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Nitrogen utilization efficiency by naturally colored cotton cultivars in semi-arid region[1]

Eficiência no uso de nitrogênio por cultivares de algodão naturalmente colorido em região semiárida

Francilene de Lima Tartaglia[2], Almir Rogerio Evangelista de Souza[2], Allysson Pereira dos Santos[3], Aurélio Paes Barros Júnior[3]*, Lindomar Maria da Silveira[3] and Manoel Galdino dos Santos[3]

ABSTRACT - Knowledge on nitrogen (N) utilization efficiency in colored cotton enables the correct management of N fertilizers, optimizing yield and minimizing environmental degradation.The objective of this study was to evaluate the N utilization efficiency and to determine the accumulation of dry matter and N by naturally colored cotton cultivars subjected to N fertilization in the Brazilian semi-arid region.The experiment was carried out under field conditions, at the Farm of the Federal Rural University of the Semi-Arid, in 2016 and 2017. The experimental design was in randomized blocks with split plots and four replicates, randomizing five N doses (0; 50; 100; 150 and 200 kg ha^{-1}) in the main plot and four colored cotton cultivars (BRS Safira, BRS Rubi, BRS Topázio and BRS Verde) in the subplots. Dry matter and N accumulations, agronomic, recovery, agrophysiological and physiological efficiencies in N utilization, and harvest index were evaluated. Cotton accumulates around 130 kg ha^{-1} of N along its cycle and directs 56.3% to seeds, 29% to leaves, 10.6% to stem and 3.8% to fibers. Nitrogen agronomic efficiency and recovery efficiency decrease with increased N doses. The cultivar BRS Topázio is the most responsive to N fertilization and the cultivar BRS Verde is the least responsive.

Key words: *Gossypium hirsutum* L.. Recovery efficiency. Dry matter accumulation.

RESUMO - O conhecimento sobre a eficiência do uso de nitrogênio (N) no algodoeiro colorido permite o correto manejo dos fertilizantes nitrogenados, otimizando o rendimento e minimizando a degradação ambiental. O objetivo do trabalho foi avaliar a eficiência no uso de N e determinar o acúmulo de matéria seca e N por cultivares de algodão naturalmente coloridas submetidas à adubação nitrogenada no semiárido brasileiro. O experimento foi realizado em condição de campo, na Fazenda da Universidade Federal Rural do Semi-Árido, em 2016 e 2017. O delineamento experimental foi em blocos casualizados com parcelas subdivididas e quatro repetições. Na parcela principal casualizou-se cinco doses de N (0; 50; 100; 150 e 200 kg ha^{-1}) e nas subparcelas, quatro cultivares de algodão colorido (BRS Safira, BRS Rubi, BRS Topázio e BRS Verde). Avaliou-se o acúmulo de matéria seca e de N, eficiência agronômica, de recuperação, agrofisiológica e fisiológica no uso de N e índice de colheita. O algodoeiro acumula em torno de 130 kg ha^{-1}de N no seu ciclo e direciona 56,3% para sementes, 29% para folhas, 10,6% para caule e 3,8% para fibras. A eficiência agronômica e a eficiência de recuperação de N decrescem com aumento nas doses de N. A cultivar BRS Topázio é a mais responsiva à adubação nitrogenada e a cultivar BRS Verde a menos responsiva.

Palavras-chave: *Gossypium hirsutum* L.. Eficiência de recuperação. Acúmulo de matéria seca.

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*Author for correspondence
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[1]Parte da Tese do primeiro autor apresentada ao Curso de Pós-Graduação em Fitotecnia, Universidade Federal Rural do Semi-Árido/UFERSA

[2]Instituto Federal de Educação, Ciência e Tecnologia de Alagoas, *Campus* Piranhas, Piranhas-AL, Brasil, francilene.tartaglia@ifal.edu.br (ORCID ID 0000-0001-6023-0033), almir.souza@ifal.edu.br (ORCID ID 0000-0002-9266-5063)
[3]Programa de Pós-Graduação em Fitotecnia, Departamento de Ciências Agronômicas e Florestais, Centro de Ciências Agrárias, Universidade Federal Rural do Semi-Árido/UFERSA, Mossoró-RN, Brasil, allyssoneng@gmail.com (ORCID ID 0000-0002-2224-241X), aurelio.barros@ufersa.edu.br (ORCID ID 0000-0002-6983-8245), lindomarmaria@ufersa.edu.br (ORCID ID 0000-0001-9719-7417), manoel.galdino5@gmail.com (ORCID ID 0000-0003-4972-5849)

INTRODUCTION

Naturally colored cotton is a product with great environmental appeal, as it dispenses with the fiber dyeing process, avoiding the release of chemical and toxic effluents into the environment (GUARATINI; ZANONI, 2000). However, colored cotton is mainly grown in the northeast region of Brazil, with low technology and without the use of irrigation and fertilizers, which results in low yields.

