

LIQUID NITROGEN FERTILIZATION ON THE YIELD AND PHENOLOGIC VARIABLES OF NARROW-ROW COTTON

ADUBAÇÃO NITROGENADA LÍQUIDA NA PRODUTIVIDADE E VARIÁVEIS FENOLÓGICAS EM ALGODOEIRO ADENSADO

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ABSTRACT: Slow-release liquid nitrogen fertilizer sources have been around since 1970. However, this technique is not widely used in the field, probably due to the low cost per ton of nitrogen in the solid form. This study aimed to evaluate the combination of the conventional and slow-release nitrogen fertilization on the yield and phenological variables in a narrow-row cotton crop. Treatments consisted of the combination of the nitrogen fertilizer applied as topdressing in solid form (via soil) and pulverized in the liquid form (via urea formaldehyde - UF): 0% of solid N + 0% of liquid N (0S0L); 100% of solid N + 0% of liquid N (100S0L); 75% of solid N + 25% of liquid N (75S25L); 50% of solid N + 50% of liquid N (50S50L); 25% of solid N + 75% of liquid N (25S75L); e 0% of solid N + 100% of liquid N (0S100L). The cotton crop was phenotypically evaluated at 35, 70, and 130 DAE (Days after emergence) and at the harvest time. The variation between the source of the solid nitrogen fertilizer applied to the soil (ammonium nitrate) and the liquid Nitrogen fertilizer applied by spraying (UF) affects the phenology, physiology, and yield components of the narrow-row cotton crop. The highest yield of the narrow-row cotton crop under the experimental conditions was achieved when 25% of the dose of the solid nitrogen fertilizer was applied as topdressing via soil, and 75% of the dose of the slow-release nitrogen fertilizer was sprayed. This technique provides higher profitability of the produced cotton in relation to the conventional application of the N solid fertilizer via soil.

KEYWORDS: Correlation. Cotton. NDVI. Nitrogen.

INTRODUCTION

Among the cotton species grown in Brazil, upland cotton (*Gossypium hirsutum* var. latifolium Hutch) stands out for the production volume and value and the high use of inputs, such as correctives, fertilizers, herbicides, insecticides, fungicides, and growth regulators (FREIRE, 2015). Nitrogen (N) is one of the most important inputs applied to this crop. N is fundamental for plant development, mainly for the vegetative organs. When applied at adequate doses, this element stimulates growth and flowering, regularizes the plant cycle, increases yield, and improves fiber length and resistance. At high doses, N increases the plant vegetative development to the detriment of production and late formation of cotton bolls (PILBEAM, 2011; BORIN et al., 2017; KHAN et al., 2017).

Nitrogen fertilization in cotton crops is performed mainly by using a solid source. Urea applied to the surface without incorporation is the most common procedure of solid N fertilization (FREIRE, 2015). This method, however, increases

losses by volatilization. Studies have reported losses of up to 50% of N, after four days in the field, due to ammonia volatilization (FRAZÃO et al., 2014).

Slow-release nitrogen fertilizers have been available since the 1970s (GUELFI, 2017). However, this technique is not widely used in the field, probably due to the low cost per ton of nitrogen in the solid form, which may appear to be a better investment. Nevertheless, new technology should not be economically evaluated only by the cost reduction but also by changes it causes to the crop's profitability (KAY et al., 2015).

The application of nutrients with slow and controlled release, especially in the case of Nitrogen, which has a high loss rate, can complement the traditional forms of fertilizer applications to the soil. Nitrogen fertilizers of improved efficiency can be classified into three categories, according to the technologies used in their production processes: (i) stabilized, (ii) slow release; and (iii) controlled release (GUELFI, 2017).

