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Effects on soil chemical attributes and cotton yield from ammonium sulfate and cover crops

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ABSTRACT. Fertilizer use in no-till systems must be aligned with a correct interpretation of soil chemical attributes and crop demands. The objectives of this work were evaluate the effects of pre-sowing application of ammonium sulfate (AS) and of cover crops on the yields and soil chemical attributes of no-till cotton (*Gossypium hirsutum* L. r. *latifolium* Hutch*)* over two harvesting years. The experiment was arranged in randomized complete block design, with the plots in strips, and the variables were three cover crops (*Raphanus sativus* L., *Avena strigosa* L. and *Avena sativa* L.) and four AS doses (0, 150, 300, and 450 kg ha^{-1}) applied over millet dry biomass. The cotton in the experimental plots was manually harvested on April 25, 2007 and April 24, 2008. The soil samples were collected between cotton rows in all plots on May 5, 2007 and May 12, 2008, at depths of 0.0-0.05, 0.05-0.10, and 0.10-0.20 m for soil fertility analyses. The increasing doses of AS induced lower soil pH, and calcium (Ca) and magnesium (Mg) levels in the superficial soil layer, as well as higher exchangeable aluminum (Al) and sulfur (S) levels until a depth of 0.20 m. Seed cotton yields increased with increasing AS doses.

Keywords: *Gossypium hirsutum,* fertilizer management, soil fertility, no-till.

Efeito nas características químicas do solo e produtividade do algodoeiro em função de sulfato de amônio e plantas de cobertura

RESUMO. A adubação no sistema plantio direto deve ser aliada a uma correta interpretação das características químicas do solo e necessidade das culturas. O trabalho objetivou avaliar em dois anos de cultivo, o efeito da aplicação de sulfato de amônio (SA) em pré-semeadura do algodoeiro e de plantas de cobertura, implantadas em semeadura direta, sobre atributos químicos do solo e produtividade do algodoeiro. O delineamento experimental foi o de blocos ao acaso, disposto em faixas, compostos por três plantas de cobertura (nabo forrageiro, aveia preta e aveia branca); e 4 doses de adubação nitrogenada (0, 150, 300 e 450 kg ha^{-1} de sulfato de amônio), aplicadas sobre a palhada do milheto. A colheita das parcelas experimentais do algodoeiro foi manual em 25/04/07 e 24/04/08. Em 05/05/07 e 12/05/08 foram coletadas amostras de solo nas profundidades de 0,0-0,05; 0,05-0,10 e 0,10-0,20 m, na entrelinha do algodoeiro para caracterização da fertilidade. O aumento de doses de sulfato de amônio reduziu os valores de pH, e teores de Ca e Mg na superfície do solo, bem como aumentou a concentração de Al^{+} trocável e de enxofre até 0,20 m. A produtividade de algodão em caroço aumentou com as doses de sulfato de amônio.

Palavras-chave: *Gossypium hirsutum*, manejo da adubação, fertilidade do solo, plantio direto.

Introduction

Cotton is an important crop worldwide, with a high aggregated value due to its many processed derivates and the high consumer demand. Fertilizer recommendations for cotton are based on soil and leaf analysis. However, it is necessary to interpret such results with respect to the field management history of the farm or region. Soil fertility evaluation aims to quantify the availability of soil nutrients in order to overcome deficiencies and promote the growth and development of plants (CANTARUTTI et al., 2007). Nevertheless, under 'Cerrado' conditions, there are no nitrogen (N) and sulfur (S) reference indices to assist with a safe recommendation.

Areas under no-till systems frequently exhibit interactions among applied fertilizers and crops, cover crops, soil and soil microorganisms. Such interactions are usually driven by complex dynamics, especially for cotton, and require detailed research (ALVES et al., 2006; LAMAS; STAUT, 2005).

Nitrogen is the nutrient most necessary to the cotton plant; an excess or a deficiency can lead to losses in cotton yield and quality (ROSOLEM; VAN MELLIS, 2010).

The occurrence of sulfur deficiency in cotton has increased due to the decrease in the use of S-bearing fertilizer and reduced atmospheric S deposition. The application of 22 or 34 kg ha^{-1} S increased the lint yield by 8 - 9% and micronaire by 4 - 5% when compared to no S when averaged over three normal growing seasons (2008-2010) (YIN et al., 2011).