For naturally colored cotton to become an option of cultivation in other regions of the country and in large areas, it is important to establish technologies suitable for its cultivation. Among these, determining the ideal nitrogen (N) dose for each cultivar is extremely important, since N is the nutrient most extracted and exported by cotton crop and is related to increased yield (DEVKOTA *et al*., 2013; REIS JÚNIOR *et al*., 2012; STAMATIADIS *et al*., 2016).

The N content accumulated in cotton is important because fiber yield is positively related to N accumulation in the plant (DONG *et al*., 2010). However, high N doses cause excessive vegetative development and reductions of yield, fiber percentage and N utilization efficiency (DEVKOTA *et al*., 2013; DU *et al*., 2016; LI *et al*., 2017; ROCHESTER, 2011). Thus, N supply must be carried out based on technical criteria, so that it contributes to increasing fiber yield.

N utilization efficiency (NUE) is defined as the ratio between the harvested product (grains, fibers or dry matter) and the N dose applied (FAGERIA, 1998; FAGERIA; BALIGAR, 2005; STAMATIADIS *et al*., 2016). In annual crops, nutrient recovery efficiency is considered low, on average 50% for N, 10% for P and 40% for K (BALIGAR; BENNETT, 1986). For cotton, N recovery efficiency varies among values of 17.8% (DU *et al*., 2016), 32.9% (LI *et al*., 2017), 49% (LOU *et al*., 2018), 57% (ARAÚJO; CAMACHO; VINCENSI, 2013) and 70% (YANG *et al*., 2013).

NUE determinationin colored cotton is an important approach to evaluate the destination of N fertilizers applied and their importance in colored fiber yield. In view of the above, the objective of this study was to evaluate the N utilization efficiency and to determine the accumulation of dry matter and N by naturally colored cotton cultivars subjected to N fertilization in the Brazilian semi-arid region.

MATERIAL AND METHODS

The soil of the experimental area is classified as *Latossolo Vermelho Amarelo Distrófico* (Oxisol) with sandy texture (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2013). Two months prior to the installation of the experiments, soil samples were collected at 0-20 cm depth and characterized physically and chemically (Table 1).

The soil was prepared with one plowing and oneharrowing, chemically corrected with dolomitic limestone, and fertilized with phosphorus (single superphosphate) in the sowing hole and below the seeds, and with potassium (KCl) together with the N doses. Phosphate and potassium fertilization was performed according to soil analysis, following the recommendations of Pedroso Neto *et al.* (1999). Micronutrients were supplied using a commercial formulation containing 2.1% B, 0.36% Cu, 2.66% Fe, 2.48% Mn, 0.036% Mo, and 3.38% Zn through irrigation water when the flower buds appeared (PEDROSO NETO *et al*., 1999).

Irrigation was performed with a localized drip system, with emitters spaced every twenty centimeters and flow rate of 1.5 liters per hour. The applied water depth was based on daily crop evapotranspiration and calculated according to Allen *et al*. (1998). Meteorological data were collected from the automatic meteorological station, belonging to the National Institute of Meteorology (INMET) of Mossoró-RN and are presented in Figure 1.

The experimental design used was in randomized blocks with split plots and four replicates. N doses were arranged in the main plots, while colored cotton cultivars were arranged in the subplots. The experimental units were 2.8 x 3.8 m, containing four plant rows, with usable area consisting of two rows, totaling 10.64 m^2.

The N doses used were: 0, 50, 100, 150 and 200 kg ha^{-1}, applied in the form of urea (45% N) and supplied to plants through irrigation water. The doses were split into four equal portions, applied at different stages of crop development (seedling emergence, plant with three true leaves, appearance of floral bud and beginning of cotton flowering). The colored cotton cultivars used were BRS Verde (green fiber), BRS Rubi and BRS Safira (reddish fiber) and BRS Topázio (light brown fiber).

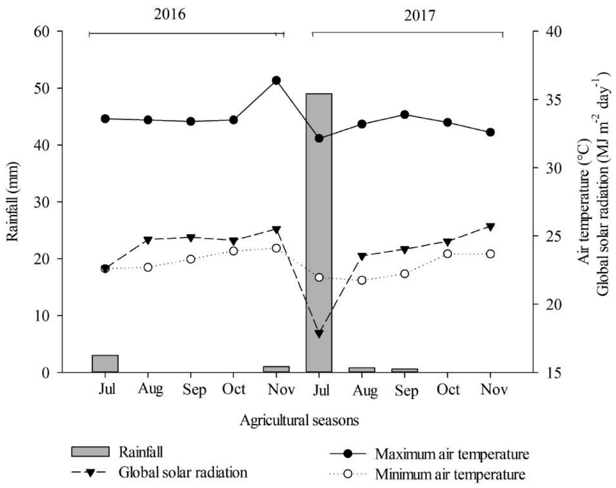
Sowing was performed on July 6, 2016 (1st season) and July 26, 2017 (2nd season), manually, by placing three seeds per hole at a depth of three to five centimeters. The emergence occurred on July 10, 2016 and on July 30, 2017, respectively. The spacing used was 0.7 x 0.2 m. The main plots consisted of 2.8 m x 64.0 m (179.2 m^2).