Urea formaldehyde (UF), a slow-release or chemically modified Nitrogen fertilizer, is the

condensed product of urea and aldehydes (YAMAMOTO et al., 2016). The availability of N from slow-release fertilizers may depend on the decomposition of the polymer chains into CO₂ and NH₃ by the microbiological activity. However, some scientific controversy is still observed in its metabolic pathway (NARDI et al., 2018). Soil properties and environmental factors, such as the clay content, pH, moisture, and temperature, affect the N decomposition and release from this category of nitrogen fertilizers (GUELFI, 2017).

However, is it possible that the cotton yield of the second harvest differs based on the variation of the source and doses applied? The amount of N to be applied to the cotton crop should be divided into sowing and two topdressings, mainly in areas with the conventional crop management system and/or sandy soils with low organic matter content (KHAN et al., 2017). According to Borin et al. (2017), the N sufficiency level is expected to change, which may require adjustments for the cotton crop in the second harvest. Thus, new studies in different environments and with current cultivars are necessary to establish new standards in the second harvest.

The appropriate N fertilization affects the phenology of the cotton crop in several aspects, such as yield and qualitative traits. Plants with larger leaf area resulting from higher N supply may provide greater light interception, increasing the photosynthesis and biomass, affecting qualitative variables of production, such as micronaire and fiber length (PILBEAM, 2011; MOTOMIYA et al., 2014).

N supply and the increase of plant mass in cotton are closely correlated, which can be indirectly measured by vegetation indices (VI), such

as the Normalized Difference Vegetation Index (NDVI) (MOTOMIYA et al., 2014; SOUZA et al., 2017). Thus, remote sensing techniques have been improved for they provide precise and valuable information owing to their potential of measuring phenological variables and detecting both temporal and spatial variability (RAPER; VARCO, 2015).

Studies on the effects of Nitrogen fertilizer, mainly by the combination of conventional and slow-release fertilizers, on the phenology of the second-harvest narrow-row cotton, are still scarce. This study aimed to evaluate the combination of conventional and slow-release nitrogen fertilizers on yield and phenological traits of a narrow-row cotton crop.

CONTENTS

This study was carried out during the second harvest of the 2012 agricultural year, at the Amambaí Farm, Chapadão do Céu/GO, located at 18°33'89"S and 52°60'53"W, at approximately 850 m asl. According to the Köppen's classification, the climate of the region is rainy tropical, with wet summer and dry winter (Aw). The soil is classified as Dystrophic Clayey Red-Yellow Latosol (SANTOS et al., 2013). The rainfall recorded during the cultivation is shown in Figure 1. Cotton was cultivated as the second harvest by sowing cultivar FiberMax on 01/10/2012, at a spacing of 0.45m between rows, and a target population of 150 thousand plants per hectare. Each plot (experimental unit) was composed of twenty-five 10m-long plant rows. Evaluations considered only the three central rows.

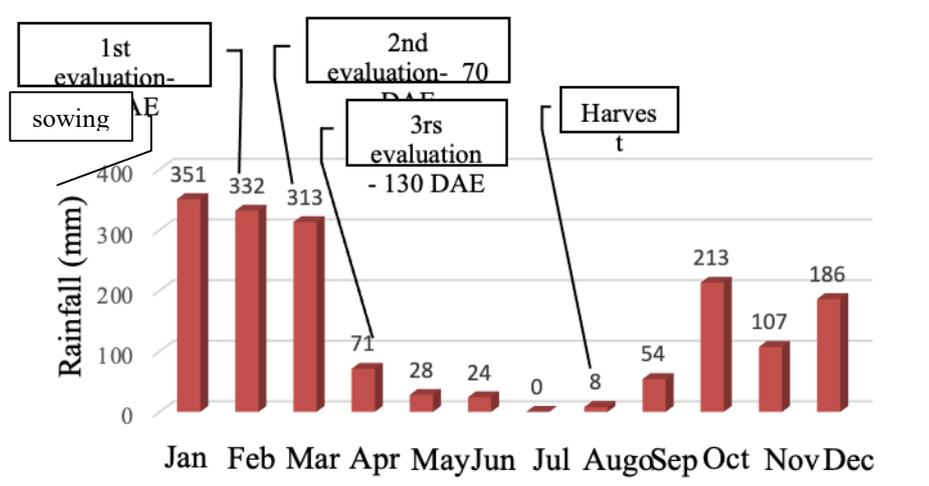


Figure 1. Monthly rainfall evaluation in Chapadão do Céu/GO, measured by an automatic weather station located on the farm.