The relevance of cover crops has long been recognized in agriculture because the use of dry biomass on the soil increases crop yields through improvements in the organic matter content and physical attributes of the soil, thereby reducing the demand for additives (DUFRANC et al., 2004; OLIVEIRA et al., 2004; PINHEIRO et al., 2004; ROSCOE; BUURMAN, 2003).

Therefore, this work aims to evaluate the effects of the pre-sowing application of ammonium sulfate and of cover crops on no-till cotton yields and soil chemical attributes over two years.

Material and methods

The experiment was performed in Selvíria, Mato Grosso do Sul State, Brazil, a region of 'Cerrado' native vegetation (20° 20' S latitude, 51° 24' W longitude and an altitude of 344 m). The region shows an Aw type climate according to the Köppen classification, defined as tropical-humid with a rainy summer and dry winter and an average annual temperature of 24.5°C, an average annual rainfall of 1.232 mm and an average annual relative humidity of 64.8%, as shown in Figure 1. The soil was classified as an Oxisol (very clayed) (SANTOS et al., 2006) with 500, 50 and 450 g kg^{-1} of clay, silt and sand, respectively.

The soil samples were collected in June 2005 for the characterization of chemical attributes. The analysis produced the following results: organic matter (OM) = 24 g dm^{-3}; pH ($CaCl_2$) = 4.9; phosphorus (P resin) = 10 mg dm^{-3}; potassium (K), calcium (Ca), magnesium (Mg), potential acidity (H+Al), exchangeable acidity (Al) and cation exchange capacity (CEC) (mmol$_c$ dm^{-3}) = 4.6, 18, 10, 24, 0, and 57, respectively; and base saturation (V%) = 57%.

The experiment followed a randomized complete block design arranged in strips, and the treatments consisted of three cover crops preceding the no-till cotton: forage turnip (*Raphanus sativus* L.), black oat (*Avena strigosa* L.) and white oat (*Avena sativa* L.), which were cultivated in strips under a no-till system during the winter, and four ammonium sulfate (AS) (200 and 240 g kg^{-1} N and S, respectively) doses (0, 150, 300, and 450 kg ha^{-1}) applied over the dry millet biomass the day before the sowing of no-till cotton. For two research years, the millet strain BN-2 grew approximately seventy days, was handled ten days before cotton sowing and was used to protect the soil surface.

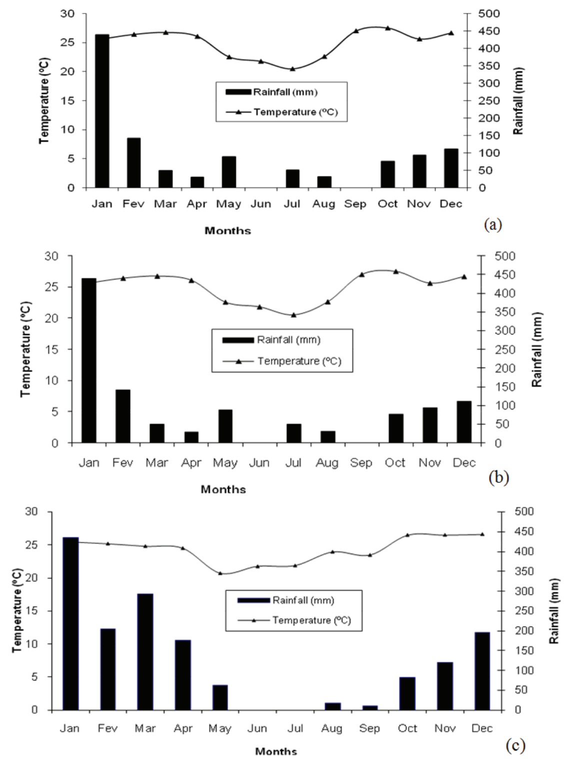

Figure 1. Rainfall and average temperatures between years 2006(a); 2007(b); 2008(c). Selvíria, Mato Grosso do Sul State, Brazil.

In 2004, the research area was cultivated with cotton. To provide the installation conditions for the no-till system, the soil was prepared to a depth of 0.3 m using a moldboard plow and disc harrow in July 2005. Limestone (1 ton ha^{-1}) was then applied to reach 70% base saturation and was incorporated using a disc harrow based on previous soil analyses (SILVA; RAIJ, 1997).