Thinning was performed when the plants had three true leaves, by manually uprooting excess plants, leaving only one plant per hole. Phytosanitary management was performed according to the need, keeping the plants free of weeds, pests and diseases.

Table 1 - Physical-chemical characterization of the soil of the experimental area where the experiments were installed in the 2016 and 2017 seasons

Season	Sand	Silt	Clay	pH water	OM g kg^{-1}	P	K	Na	Ca	Mg	Al^{3+}	H+Al	EC ds/m
	kg kg^{-1}					mg dm^{-3}			cmol dm^{-3}				
2016	0.90	0.02	0.08	4.40	7.52	3.0	27.1	8.0	0.40	0.30	0.15	1.49	0.02
2017	0.88	0.02	0.10	5.00	4.38	1.9	32.4	1.6	1.40	0.70	0.00	1.98	0.06

Figure 1- Rainfall, minimum and maximum air temperatures (°C) and global solar radiation incident on the surface (Rg, MJ m^{-2} d^{-1}) along the colored cotton cycle in the 2016 and 2017 seasons



Harvest was performed manually when the weeds of the lower half of the plant were open, approximately 100 days after emergence (DAE), and lasted until the opening of all the bolls, harvesting all the plants from the usable area.

Cotton fiber yield was determined by multiplying seed cotton yield by fiber percentage (determined in fiber samples sent to the laboratory of Embrapa Cotton in High Volume Instrument - HVI), converted to kg ha^{-1} (Table 2).

Dry matter was determined at 125 (1st season) and 114 (2nd season) days after emergence, when two plants were collected per experimental unit, taken to the laboratory and separated into leaves (leaf + petiole), stem (stem + empty capsules), seeds and fiber. Leaves and stems were washed in distilled water and then the structures (leaf, stem + capsules, seed and fiber) were separately placed in paper bags and taken to a forced air circulation oven at a temperature of 65 °C until constant weight was obtained. Subsequently, dry matter was determined by weighing the constituent parts of the cotton plant in grams, and subsequently converted to kg ha^{-1}.

N accumulation was determined in each plant component by the Kjeldahl method (MALAVOLTA; VITTI; OLIVEIRA, 1997). First, the N content was determined in each structure and then the N content was multiplied by the accumulated dry matter, obtaining the N accumulation per hectare. The efficiency indices were determined according to the methodology proposed by Fageria and Baligar (2005) and Fageria, Santos and Cutrim (2007), as follows:

$$Agronomic\ efficiency\ (AE) = FY_{WN}\text{-}FY_{WON}/Q_{NA} \quad (1)$$

Where - FY_{WN} is the fiber yield with nitrogen fertilizer; FY_{WoN} is fiber yield without nitrogen fertilizer; Q_{NA} is the quantity of N applied, in kilograms.

$$Physiological\ efficiency\ (PE) = (BY_{WN}\text{-}BY_{WON})/(NA_{WN}\text{-}NA_{WON}) \quad (2)$$

Where - BY_{WN} is biological yield (total shoots) with nitrogen fertilizer; BY_{WoN} is biologicalyield without nitrogen fertilizer; NA_{WN} is the nitrogen accumulation in the total shoots with nitrogen fertilizer application; and NA_{WoN} is the nitrogen accumulation in the total shoots without nitrogen fertilizer application.

$$Agrophysiological\ efficiency\ (APE) = (FY_{WN}\text{-}FY_{WON}/(NA_{WN}\text{-}NA_{WON}) \quad (3)$$

Where - FY_{WN} is the fiber yield with nitrogen fertilizer; FY_{WoN} is the fiber yield without nitrogen fertilizer; NA_{WN} is the nitrogen accumulation in the total shoots with nitrogen fertilizer application; and NA_{WoN} is the nitrogen accumulationin the total shoots without nitrogen fertilizer application.

$$Recovery\ efficiency\ (RE) = (NA_{WN}\text{-}NA_{WON})/Q_{NA} \quad (4)$$

Where - NA_{WN} is the nitrogen accumulationin the total shoots with nitrogen fertilizer; NA_{WoN} is the nitrogen accumulationin the total shoots without nitrogen fertilizer; and Q_{NA} is the quantity of *N* applied in kilograms.

The harvest index was obtained by the quotient between seed cotton yield (kg ha^{-1}) and the total dry matter yield of the shoots (kg ha^{-1}).

The data were subjected to analysis of variance in each agricultural season (2016 and 2017) and, subsequently, the data were subjected to joint analysis.

