS}	0.28^{NS}	1.35^{NS}	1.50^{NS}	0.96^{NS}
N rate	160.81*	26.18*	0.68^{NS}	13.31*	20.16*	37.63*	205.31*
N source × N rate	1.70^{NS}	0.71^{NS}	1.02^{NS}	0.28^{NS}	1.41^{NS}	1.23^{NS}	5.40*
CV (%)	4.68	5.11	4.61	4.01	5.30	4.21	12.78

*Significant at the 5.0% level.
^{NS}Non-significant.
CV, coefficient of variation.

of this study, since it contains S in its composition, the source $(NH_4)_2SO_4$ generated the most significant increase, a linear increase of 18.8% in foliar S concentration (Table 3).

Conclusions

Despite its good yield and the excellent quality of its oil, the sunflower cultivation is little studied in Brazil, especially from the point of view of plant nutrition. Nitrogen is one of the most important plant nutrients, and in case of shortage, yield is significantly decreased. N sources and rates and the N sources × N rates significantly influenced AY, SDW, capitulum diameter, height, stem diameter, and chlorophyll content, with a positive linear effect of nitrate and amide sources on AY ($Ca(NO_3)_2$, KNO_3, $CO(NH_2)_2$) and quadratic effect for ammoniacal N sources (NH_4NO_3 and $(NH_4)_2SO_4$). Except for K, the N, P, Ca, Mg, and S concentrations in the leaves and N concentration in the achene were affected by N rates. According to EqUrea, on the average of N rates, urea ($CO(NH_2)_2$) was the most efficient source in AY. Therefore, the use of appropriate management practices and the selection of N fertilizers can improve AY in soil with high OM content.

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