No-till cotton was cultivated during the 2005/2006 harvesting year and sowed over millet dry matter (DM). After that, the cultivation of no-till winter cover crops (forage turnip, white oat, and black oat) began on May 6, 2006. The seeds were sowed in strips in the experimental plots, with 0.17 m between rows, using the following plant densities: 30 kg ha^{-1} forage turnip seeds and 50 kg ha^{-1} white and black oat seeds. No mineral fertilization was applied, and the area was irrigated whenever needed during seedling emergence and crop settlement. On August 10, 2006, at the beginning of flowering, the DM on the experimental unit (floor area of 18 m^2) was determined, and the aerial parts of 3 m^2 of each cover crop were collected, resulting in DM values of 2105 kg ha^{-1} forage turnip, 1950 kg ha^{-1} black oat and 1720 kg ha^{-1} white oat.

On August 11, 2006 the cover crops were desiccated by applying 3 L ha^{-1} glyphosate (herbicide). On August 24, 2006, the millet was seeded in the area, with 0.45 m between rows, using 10 kg ha^{-1} seeds to obtain the biomass. Seventy-two days after the millet sowing, the plants were desiccated with 4 L ha^{-1} glyphosate (herbicide), and ten days after desiccation, the plants were handled with a straw chopper rotor coupled to a tractor. This plant density provided 6 ton ha^{-1} millet DM that was used as the soil cover.

On November 17, 2006, before no-till cotton sowing, the area was manually fertilized over the dry millet biomass by broadcasting AS doses. The cotton (*Gossypium hirsutum*, Delta Opal cultivar) was then seeded directly over the dry millet biomass on November 18, 2006 using eleven seeds m^{-1}. Each experimental unit consisted of four rows (5 m long, spaced 0.9 m apart). Seedling emergence occurred five days after sowing, after which eight seedlings per linear meter remained. This cotton cultivar was chosen due to its high productivity under the local field conditions (FERRARI et al., 2008).

Phosphorus (P) and potassium (K) fertilizers were applied at sowing according to Silva and Raij (1997), based on the soil analysis, with 100 kg ha^{-1} P_2O_5 as a simple superphosphate and 60 kg ha^{-1} K_2O as potassium chloride.

Seventy days after the emergence, a unique application of mepiquat chloride (growth regulator) was sprayed in the early morning (to avoid high temperatures) at the rate of 250 g active ingredient (a.i.) ha^{-1} using a backpack sprayer.

Pests and diseases were monitored and controlled to guarantee homogeneous cotton growth and development in all experimental plots.

On April 25, 2007 only the two central rows of seed cotton were harvested. After harvest, the crop remnants were destroyed using a rotary shredder coupled to the tractor mower.

In the second agricultural year (2007/2008), the field activities followed exactly the same schedule: the three cover crops were sowed on May 11, 2007 and desiccated on August 15, 2007 (forage turnip, black oat and white oat DMs of 2238.0, 2145.0 and 2104 kg ha^{-1}, respectively); no-till millet was seeded on August 28, 2007, desiccated on November 11, 2007 (6.2 ton ha^{-1} DM); the millet was cut and AS-fertilizer was applied on November 20, 2007; the no-till cotton was sowed on November 21, 2007; and finally, the cotton was harvested on April 24, 2008.

After the cotton harvest, the soil samples were collected for chemical analysis on May 5, 2007 and May 12, 2008. Four single soil samples were collected from each plot between the cotton rows using a soil probe and mixed to form one composite soil sample. There was one composite soil sample from each of the three depths: 0.0-0.05, 0.05-0.10, and 0.10-0.20 m (FRAZÃO et al., 2008). Therefore, the number of composite soil samples corresponded to thrice the number of experimental plots (3 soil depths x plot number). The samples were sent to the laboratory of soil fertility (Universidade Estadual Paulista-Unesp, Ilha Solteira campus, São Paulo State, Brazil) for the determinations of pH ($CaCl_2$), P, OM, Al, K, Ca, Mg, S, (H+Al), sum of bases (SB), CEC, V% and Al-saturation (m%). The analysis followed the procedures and methods described by Raij et al. (2001).

After the F-test and significant effects analyses, an average orthogonal contrast was performed to determine the best treatments.

The data were analyzed with the SAS (1999) statistical analysis software ver. 8.0. The regression equations were fit to the significant features, and the best-fitting model was selected by the coefficient of determination. The data were submitted to an analysis of variance (test F), and the means were compared using the Tukey test and polynomial regression ($p < 0.01$), according to Banzatto and Kronka (2006).