Table 2 - Fiber yield (kg ha^{-1}) in the 2016 season (A) and 2017 season (B) as a function of different colored cotton cultivars irrigated with different nitrogen (N) doses

N doses (kg ha^{-1})	Fiber cotton yield (kg ha^{-1})			
	2016 Season			
	BRS Verde	BRS Rubi	BRS Safira	BRS Topázio
0	616.50	927.75	854.25	1,245.50
50	639.00	964.50	975.00	1,508.75
100	717.50	1,173.25	1,228.00	1,824.75
150	819.50	1,297.75	1,232.00	2,042.00
200	963.50	1,275.75	1,542.00	1,721.75
	2017 Season			
0	469.75	569.00	503.00	609.50
50	638.75	877.75	970.00	1,351.50
100	696.25	901.75	902.00	1,356.50
150	738.25	1,075.25	1,077.00	1,502.75
200	756.25	991.50	1,107.25	1,624.75

Regression analysis was used for quantitative data and Tukey test ($p<0.05$) for qualitative data.

RESULT AND DISCUSSION

The cultivar factor influenced the harvest index. The interaction betweenseason and cultivar influenced agronomic efficiency, agrophysiological efficiency and N recovery efficiency. The interaction between dose and season influenced the agronomic N utilization efficiency. The interaction between dose and cultivar influenced the N recovery efficiency. The N physiological efficiency was not influenced by the studied factors.

The maximum dry matter of shoots produced by the cultivars Rubi, Safira, Topázio and Verde were 8,773.1, 9,049.8, 10,294.8 and 8,405.1 kg ha^{-1}, obtained with the N doses of 163, 166, 180 and 159 kg ha^{-1}, respectively (Figure 2A).

The N content in the total dry matter of the shoots increased with the increase in N doses (Figure 2B). The cultivars Rubi, Safira, Topázio and Verde accumulated, respectively, a maximum N contents of 144, 149, 155 and 144 kg ha^{-1} in the shoots with the N dose of 200 kg ha^{-1}, and these values were 47, 56, 62 and 49% higher than the N accumulation in the absence of N fertilization (zero dose).

The colored cotton cultivars accumulated, on average, 122.3 kg ha^{-1} of N along their production cycle (Table 3). Seeds were the structures that most accumulated N, whereas fibers were the ones with the lowest accumulation. Of all the N accumulated by the plants, 56.3% was directed to seeds, 29% to leaves, 10.6% to stem + capsules and only 3.8% to fibers.

Of all the N accumulated by cotton in the shoots (122 kg ha^{-1}), 60.3% is exported from the plantation through the harvested product (seed + fibers) and only 39.7% returns to the soil through leaves, stems and capsules (Table 3).

The agronomic efficiency in N utilization by colored cotton decreased with the increase in N doses, with higher efficiency in the 2017 season (Figure 3A). In the 2016 season, the highest agronomic efficiency was obtained with the N dose of 50 kg ha^{-1} (4.7 kg kg^{-1}) and the lowest efficiency with the N dose of 200 kg ha^{-1} (2.6 kg kg^{-1}). The N dose of 200 kg ha^{-1}reduced by 43.5% the agronomic efficiency in N utilization by colored cotton.

In the 2017 season, the highest agronomic efficiency was obtained with the N dose of 50 kg ha^{-1} (8.8 kg kg^{-1}) and the lowest efficiencywith the N dose of 200 kg ha^{-1} (1.6 kg kg^{-1}). The use of 200 kg ha^{-1} of N reduced by 81.9% the agronomic efficiency in N utilization by colored cotton.

The efficiency of N recovery by the colored cotton cultivars decreased with increasing N doses (Figure 3B). Higher doses of N resulted in lower N recovery by colored cotton.

Highest N recovery efficiency was obtained at the dose of 50 kg ha^{-1} of N, with 47.3, 77.8, 116.6 and 84.3% of N recovered by the cultivars Rubi, Safira, Topázio

Figure 2 - Dry matter (A) and N content (B) accumulated in the shoots of colored cotton cultivars irrigated with N doses in two agricultural seasons, 2016 and 2017

