Slow-release stabilized nitrogen fertilizers on initial development and nutrition of coffee plants (*Coffea arabica* L.)

Vinícius José Ribeiro*,1, Felipe Vaz Andrade2, Renato Ribeiro Passos2, Eduardo Sá Mendonça2, Laís Lemos da Silva3, Amanda Faé Sartori3

1Soil Department, University Federal of Viçosa-UFV, Viçosa, MG, Brazil
2Department of Plant Production, University Federal of Espírito Santo-UFES, Alegre, ES, Brazil
3 Agrarian Sciences Center, University Federal of Espírito Santo-UFES, Alegre, ES, Brazil

*Corresponding author: vj.ribeiro@yahoo.com.br (V. J. Ribeiro)

Abstract

Currently there is interest in aggregating technology to fertilizers in order to increase their efficiency. A good example is the use of slow and steady release nitrogen fertilizers. This study was conducted in a greenhouse to evaluate the efficiency of stabilized, slow-release nitrogen sources in the early development and nutrition of coffee plants (*Coffea arabica* L.). The treatments followed a factorial 6 × 3 being: six nitrogen fertilizer sources (conventional urea – CU; ammonium nitrate – AN; elemental sulfur coated urea - US; elemental sulfur coated urea and polymer – USP; urea combined with organic material - UO, and UO + NBPT - UO_{NBPT}); three application times, with four replications. The experiment was conducted for 150 days and the aerial part dry mass production (APDM), that of the leaf (LDM), plus the foliar N concentration and content were evaluated. The use of stabilized slow-release N fertilizers influenced (APDM) and (LDM) production as well as the foliar N concentration and content in coffee plants. The N content in the leaves followed the order: UO_{NBPT} < UO < USP < US < AN < CU, contrary to the beneficial effects regarding N availability of fertilizers with associated technology in relation to the conventional source - Urea.

Keywords: Efficiency; fertilizer; polymers; technology; urea.

Abbreviations: Ca_calculator; Mg_magnesium; K_kalium; P_phosphorus; N_nitrogen; H_acidity potential; NH_ ammonia; CU_conventional urea; AN_ammonium nitrate; US_elemental sulfur coated urea; USP_elemental sulfur coated urea plus polymer; UO_ urea combined with organic material (filter cake); UO_{NBPT}_UO + NBPT; APDM_aerial part dry mass; LDM_leaf dry mass; T1_Time1; T2_Time2; T3_Time3.

Introduction

Coffee cultivation is an important social economic activity for small and medium farmers generating wealth and foreign exchange in Brazil (Pinto et al., 2014), which stands out as the largest producer and consumer of coffee in the world.

Nitrogen (N) stands out among the nutrients needed for the growth and development of plants, by positively affecting its vegetative growth (Yin et al., 2003; Coelho et al., 2012.). N is the macronutrient that provides the highest response regarding coffee plant productivity, it also being the nutrient most in demand for the initial development of seedlings in nurseries and for field crops (Cruz et al., 2014). However, low soil N availability, added to the high demand by plants, makes this element one of the most limiting nutrients to productivity (Braun et al., 2013). Urea is the most widely used nitrogen fertilizer in Bral and its low use efficiency is frequently reported in the literature (Silva et al., 2015) and primarily attributable to losses through denitrification and NH$_3$ volatilization, the latter reaching values near 80% of the N applied (Cabezas, 1997). Various studies are being carried out in Brazil with the use of more efficient fertilizers (stabilized slow-release fertilizers) in the production of various crops (Melo et al., 2001). These fertilizers are also known as coated, intelligent, encapsulated fertilizers. According to Shaviv (2001), these fertilizers provide the nutrients to the plants in a regular and continuous manner, which results in: lower frequency of applications in soils; nutrient loss reduction due to leaching, immobilization, and also volatilization; elimination of root damage by the high salt concentrations; greater fertilizer handling convenience; contribution to NO$_3$ environmental pollution reduction, providing ecological value to an agricultural activity, and reduced production costs. Reports can be found in the literature on the higher efficiency of these fertilizers in crops such as soybean (*Glycine max*), cotton (*Gossypium sp.*) (Guarschi, et al., 2011), maize (*Zea mays*) (Ribeiro et al., 2011) and coffee (*Coffea arabica*) (Melo et al., 2001). Grohs et al. (2011) found that urea coated with B$^{2+}$ and Cu$^{2+}$ slows and reduces N loss via ammonia volatilization compared with conventional urea, with its efficiency associated with soil conditions and climate, influenced by the rice cultivation system (*Oryza sativa*). For Valderrama et al. (2011), polymer coated fertilizers may not be as efficient compared to conventional fertilizers in regard to foliar N concentration, production components and bean productivity (*Phaseolus vulgaris*). However, works aimed at the use of more efficient fertilizers in coffee plants are still scarce.