Before the installation, soil samples were collected at the 0-0.20 m depth layer for chemical analysis (Table 1). The soil is characterized as

clayey and has no fertility problems that could compromise the experimental results.

Table 1. Results of soil analysis in the experimental area.

ph	CEC	Ca+Mg	Ca	Mg	K	P(meh)	Org.							Clay	Base
CaCl ₂		cmolcdm ⁻³				mgdm ⁻³	Mat.	Cu	Fe	Mn	Zn	Na		gdm ⁻³	Saturation
							gdm ⁻³		mgdm ⁻³						%
5.1	8.5	2.4	1.9	0.5	56.3	11.6	23.6	1.5	49.9	33.1	2.7	1.0		425.6	49.7

The experiment was carried out in a randomized blocks design, with six treatments and five replications. The treatments consisted of the combination of the percentage of the nitrogen fertilizer applied as topdressing in the solid form via soil and in the liquid form via sprayer: 0% of solid N + 0% of liquid N (0S0L); 100% solid N + 0% liquid N (100 ml); 75% N solid + 25% liquid N (75S25L); 50% solid N + 50% liquid N (50S50L); 25% N solid + 75% liquid N (25S75L); and 0% N solid + 100% liquid N (0S100L). A single nitrogen recommendation of 110 kg ha⁻¹ was used during cultivation for all treatments (Freire, 2015), except for the control treatment, which received the N dose only at sowing. The solid nitrogen fertilizer applied was ammonium nitrate (27% N). The liquid nitrogen fertilizer applied by spraying (UF) was Nitamin® (33% N), characterized by the manufacturer for the slow-release of N.

At sowing, 15 kg ha⁻¹ of nitrogen and 81 kg ha⁻¹ of phosphorus were applied in the furrow, and 90 kg ha⁻¹ of potassium chloride was broadcasted. Moreover, the topdressing nitrogen fertilization was divided into two applications: ½ of the dose was applied at 25 DAE and ½ of the dose was applied at 45 DAE. The liquid fertilizer was applied using a CO₂ pressurized coastal sprayer (Herbicat), with a 3 m spray boom and six tips (0.5 m apart). The application rate was of 120 Lha⁻¹, with a constant speed of 4 km h⁻¹. The hydraulic tips used in the sprayer were Jacto, model ADI 11001. The working pressure was 400 kPa (58 PSI), generating droplets with average Volume Median Diameter. The other agricultural inputs were applied according to the monitoring of the crop and the standards for pest control and disease in the region (FREIRE, 2015).

The cotton crop was phenologically evaluated at 35, 70, and 130 DAE and at the harvest time. The following phenological traits were evaluated: mean stem diameter, plant height, total N content in the leaf, chlorophyll content in the leaf, number of bolls per plant, number of branches per plant, NDVI, and yield.

NDVI was measured at 70 DAE using a Trimble GreenSeeker® RT100 active optical sensor. The sensor was manually loaded onto the planting rows and collected one point every 0.1 seconds. The evaluations of the NDVI means for each plot were calculated using the software ESRI ArcGIS v10.5; thus, the experimental plots were georeferenced. The stem diameter was measured by a digital caliper (Instrutemp). Plant height was measured by the distance from the ground to the last shoot on the main stem.

To determine the total N content, five leaves per plant were collected in five plants of the three central rows of each experimental plot. The blades of the fifth leaf of the main stem were collected. Leaves were washed in distilled water, dried in a forced-air-circulation, ground, and subject to sulfur digestion in the laboratory. All the bolls of the three central rows of each plot were weighed to determine the cotton boll yield.