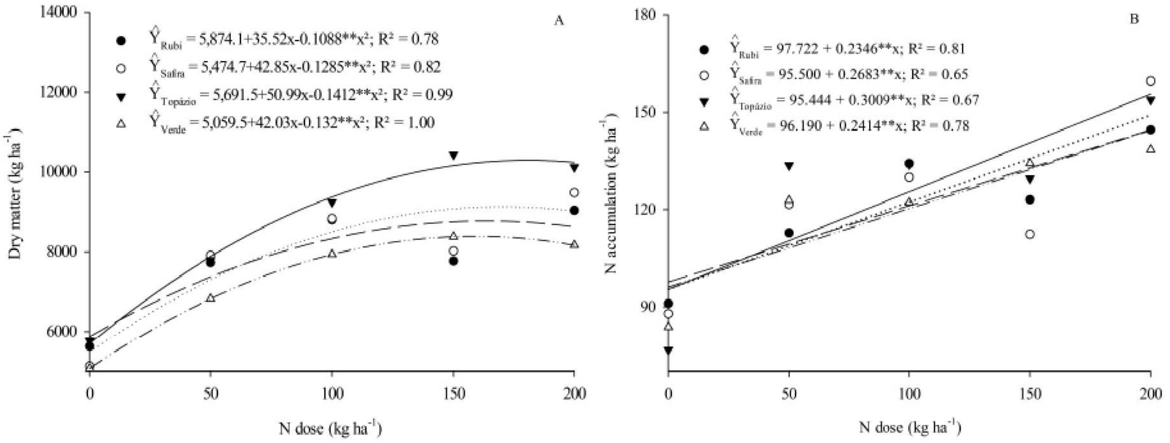
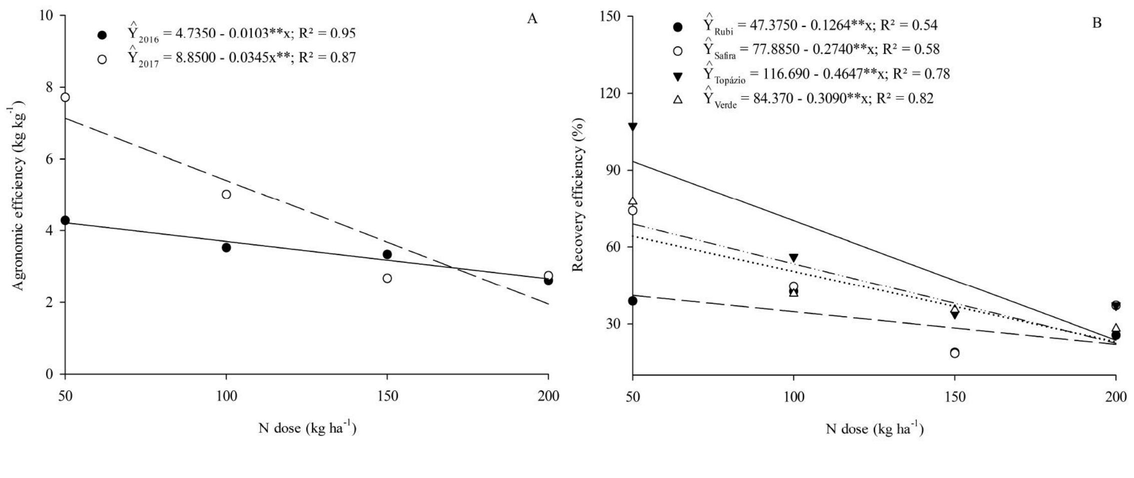


Table 3 - Distribution of N accumulated in the shoots of naturally colored cotton cultivars irrigated with different N doses in two agricultural seasons

Cultivar	Stem	Leaf	Fiber	Seed	Total
			(kg ha^{-1})		
Rubi	12.5	35.7	4.1	68.7	121.1
Safira	13.0	35.0	4.7	69.4	122.3
Topázio	13.9	35.5	6.7	69.2	125.5
Verde	12.7	35.7	3.2	68.5	120.3
Mean*	13.0	35.5	4.7	68.9	122.3

* Mean of the five N doses in two agricultural seasons; N accumulation in a population of 71,428 plants ha^{-1}

Figure 3 - Agronomic efficiency in N utilization (A) and N recovery efficiency (B) by naturally colored cotton cultivars irrigated with N doses in two agricultural seasons, 2016 and 2017



and Verde, respectively. Lowest N recovery occurred at N dose of 200 kg ha^{-1}, with 22, 23, 23.7 and 22.5% of N recovered by the cultivars Rubi, Safira, Topázio and Verde, respectively.

The cultivar that had the highest N recovery capacity was Topázio, followed by Verde and Safira. Rubi had the lowest capacity to recover the N applied to the soil.

In the 2016 season, higher agronomic efficiency in N utilization was obtained with the cultivars Safira and Topázio (4.4 and 4.5 kg kg^{-1}, respectively) and lower agronomic efficiency with the cultivars Rubi and Verde (2.9 and 2.1 kg kg^{-1}, respectively) (Table 4).

In the 2017 season, higher agronomic efficiency in N utilization was obtained with the cultivar Topázio (7.4 kg kg^{-1}). The cultivars Rubi and Safira obtained intermediate agronomic efficiency (3.4 and 4.3 kg kg^{-1}, respectively) and lower efficiency was obtained with the cultivar Verde (2.7 kg kg^{-1}). Among the agricultural seasons, the cultivar Topázio obtained greater efficiency in 2017.

Higher agrophysiological efficiency, in the 2016 season, occurred with the cultivars Topázio, Safira and Rubi, respectively, and lower with the cultivar Verde, which produced 30.7% less fiber per kilogram of N accumulated in the shoots when compared to the average of the other cultivars.

Higher agrophysiological efficiency was obtained in the 2017 season with the cultivars Rubi, Safira and Topázio (mean of 13.1 kg kg^{-1}) and lower with the cultivar Verde (5.4 kg kg^{-1}),which produced 58.5% less fiber per kg of N accumulated in the shoots when compared to the average of the other cultivars.

In the 2016 season, the N recovery efficiency ranged from 36.3 to 52.4% among the cultivars, with an average value of 43.57%. Highest recovery efficiency was obtained with the cultivar Topázio and lowest recovery efficiency with the cultivar Rubi.