This work was carried out to evaluate the aerial part (APDM) and leaf (LDM) dry mass production, as well as the foliar N content and concentration in coffee plants (*Coffea arabica* L.), after application of stabilized slow release
nitrogen fertilizers at different times, comparing the effect of these new technologies and of the fertilizer application management on plant development.

Results and Discussion

The application of nitrogen fertilizers altered the dry mass production of the aerial part (APDM) and leaf (LDM), as well as the N content and concentration in the aerial part of coffee plants (Fig.2). The results based on the N content were also presented, since the treatments with nitrogen fertilizer provided differentiated growth as to coffee plant LDM and APDM. Treatments in which there is a higher dry mass production lead to a nutrient dilution effect (Jarrell and Beverly, 1981; Partelli et al., 2014). For the C1 contrast (Table 1), that compares conventional fertilizers with other fertilizers with associated technology, there was no difference for APDM and LDM for the conventional source, but there were differences for the content and the concentration of foliar N. For the foliar N content and concentration we observed the following order: CU> AN> US> USP> OU> UO\textsubscript{NBP} (Fig. 2), demonstrating the superiority of conventional sources (CU and AN) in relation to the sources associated with technology, according to Contrast C1 (Table 1). Similar results were observed for APDM and LDM (Fig. 2 and Table 1), regardless of the source of N application time. The use of stabilized slow-release nitrogen fertilizers is, in principle, an alternative for reducing N losses, mainly via NH\textsubscript{3} volatilization and increase its availability to plants, steadily and gradually providing N to plants (Almeida and Sanches, 2012), this result allows to question the efficiency of nitrogen fertilizers with associated technology. Polymer-based coatings must have good biodegradability and small dimensions (millimeter scale) to avoid significant variations in fertilizer volume (Guo et al., 2005). For Silva et al. (2012) fertilizers with associated technology, such as encapsulation, may contain a very thick layer of coating with low permeability which impairs the nutrient availability to the soil and hence to the plant. The encapsulation process directly influences the mechanism and intensity of the nutrient release process. Characteristics such as thickness, chemical nature of the coating resin, the amount of microfissures in the coating surface and the fertilizer granule size will also contribute to determine the nutrient release rate (Trenkel, 1997). For Vieira and Teixeira (2004), the release of nutrients from fertilizers with associated technology also depends on temperature and soil moisture. These fertilizers are made up of soluble compounds, surrounded by a water-permeable resin, which regulates the nutrient supply process.

The temperature conditions (27°C) and soil moisture (60% field capacity) in our experiment favored the release of N from the fertilizer, leading to a similar effect for conventional fertilizers. Field conditions under which there is no strict temperature and soil moisture control, can lead to different results than those found, increasing the variability of plant responses to these fertilizers used. Fernandes and Fraga Jr. (2010), evaluating doses and nitrogen sources on productivity and maturation of irrigated coffee, concluded that the productivity (84.37 bags ha\textsuperscript{-1}) was higher with the use of controlled release N fertilizers. The authors justified the results by the reduction of nutrient losses and their better use by plants compared to the use of urea. For Melo et al. (2001), working with coffee plants (\textit{Coffeea arabica}), the application of 473.33 g of controlled release fertilizer caused an increase of 2.47 pairs of leaves on treated plants with respect to conventional fertilizers.