Data were subject to analysis of variance and means comparison by the Tukey's test at the 5% of probability. Then, a multivariate analysis was carried out using canonical variables to investigate the interrelationship between variables and treatments, using free software Rbio (BHERING, 2017).

The economic analysis was carried out comparing the results of the trial field and control field, extrapolating to the total area of 1,000 ha of the farm. The methodology to calculate the cost production and profit is based on the partial budget analysis (KAY et al., 2015). The factors considered in the production system were variable materials consumed throughout the production process by altering the treatments and yield. The partial budget analysis estimates the effect of new technology on the existing productive structure, i.e., only the costs and revenue that change with the introduction of the new technology were estimated.

Table 2 shows the mean of the observations of the experimental variables and the F test obtained with the cultivation of the narrow-row cotton. All

the variables had significant statistical difference ($p < 0.05$) between treatments. Therefore, cotton plants showed phenological differences, depending on the treatments applied. The low data variance led to the low coefficients of variation. The variable yield had the highest coefficient of variation (7.37%). A higher coefficient of variation is expected for this

variable (AHSAN et al., 2015), as many other factors affect cotton crop yield other than N fertilization, such as genetic variability. However, this low coefficient of variation demonstrates adequate phytosanitary practices between treatments.

Table 2. Mean of the experimental variables and F test obtained in the cultivation of the narrow-row cotton.

Variable	Mean	Fc	CV%
Number of bolls per plant	13.14	14.02*	4.59
Stem diameter at 130 DAE (mm)	14.33	16.85*	7.07
Plant height at 70 DAE (m)	0.62	0.05*	5.18
Plant height at the harvest time(m)	1.41	6.42*	4.96
Number of branches per plant	20.55	26.47*	2.82
Chlorophyll content(μgcm^{-2})	24.21	51.12*	5.07
N leaf content (g kg^{-1})	46.53	6.71*	5.57
NDVI	0.766	0.0003*	2.40
Yield (kg ha^{-1})	3629.09	317.98*	7.37

Figure 2 shows that the treatment with 75% solid N + 25% liquid N (75S25L) resulted in the highest yield among all treatments, with a mean of $4.576.5 \text{ kg ha}^{-1}$. The control treatment, without N applied as topdressing, regardless of the formulation, resulted in the lowest yield ($2.905.8 \text{ kg ha}^{-1}$) and was statistically equal to the treatment to which 100% N was applied via solid fertilizer

($3.302, 7 \text{ kg ha}^{-1}$). The quadratic response of cotton seed yield was observed in function of liquid fertilizer ratios (Figure 3). Yield had a quadratic response, with maximum value obtained when using 77.4% of liquid fertilizer. According to Borin et al. (2017), increasing doses of Nitrogen have a significant effect on the leaf nutrient content and yield of the cotton crop.