In the 2017 season, the N recovery efficiency ranged from 25.1 to 51.2%, with an average value of 38.8%. Highest N recovery efficiency was obtained with the cultivar Topázio and lowest with Rubi. The cultivars Rubi and Safira obtained higher efficiency in the 2016 season.

The harvest index varied between 0.32 and 0.38, with an average of 0.34. Highest harvest index was reached with the cultivar Topázio.

Cotton plants grown in the absence of N fertilization showed small size and lower numbers of leaves, reproductive branches and bolls, which resulted in lower dry matter production (Figure 2A). With the increase in N doses, the plants showed a higher volume of leaves, branches and bolls. Between the N doses of 100 and 150 kg ha^{-1}, the plants showed similar development in size and shape. At N dose of 200 kg ha^{-1}, the plants had greater height and higher number of leaves, but the number of bolls was lower.

The increase in N doses, besides causing an increment in dry matter production, also increased the accumulation of N in cotton (Figure 2B), which has also been verified by Zhang *et al*. (2012), Xiaoping *et al*. (2008), Araújo, Camacho and Vincensi (2013) and Rochester (2011).

The total N accumulation in colored cotton ranged from 132.6 to 112.0 kg ha^{-1} in the 2016 and 2017 seasons, with an average of 122.3 kg ha^{-1}. These values are within the accumulation range found by other authors, such as Du *et al*. (2016), 128 to 241 kg ha^{-1} of N, and Rochester (2011), 101 and 162 kg $ha^{-1}$of N, for white cotton.

In the absence of N, the plants showed visual symptoms of N deficiency, such as chlorosis, reduction in height, size and number of leaves and number of bolls, symptoms that were mitigated by the increase in N doses. From the N dose of 100 kg ha^{-1}, the visual symptoms of N deficiency were no longer observed.

The N absorbed by cotton was directed mainly to reproductive structures (60.2%), to the detriment of vegetative structures (39.4%) (Table 3). These results were also obtained by Yang *et al.* (2013) and Tang *et al*. (2012). Greater accumulation of N in reproductive structures may have occurred because the dry matter collection was performed at the end of the crop cycle, when many leaves senesced and much of the N stored in the plant had been translocated to the reproductive organs, for seed and fiber production (ROSOLEM *et al*., 2012; TANG *et al*., 2012; YANG *et al*., 2013).

Table 4 - Efficiency of N utilization by naturally colored cotton irrigated with different N doses in two agricultural seasons

Cultivar	AE (kg fiber/kg N)		APE (kg fiber/kg N)		RE (%)		HI
	2016	2017	2016	2017	2016	2017	
Rubi	2.9 Ab	3.4 Abc	7.5 Ba	12.9 Aa	36.3 Ab	25.1 Bb	0.32 b
Safira	4.4 Aa	4.3 Ab	7.8 Ba	13.1 Aa	46.7 Aab	32.3 Bb	0.34 b
Topázio	4.5 Ba	7.4 Aa	8.1 Ba	13.4 Aa	52.4 Aa	51.2 Aa	0.38 a
Verde	2.1 Ab	2.7 Ac	4.9 Ba	5.4 Ab	38.9 Aab	46.7 Aa	0.34 b

Equal lowercase letters in the column and uppercase letters in the row do not differ by Tukey test at 0.05 probability level. AE: agronomic efficiency; APE: agrophysiological efficiency; RE: recovery efficiency; HI: harvest index

Higher N accumulation in the shoots of cotton occurred in the 2016 season and the values were 15.8, 25.7, 12, 79.3 and 18.3% higher than in 2017, for stem, leaf, fiber and shoot dry matter, respectively (Table 3). Lower N accumulation by cotton in the 2017 season may be due to higher rainfall in the first 30 days after sowing (Figure 1), a period in which ¾ of the N dose was applied, which may have caused loss of N by leaching. Stamatiadis *et al*. (2016) obtained a 20% difference in N absorption between one season and another, attributing this difference to the higher rainfall that occurred at the beginning of the crop cycle, which influenced the level of soil N (nitrate).

The agronomic efficiency in N utilization and N recovery efficiency decreased with the increase in N doses (Figure 3A and 3B), corroborating the results obtained by Devkota *et al.* (2013), Lou *et al*. (2018), Rochester (2011), Stamatiadis *et al*. (2016), and Zhang *et al*. (2012). High N doses applied to the soil are considered the main factor that negatively affects the N utilization efficiency in cotton crop (ROCHESTER, 2011; STAMATIADIS *et al*., 2016). The negative relationship between N utilization efficiency (NUE) and N doses occurs because the N supply exceedsthe capacity of N assimilation by plants (MEISINGER; SCHEPERS; RAUN, 2008), which leads to the loss of excess N not absorbed into the environment.

The agronomic efficiency for N utilization (Figure 3A) was on average 6.7 kg kg^{-1} at the lowest N dose applied (50 kg ha^{-1}) and 2.13 kg kg^{-1} at the highest N dose (200 kg ha^{-1}). For seed cotton, Devkota *et al*. (2013), obtained an average of 5.5 and 14.1 kg kg^{-1} in two seasons, respectively, and Lou *et al*. (2018), found an average of 6.3 kg kg^{-1} for fertigated cotton, in two seasons.