When comparing the physical coating technologies (US + USP) and the organic coating (UO + UO\textsubscript{NBP}) (Contrast C2, Table 1) we see that the fertilizers coated with physical protection were more efficient in producing APDM, LDM and foliar N content and concentration for the experimental conditions of this study. Fertilizers coated with sulfur and polymers represent a significant fraction of the controlled release fertilizer market. These fertilizers usually have a parabolic N release pattern. This release depends mainly on the quality and thickness of the granule coating (Trenkel, 2010). In Contrast C3 (Table 1), in which US is compared to USP, it was noted that polymer and sulfur-coated (USP) fertilizer did not promote an increase in foliar N concentration. Maestrolo et al. (2014) found no differences in foliar N in corn comparing common urea and polymer-coated urea. For the N, APDM and LDM contents, the US nitrogen fertilizer was more efficient. Various studies have demonstrated that the urea with polymer coating is not efficient in increasing corn grain productivity (Civardi et al., 2011; Guareschi et al., 2013; Maestrolo et al., 2014). These results may be associated with the thick coating over the fertilizer which may delay the release of the nutrient to the plant (Trenkel, 2010). When comparing UO with UO\textsubscript{NBP} (C4, Table 1), the UO fertilizer was more efficient in the production of APDM, LDM and N concentration and content. These results are contrary to those obtained by Espíndula et al. (2013) who observed a linear increase in dry mass yield of wheat plants with increased doses of urea treated with NBPT, higher than the yields obtained with urea at doses of 90 and 120 kg ha\textsuperscript{-1} N and those of Garcia et al. (2011), wherein the use of NBPT associated with the urea on coffee (\textit{Coffeea arabica L.}) conducted in pots promoted greater use of N with a gain of 18% in the plant dry mass production and 32% in their absorbed N. For the fertilizer application times, all sources behaved in a similar manner (Table 2). The split fertilizer applications led to greater efficiency (or availability) of the nitrogen fertilizer. These results corroborate Amado et al. (2002) and Silva et al. (2005) in which the nitrogen fertilizer parceling and application time constitute an alternative to increase N fertilizer efficiency in the crops and mitigate their losses. This is supported by the better N use, the result of synchronization between applications and the high plant nutrient demand period (Amado et al., 2002).

In contrast, C5 (Table 2), when splitting the application of nitrogen fertilizers there were higher APDM and LDM content, and foliar N concentration. Thus, the results obtained in our study do not corroborate with that indicated by Zabini et al. (2008). These authors, assessed the feasibility of coffee plant fertilization with controlled release N application and found that the fertilizers used, formulated with a controlled release N, are technically feasible to provide N for coffee plants in a single application, with reduced nutrient doses and manpower.

The application of nitrogen sources via parceling in three times led to an increased N content and concentration in leaves (C6, Table 2). Teixeira et al. (2010), applying the rates of 0, 50, 100, 150 and 200 kg ha\textsuperscript{-1} of N as ammonium sulfate, urea and urea with NBPT at two application times (at sowing, along the lines or coverage), observed that the N sources had a similar effect, for both times, on plant height and grain yield in irrigated wheat. These contradictory results reinforce the need for further studies on these coating technologies related to the constant and gradual N supply to plants, considering coating type (Guareschi et al., 2013.); coating quality and thickness (Rodrigues et al., 2013.) and control of the experimental environment, such as soil temperature and moisture concentration (Lanna et al., 2010; Costa et al., 2003). Any changes in these characteristics may reflect in contradictory or inconsistent results and interpretations.

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Materials and Methods

Experimental site

The experiment was conducted in a greenhouse of the Agricultural Sciences Center of the Federal University of Espírito Santo (CCA - UFES) in Alegre - ES. The site is located at an altitude of 250 m, at 20º45’48” South and 41º31’57” West (Fig. 1).

Soil and climatic characteristics

The climate in the region is Cwa (subtropical climate, warm and humid in summer and dry in winter) according to the Köppen classification, with average annual rainfall of 1,200 mm and average annual temperature of 23°C. For this experiment, samples were collected from a Latossolo Vermelho Amarelo distrófico (Embrapa, 2013) at a depth of 20-40 cm. Once collected, the samples were air dried, declodded, and passed through a 2.0 mm sieve to obtain fine air-dried soil (FADS). The chemical and physical analyzes of soil samples, performed according to Embrapa (1997) and Almeida et al. (2012), respectively, revealed the following attributes: pH (in H₂O) = 4.80; P = 6.34 mg dm⁻³; K = 14.00 mg dm⁻³; Ca = 0.70 cmol dm⁻³; Mg = 0.70 cmol dm⁻³; Al³⁺ = 0.25 cmol dm⁻³; H⁺+Al = 4.29 cmol dm⁻³; Sum of Bases = 1.44 cmol dm⁻³; CEC capacity = 5.73 cmol dm⁻³; CECt = 1.69 cmol dm⁻³; V = 25.13%; Sand = 296 g kg⁻¹; Silt = 32 g kg⁻¹; Clay = 672 g kg⁻¹.