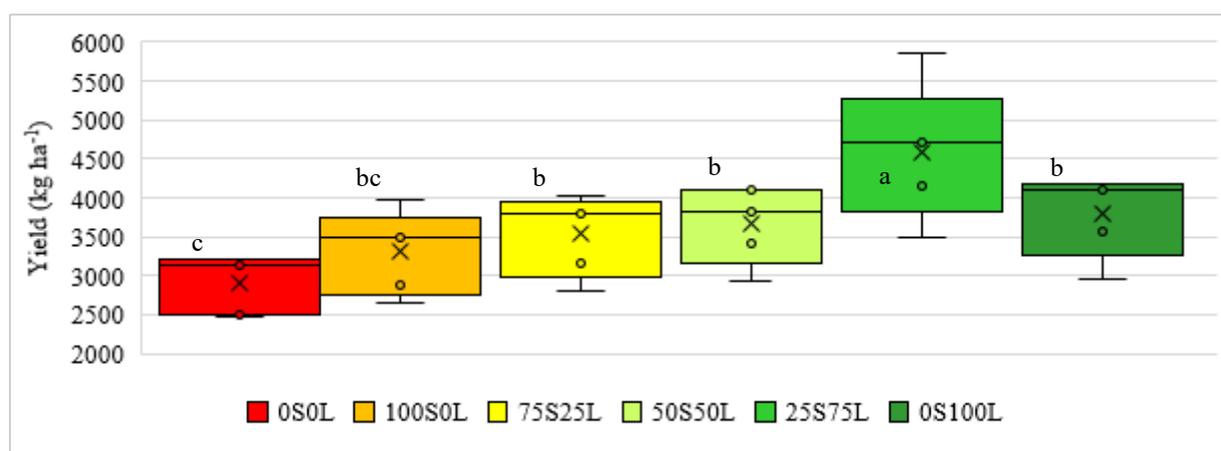


Figure 2. Variability of the cotton yield measured for all treatments, in which xSyL means from 0 to 100% solid (S) N fertilizer or liquid (L) N fertilizer. Different letters in the treatments differ from each other by the Tukey's test at the 5% probability.

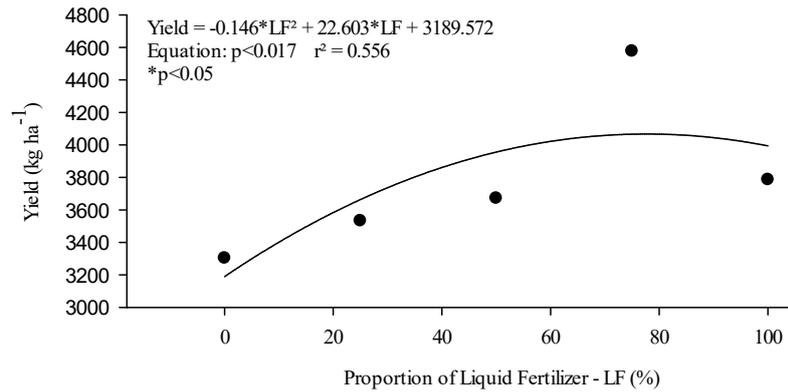


Figure 3. Cotton yield measured in all treatments in relation to the increase of the proportion of the liquid fertilizer applied in combination with the solid fertilizer, in which 110 kg ha⁻¹ of N was applied to all the treatments.

Treatments which received a higher amount of N applied via solid fertilizer to the soil tended to lower yield means, most probably due to the higher N losses to the environment. According to Souza et al. (2017), losses by leaching and denitrification can reach up to 70% of the N applied, especially when urea is used. Nitrogen applied as liquid fertilizer (via UF) has a slow release and the fertilizer applied via soil is readily available to the plant. However, the latter is highly susceptible to leaching and losses (FLORIO et al., 2016). Cotton yield reduced in the treatment that received 100% of the dose of N applied via UF. This result might have been due to the excess of N availability to the crop since the academic base for N application as topdressing is experimentally carried out with solid fertilization via soil and not with liquid N via slow-release UF. N excess causes the excessive growth of the shoots and compromises its management, mainly for growth regulator applications (MOTOMIYA et al.,

2014). Thus, further scientific studies should be carried out aiming at the recommendation of the ideal N dose applied via liquid spraying of slow release fertilizers to cotton crops. According to Frazão et al. (2014), the use of N fertilizers that are more modern than urea led to higher N content in the leaf and higher yields.

Figure 4 shows a linear and positive correlation between the cotton seed yield and the NDVI vegetation index measured at 90 DAE. Therefore, the vegetation index allowed inferring the cotton yield even before harvesting. Thus, cotton yield increases in function of the nitrogen fertilization. This is because N applied via liquid UF increases plant mass, which enables measuring this gain by multispectral sensors (RAPER; VARCO, 2015). Moreover, plants with low N supply have low shoot growth, high root-shoot ratio, and low net growth, affecting crop yield (PILBEAM, 2011).