The N recovery efficiency decreased with the increase in N doses (Figure 3B), being on average 81.5% at the N dose of 50 kg ha^{-1} and 22.8% at the N dose of 200 kg ha^{-1}. Some authors have found average N recovery efficiency in cotton of 49.1% (LOU *et al*., 2018), 57% (ARAÚJO; CAMACHO; VINCENSI, 2013), 18.3% (ZHANG *et al*., 2012) and between 44% and 24% (DEVKOTA *et al*., 2013).

The low N recovery efficiency, on average 22.8%, at the N dose of 200 kg ha^{-1}led to large losses of N to the environment (77.2%), evidencing that, with the increase in the applied N dose, there is a reduction in N recovery by colored cotton plants. Application of 200 kg ha^{-1} of N caused a loss of 77.2% of the applied N, which is probably due to ammonia volatilization because, according to Tian *et al*. (2017), there is a positive linear correlation between the increase in N doses and ammonia volatilization.

Agrophysiological efficiency ranged from 7.1 to 11.2 kg kg^{-1} in the 2016 and 2017 seasons, respectively (Table 4). Rochester (2011) found an average value of 12.5 kg kg^{-1} and Stamatiadis *et al*. (2016), obtained 6.9 and 8.8 kg kg^{-1} in the 2008 and 2009 seasons, respectively. For the production of 100 kg of colored fiber, it was necessary to accumulate 13.3, 12.7, 12.2 and 20.3 kg N in 2016 and 7.7, 7.5, 7.4 and 18.2 kg N in 2017 for the cultivars Rubi, Safira, Topázio and Verde, respectively.

In the 2017 season, agrophysiological efficiency was on average 30% higher than in 2016, with higher fiber production for the same amount of N accumulated. This is because, with higher rainfall in 2017 (Figure 1), a greater amount of N was possibly lost by leaching, so plants directed a greater amount of N absorbed to fiber and seed production, instead of producing leaves and branches.

The cultivar Topázio obtained higher N recovery efficiency (Figure 3B), higher agrophysiological efficiency, higher N accumulation in the plant and in the fiber, and higher harvest index (Table 4), results that resulted in higher fiber yield (Figure 2). The cultivar Verde obtained lower N accumulation in the plant (Figure 2B) and in the fibers (Table 3), lower agronomic efficiency in N utilization and lower agrophysiological efficiency (Table 4), which resulted in lower fiber yield (Table 2).

The best results obtained with the cultivar Topázio are probably due to its genetic superiority, since it originates from a white fiber cultivar of high fiber yield, Delta Opal. The cultivars Rubi, Safira and Verde originate from cultivars with lower genetic selection for fiber yield (CARVALHO; ANDRADE; SILVA FILHO, 2011), and thus with lower response to N fertilization.

N utilization efficiency decreased with the increase in N doses, which confirms that high N doses cause large losses of N from the soil-plant system (STAMATIADIS *et al*., 2016; WEI *et al*., 2012). The high level of N loss, besides causing environmental problems, increases the cost of production, reducing the profits of the producer. Thus, it is extremely important to select cultivars with greater efficiency for N utilization, as well as defining the best N dose, making possible to have high yields with lower amount of N applied.

CONCLUSIONS

1. Naturally colored cotton accumulates around 130 kg ha^{-1} of N along its production cycle;
2. The N accumulated in colored cotton is directed, in descending order, to seeds (56.3%), leaves (29%), stems (10.6%) and fibers (3.8%);
3. The agronomic efficiency in N utilization and N recovery efficiency decrease with increasing doses of N;

4. The cultivar BRS Topázio is the most responsive to N fertilization, with higher dry matter production, higher N accumulation, higher efficiency in N utilization and higher harvest index;

5. The cultivar BRS Verde is the least responsive to N fertilization, with lower dry matter production, lower N accumulation and lower agronomic and agrophysiological efficiencies in N utilization.

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REFERENCES

ALLEN, R. G. *et al*. **Crop evapotranspiration**: guidelines for computing crop water requirements. Rome: FAO, 1998. 300 p. (FAO Irrigation and Drainege.Paper, 56).

ARAÚJO, E. de O.; CAMACHO, M. A.; VINCENSI, M. M. Nitrogen use efficiency by cotton varieties. **Revista de Ciências Agrárias**, v.36, n.1, p.10-16, 2013.

BALIGAR, V. C.; BENNETT, O. L. NPK - fertilizer efficiency: a situation analysis for the tropics. **Fertilizer Research**, v. 10, p. 147-164, 1986.

BORGES, V. P. *et al*. Energy balance and evapotranspiration of melon grown with plastic mulch in the Brazilian semiarid region. **Scientia Agricola**, v. 72, n. 5, p. 385-392, 2015.