Experimental design

Different N sources were added to soil samples at different application times. The N sources used were conventional urea - CU; ammonium nitrate - AN; elemental sulfur coated urea - US; urea coated with elemental sulfur and polymer - USP; urea combined with organic material (filter cake) - UO; NBPT and UO + (N-(n-Butyl) thiophosphoric triamide) - UO + NBPT. The N dose was 75 mg dm⁻³, adapted from Novais et al. (1991), considering the volume of soil used and it was applied at 2 cm of depth.

The treatments followed a factorial 6 × 3 where the factors studied were: six N sources (CU, AN, US, USP, UO, UO + NBPT) × three application times (Time 1: 100% of the N dose applied at the beginning of the experiment; Time 2: 50% of the N dose applied at the beginning of the experiment and 50% after forty-five days, and Time 3: 33.4% of the N dose applied at the beginning of the experiment and two more applications of 33.3% at two-forty-five day intervals). The experiment was arranged in a randomized block design (RBD), with four replications.

Soil preparation and conduction

Soil samples (2 dm³) were placed in plastic bags for liming by the Al³⁺ neutralization and elevated Ca²⁺ + Mg²⁺ concentration method (Alvarez V and Ribeiro, 1999). Soil moisture was adjusted to 60% of field capacity (Reichardt, 1988). After 21 days of incubation, the soil was air dried, declodded and sieved in a 2 mm sieve (FADS) for mounting the experiment.

Soil samples (FADS) were weighed (10 dm³) and placed in pots with a 12 dm³ capacity, respecting the density of the studied soil. The fertilization (P, K and micronutrients) was performed according Novais et al. (1991) throughout the total soil volume before planting the Arabica coffee seedlings, Red Catuaí IAC 44 cultivar, at the three to four true leaf pair stage. Irrigation of the pots was performed daily according to need, maintaining constant moisture for all pots at 60% of field capacity. The control of weeds, pests and diseases was conducted when necessary.

Table 1. Contrasts of the averages of aerial part (APDM) and leaf dry mass (LDM) and foliar Nitrogen (N) content and concentration for different N sources.

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>APDM</th>
<th>LDM</th>
<th>N_content</th>
<th>N_concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.08</td>
<td>-0.06</td>
<td>28.49**</td>
<td>2.47**</td>
</tr>
<tr>
<td>C2</td>
<td>1.02**</td>
<td>0.91**</td>
<td>34.69**</td>
<td>0.24</td>
</tr>
<tr>
<td>C3</td>
<td>2.18**</td>
<td>1.54**</td>
<td>55.98**</td>
<td>-0.06</td>
</tr>
<tr>
<td>C4</td>
<td>-2.67**</td>
<td>-1.26**</td>
<td>54.03**</td>
<td>-1.07</td>
</tr>
</tbody>
</table>

C1 = (CU + AN) vs (US USP + + + UO UONBPT); C2 = US + USP vs UO + UONBPT; C3 = US vs USP; C4 = UONBPT vs OU; CU: conventional urea; AN: ammonium nitrate; US: elemental sulfur coated urea; USP: urea coated with elemental sulfur and polymer; UO: urea combined with organic material (filter cake); UO + NBPT; UO + NBPT, °, * and ** Significant at 10, 5 and 1%, respectively.

Fig1. Location of the study area.
Table 2. Contrasts of the averages of nitrogen source application times for the aerial part (APDM) and leaf (LDM) dry mass and foliar Nitrogen (N) content and concentration.