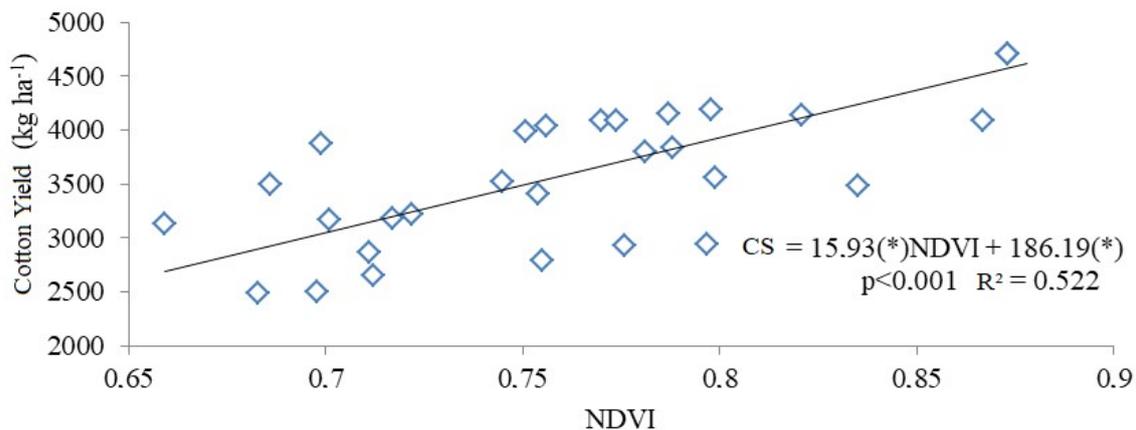


Figure 4. Linear correlation between NDVI measured at 90 DAE and cotton yield.

The regression model between cotton yield and NDVI had a coefficient of determination of 52.2%. Baio et al. (2018) studied the relationship

between yield and NDVI in several cotton crops and verified that the increase in the NDVI variability, indicated by the CV of this vegetation index within

the field, decreases the mean cotton yield. The variability found in the present study may have been due to the application of the different treatments, which resulted in different mean yields. Thus, this study indicates the need for experiments that evaluate the management of nitrogen fertilization in cotton crops using a multispectral optical sensor to measure the NDVI. This technique can be used to reduce the production cost by applying the required amount of N according to the variability of the vegetation index since fertilizers are one of the most costly inputs for the cotton crop.

The canonical variables analysis revealed that the sum of the first two variables ranged from 96.2 to 99.9, which is much higher than the

minimum of 70% (Figure 5), demonstrating the credibility of the analysis' result (BHERING, 2017). Treatments showed a close relation with yield from the increase of the N dose applied as liquid fertilization (UF). Also, the treatment that used 25% in solid form and 75% in the liquid form (25S75L) had the highest yield increase. Thus, this treatment was the one that most affected the cotton crop yield. It also had the highest relation with the variables liquid nitrogen, NDVI, number of branches per plant, and stem diameter. Similar results were found by Souza et al. (2017), which showed the positive relationship between NDVI and cotton phenological variables, such as number of branches and bolls per plant.