CARVALHO, L. P. de; ANDRADE, F. P. de; SILVA FILHO, J. L. da. Cultivares de algodão colorido no Brasil. **Revista Brasileira de Oleaginosas e Fibrosas**, v. 15, n. 1, p. 37-44, 2011.

DEVKOTA, M. *et al*. Tillage and nitrogen fertilization effects on yield and nitrogen use efficiency of irrigated cotton. **Soil & Tillage Research**, v. 134, p. 72-82, 2013.

DONG, H. *et al.* Effects of plant density and nitrogen and potassium fertilization on cotton yield and uptake of major nutrients in two fields with varying fertility. **Field Crops Research**, v. 119, p. 106-113, 2010.

DU, X. *et al*. Nitrogen use efficiency of cotton (*Gossypiumhirsutum* L.) asinfluenced by wheat–cotton cropping systems. **European Journal of Agronomy**, v. 75, p. 72-79, 2016.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Sistema brasileiro de classificação de solos**. Brasília, 2013. 353 p.

FAGERIA, K. N. Otimização da eficiência nutricional na produção das culturas. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 2, p. 6-16, 1998.

FAGERIA, N. K.; BALIGAR, V. C. Enhancingnitrogen use efficiency in cropplants. **Advances in Agronomy**, v. 88, p. 97-185, 2005.

FAGERIA, N. K.; SANTOS, A. B. dos; CUTRIM, V. dos A. Produtividade de arroz irrigado e eficiência de uso do nitrogênio influenciadas pela fertilização nitrogenada. **Pesquisa Agropecuária Brasileira**, v. 42, n. 7, p. 1029-1034, 2007.

GUARATINI, C. C. I.; ZANONI, M. V. B. Corantes têxteis. **Química Nova**, v. 23, p. 71-78, 2000.

LI, P. *et al*. Effects of nitrogen rate and split application ratio on nitrogen use and soil nitrogen balance in cotton fields. **Pedosphere**, v. 27, n. 4, p. 769-777, 2017.

LOU, Z.*et al*. Effects of reduced nitrogen rate on cotton yield and nitrogen use efficiency as mediated by application mode or plant density. **Field Crops Research**, v. 218, p. 150-157, 2018.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. **Avaliação do estado nutricional das plantas**: princípios e aplicações. 2. ed. Piracicaba: POTAFOS, 1997. 319p.

MEISINGER, J. J.; SCHEPERS, J. S.; RAUN, W. R. **Crop nitrogen requirement and fertilization, nitrogen in agricultural systems**. Madison:American Society of Agronomy, 2008. p. 563-612. (Agronomy monograph, 49).

PEDROSO NETO, J. C. *et al.* Algodão. *In:* RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais**: 5ª aproximação.Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais, 1999. p. 278-279.

REIS JÚNIOR, R. dos A. *et al*. Productivity and agronomic efficiency of cotton plants in response to nitrogen and súlfur supply. **Revista Brasileira de Ciências Agrárias**, v. 7, n. 4, p. 555-561, 2012.

ROCHESTER, I. J. Assessing internal crop nitrogen use efficiency in high-yielding irrigated cotton. **Nutrient Cycling in Agroecosystems**, v. 90, p. 147-156, 2011.

ROSOLEM, C. A. *et al.* Acúmulo de nitrogênio, fósforo e potássio pelo algodoeiro sob irrigação cultivado em sistemas convencional e adensado. **Revista Brasileira de Ciências do Solo**, v. 36, p. 457-466, 2012.

STAMATIADIS, S. *et al*. Nitrogen uptake and N-use efficiency of Mediterranean cotton undervaried deficit irrigation and N fertilization. **European Journal of Agronomy**, v. 73, p. 144-151, 2016.

TANG, H. Y. *et al*. Improvement of fertilizer N recovery by allocating more N for later application in cotton (*Gossypium hirsutum* L.). **International Journal of Basic and Applied Sciences**, v. 12, p. 32-37, 2012.

TIAN, X. *et al*. Controlled-release urea decreased ammonia volatilization and increased nitrogen use efficiency of cotton. **Journal of Plant Nutrition and Soil Science**, v. 180, p. 667-675, 2017.

WEI, C. Z. *et al*. The fate of fertilizer N applied to cotton in relation to irrigation methods and N dosage in arid area. **Journal of Arid Land**, v. 4, n. 3, p. 320-329, 2012.

XIAOPING, X. *et al*. Accumulation characteristics of biomass and nitrogen and critical nitrogen concentration dilution model of cotton reproductive organ. **Acta Ecologica Sinica**, v. 28, n. 12, p. 6204-6211, 2008.

YANG, G-Z.*et al*. Fertilizer 15^{N} accumulation, recovery and distribution in cotton plant as affected by N rate and split. **Journal of Integrative Agriculture**, v. 12, n. 6, p. 999-1007, 2013.

ZHANG, D. *et al*. Lint yield and nitrogen use efficiency of field-grown cotton vary with soil salinity and nitrogen application rate. **Field Crops Research**, v. 138, p. 63-70, 2012.