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>Sources</th>
<th>APDM</th>
<th>LDM</th>
<th>N_content</th>
<th>N_concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>CU</td>
<td>18.11*</td>
<td>12.37*</td>
<td>500.47**</td>
<td>39.75**</td>
</tr>
<tr>
<td></td>
<td>AN</td>
<td>18.53*</td>
<td>11.93*</td>
<td>494.44**</td>
<td>41.20**</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>19.35*</td>
<td>13.81*</td>
<td>498.14**</td>
<td>35.82**</td>
</tr>
<tr>
<td></td>
<td>USP</td>
<td>20.65*</td>
<td>12.54*</td>
<td>427.79**</td>
<td>34.18**</td>
</tr>
<tr>
<td></td>
<td>UO</td>
<td>22.71*</td>
<td>14.56*</td>
<td>531.20**</td>
<td>36.94**</td>
</tr>
<tr>
<td></td>
<td>UO NBPT</td>
<td>15.87*</td>
<td>10.50*</td>
<td>401.46**</td>
<td>37.43**</td>
</tr>
<tr>
<td>C6</td>
<td>CU</td>
<td>4.98**</td>
<td>3.22**</td>
<td>182.47**</td>
<td>4.9**</td>
</tr>
<tr>
<td></td>
<td>AN</td>
<td>1.65**</td>
<td>1.29**</td>
<td>103.07**</td>
<td>4.40**</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.39</td>
<td>2.39**</td>
<td>118.75**</td>
<td>2.48**</td>
</tr>
<tr>
<td></td>
<td>USP</td>
<td>-1.10**</td>
<td>-0.71**</td>
<td>-16.04</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>UO</td>
<td>-1.76**</td>
<td>-1.49**</td>
<td>-20.49</td>
<td>2.41**</td>
</tr>
<tr>
<td></td>
<td>UO NBPT</td>
<td>5.15**</td>
<td>2.82**</td>
<td>156.74**</td>
<td>5.24**</td>
</tr>
</tbody>
</table>

C5 = Time 2: 50% of the N dose applied at the beginning of the experiment and 50% after forty-five days, plus Time 3: 33.4% of the N dose applied at the beginning of the experiment and two more applications of 33.3% at two forty-five day intervals versus Time 1: 100% of the N dose applied at the beginning of the experiment. C6 = Time 3: 33.4% of the N dose applied at the beginning of the experiment and two more applications of 33.3% at two forty-five day intervals versus Time 2: 50% of the N dose applied at the beginning of the experiment and 50% after forty-five days. CU: conventional urea; AN: ammonium nitrate; US: elemental sulfur coated urea; USP: urea coated with elemental sulfur and polymer; UO: urea combined with organic material (filter cake); UO NBPT: UO + NBPT; NBPT: N-(n-Butyl) thiophosphoric triamide. *, ** and *** Significant at 10, 5 and 1%, respectively.

Fig 2. Average aerial part (APDM) and leaf dry mass production (LDM) and nitrogen (N) content and concentration in coffee plants (Coffea arabica L.) conducted over a period of 150 days, on different N sources and application times. CU: conventional urea; AN: ammonium nitrate; US: elemental sulfur coated urea; USP: urea coated with elemental sulfur and polymer; UO: urea combined with organic material (filter cake); UO NBPT: UO + NBPT; T1: 100% of the N rate applied at the beginning of the experiment; T2: 50% of the N dose applied at the beginning of the experiment and 50% after forty-five days; and T3: 33.4% of the N dose applied at the beginning of the experiment and two more applications of 33.3% at two forty-five day intervals. NBPT: N-(n-Butyl) thiophosphoric triamide.
Variables analyzed

At the end of the experiment (150 days), the plants were cut about 1 cm from the soil, and stems and leaves separated, which were separately placed in paper bags and brought to a forced-air-circulation oven at a temperature 65°C to determine the leaf (LDM) and aerial part dry mass (APDM), which includes the stem and leaves. The samples were then ground and digested to obtain foliar N content and concentration. The N concentration was obtained by digesting 0.5 g of dry mass, H₂SO₄ and H₂O₂ plus the digestion mixture (Na₂SO₄, CuSO₄·5H₂O) followed by Kjeldahl semimicro steam drag distillation according to Tedesco et al. (1995). The leaf N content was calculated by multiplying the N concentration by the respective values of the dry mass weight, obtained in the samples (C = DM x T / 1000, where C = nutrient content (mg pot⁻¹); DM = dry weight (g pot⁻¹) and T = nutrient concentration (g kg⁻¹).

Statistical analysis

The results were submitted to analysis of variance using the SAEG program (SAEG, 2007) described by Euclides (1983), and the effects broken down between the qualitative factors (sources, times) were broken down in the contrasts.

Conclusions

The fertilizers with associated technology studied were not effective in increasing the foliar N concentration and content in coffee plants (Coffea arabica L.). Urea and ammonium nitrate provided greater foliar N content and concentration in coffee plants (Coffea arabica L.). For fertilizers with associated technologies, the increase in foliar N content followed the order: US> USP> OU> UO+_NBPT. The parceling of nitrogen fertilization provided higher APDM and LDM production and higher foliar N concentration and content in coffee plants (Coffea arabica L.), even when using fertilizers with associated technologies.

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References