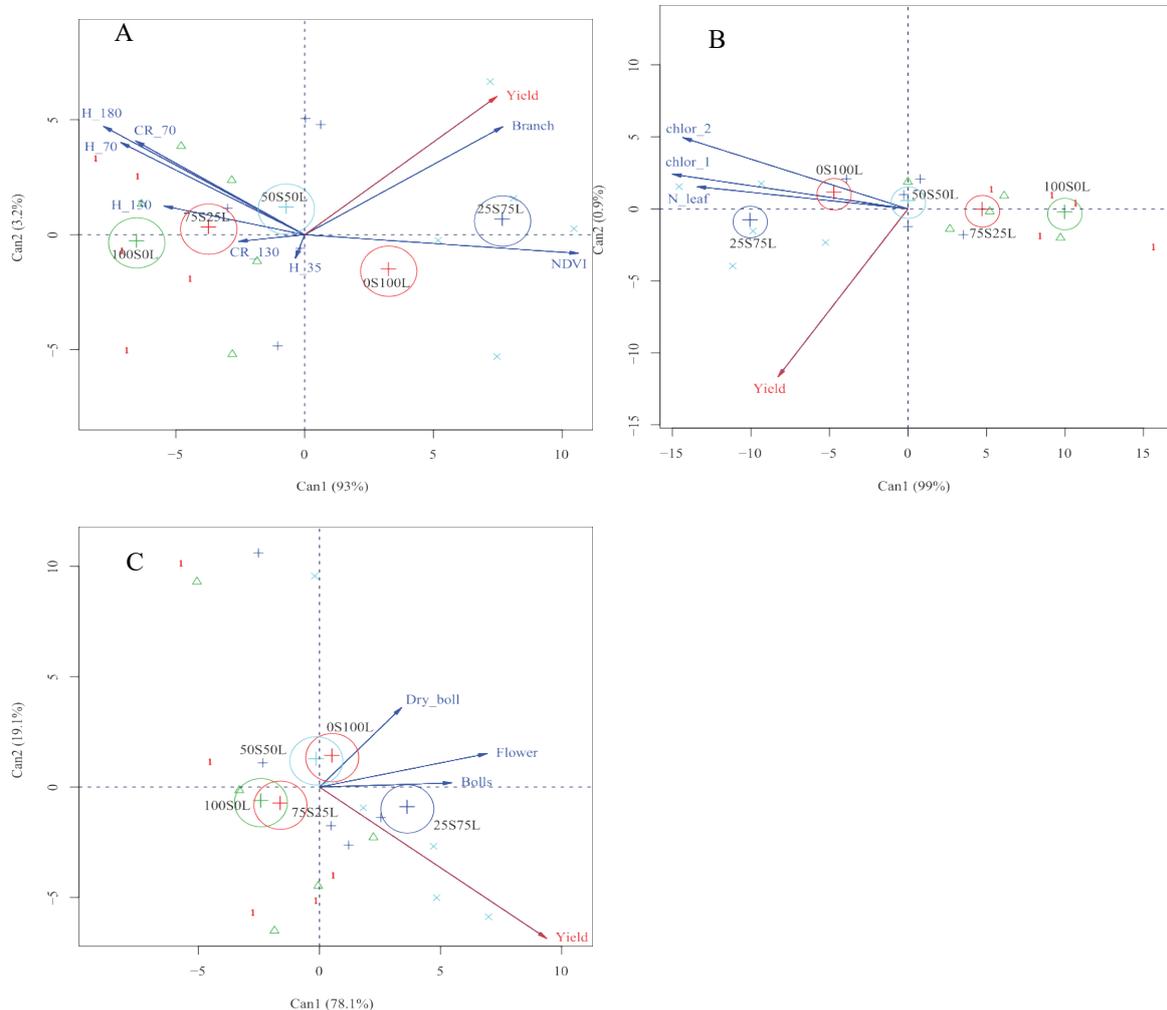


Figure 5. Canonical variables analysis for the results of treatments applied via solid (S) and liquid (L) nitrogen source, and combinations of both sources (0, 25, 50, and 100%), according to the phenological variables (A), physiological variables (B), and yield components (C): Yield; NDVI; N_Leaf - liquid N content; N_Br - number of branches per plant; C_1 and 2 - Chlorophyll 1 and 2; D – plant stem diameter; and H_35, 70, 130 and Harv - plant height corresponding to the to DAE and plant height at the harvest time.

The canonical variables analysis demonstrated that the control treatment (0S0L) is

not associated with any of the variables evaluated. Treatments which received higher N doses via solid

Liquid nitrogen...

fertilization (100S and 75S) had higher plant height values. According to Luo et al. (2015), a combination of liquid application and application via soil of a nitrogen fertilizer led to better results in cotton growth than the methods applied individually.

Partial budget analysis (Table 3) reflects the expected average annual changes in economic revenues and expenses per hectare using the new

technology, such as liquid N fertilizer applied via liquid spraying. The use of liquid N fertilizer resulted in a higher cost production of US\$ 751.04 ha⁻¹ owing to its higher cost at the local market. However, the use of this new technology increased the total revenue by US\$ 328.86 ha⁻¹ because the seed yield difference between treatments 100S0L and 25S75L is of 1,273.80 kg ha⁻¹.

Table 3. Partial budget analysis for solid and liquid N fertilizer applied via liquid spraying on cotton yield.

	25S75L	100S0L
Cost factors	Production Costs (US\$ ha ⁻¹)	
Solid Fertilizer	37.53	150.12
Liquid Fertilizer	863.64	0.00
Total cost ¹	901.17	150.12
Total additional cost	751.04	-
Total additional gross revenue ²	1,079.90	-

Assumptions: ¹based on the local market; ²based on mean seed yield from both crop season, cotton lint price at US\$ 2.13 kg⁻¹ (Conab 2018), and a ratio of 39.8% between cotton lint/seed yield for the cotton variety.

Our findings indicates that the variation between the N fertilizer source, i.e., solid nitrogen fertilizer applied via the soil (ammonium nitrate) and the liquid nitrogen fertilizer applied via spraying (UF), affects the phenology, physiology, and components of the narrow-row cotton yield. The highest yield obtained for narrow-row cotton under

the experimental conditions is achieved when 25% of the dose of the solid nitrogen fertilizer is applied via soil, and 75% of the dose of the slow-release nitrogen fertilizer is sprayed. This technique reveals higher additional profitability to the cotton produced in relation to the conventional application of the solid fertilizer via soil.

RESUMO: Fontes de fertilizantes nitrogenados líquidos de liberação lenta existem desde 1970. No entanto, esta técnica não é amplamente utilizada no campo, provavelmente devido ao baixo custo por tonelada de nitrogênio na forma sólida. Este trabalho teve como objetivo avaliar a combinação da adubação nitrogenada convencional e de liberação lenta sobre a produtividade e as variáveis fenológicas em uma cultura de algodão de fileira estreita. Os tratamentos consistiram da combinação do fertilizante nitrogenado aplicado como cobertura na forma sólida (via solo) e pulverizado na forma líquida (via uréia formaldeído - UF): 0% de N sólido + 0% de N líquido (0S0L); 100% de N sólido + 0% de N líquido (100 S); 75% de N sólido + 25% de N líquido (75S25L); 50% de N sólido + 50% de N líquido (50S50L); 25% de N sólido + 75% de N líquido (25S75L); e 0% de N sólido + 100% de N líquido (0S100L). A cultura do algodão foi avaliada fenotipicamente aos 35, 70 e 130 DAE (dias após a emergência) e no momento da colheita. A variação entre a fonte de adubação nitrogenada aplicada ao solo (nitrato de amônio) e o fertilizante nitrogenado líquido aplicado por pulverização (UF) afeta os componentes fenológicos, fisiológicos e produtivos da cultura de algodão de fileiras estreitas. O maior rendimento da cultura de algodão de linha estreita nas condições experimentais foi alcançado quando 25% da dose do fertilizante de nitrogênio sólido foi aplicado como cobertura de solo via solo, e 75% da dose do fertilizante de nitrogênio de liberação lenta foi pulverizada. Esta técnica proporciona maior rentabilidade do algodão produzido em relação à aplicação convencional do fertilizante N via solo.

PALAVRAS-CHAVE: Algodão. Correlação. NDVI. Nitrogênio.

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