Results and discussion

In 2007, soil pH values at a depth of 0.0-0.05 m varied with the different pre-sowing AS doses; that is, the pH decreased from 4.4 (control plot) to 4.0 (plots with AS) (Table 1). Such a pH decrease is known to be caused by the acidification effect of NH_4-N fertilizers resulting from the release of protons during ammonium nitrification (HELYAR, 1991).

In 2007 and 2008, increasing AS doses resulted in a pH decrease at a depth of 0.05-0.10 m, similar to the effects observed on the surface (0.0-0.05 m depth). The plots with the highest AS doses had pH values of 4.1 and 4.2 compared to the control plot pH values of 4.4 and 4.5 in 2007 and 2008, respectively (Table 1). In the same manner, a pH decrease as a function of AS levels was observed at the 0.10-0.20 m soil depth in 2008; the averages were derived from a quadratic adjustment with the minimum point in the 40 kg ha^{-1} AS. Franchini et al. (2000), when studying N fertilization under a no-till system, also observed that soil acidification was characterized by a soil pH decrease, Ca decrease and acidity increase caused by exchangeable Al and H+Al (potential acidity). These variables were indicated as the main chemical alterations observed under no-till cropping systems.

Table 1. pH in $CaCl_2$, organic matter (OM), cation exchenge capacity (CEC) and base saturation (V%) in the soil under cotton Delta Opal cultivar, increasing ammonium sulfate doses and cover crops for two years and three depths. Selvíria, Mato Grosso do Sul State, Brazil.

		pH ($CaCl_2$)		OM† (g dm^{-3})		CEC† ($mmol_c$ dm^{-3})		V† (%)	
		2007	2008	2007	2008	2007	2008	2007	2008
0 – 0.05 m									
Cover Crops (c)	W-oats†	4.2	4.3	12.5	14.9	-	96.0	41.1	-
	B-oats†	4.1	4.4	14.1	15.5	-	101.9	45.3	-
	F-turnip†	4.0	4.8	13.9	15.2	-	103.0	40.5	-
Ammonium sulfate (a)	0	4.4^{**1}	4.8	13.6	15.3	-	89.8^{*2}	49.8	-
	150	4.0	4.3	13.5	15.3	-	96.6	39.3	-
	300	4.0	4.7	13.2	14.5	-	107.1	39.4	-
	450	4.0	4.2	13.8	15.7	-	106.7	40.8	-
CV%		5.78	22.75	13.98	7.11	-	13.40	24.01	-
0.05 – 0.10 m									
Cover Crops (c)	W-oats	4.2	4.2	11.9	14.00	62.0	90.9	43.1	32.4
	B-oats	4.2	4.2	12.7	13.1	63.0	94.9	46.7	30.3
	F-turnip	4.0	4.2	13.1	14.1	62.2	91.7	42.4	31.5
Ammonium sulfate (a)	0	4.4^{*3}	4.5^{*4}	12.6	13.33	60.9	85.3	46.7	42.0^{**5}
	150	4.1	4.1	12.8	13.66	65.3	90.7	42.2	27.7
	300	4.0	4.0	12.5	13.77	60.0	102.3	44.1	22.3
	450	4.1	4.2	12.3	14.22	63.4	91.6	43.1	33.5
CV%		6.42	7.76	12.94	8.56	10.13	13.32	20.53	32.58
0.10 – 0.20 m									
Cover Crops (c)	W-oats	4.3	4.54	11.3	14.0	58.6	88.7	48.5	40.9
	B-oats	4.5	4.5	12.7	13.1	61.9	86.7	49.2	40.7
	F-turnip	4.3	4.4	12.8	13.4	61.5	87.4	47.3	40.0
Ammonium sulfate (a)	0	4.4	4.7^{*6}	12.3	13.3	60.0	81.1	46.2	44.6
	150	4.3	4.3	12.7	13.5	64.4	90.2	49.4	35.1
	300	4.4	4.4	11.8	13.2	59.3	90.1	48.6	39.3
	450	4.4	4.5	12.2	14.0	59.0	89.1	49.2	43.0
CV%		5.83	7.27	12.72	8.58	11.05	9.95	16.52	25.70

Polinomial Equations

$^1\hat{y} = 4.449 - 0.00268x + 0.000036^{*}x^2$ $R^2 = 0.97$ Mín = 37 kg AS ha^{-1}. $^2\hat{y} = 91.044 + 0.0414^{**}x$ $R^2 = 0.85$. $^3\hat{y} = 4.418 - 0.00248x + 0.000036^{*}x^2$ $R^2 = 0.99$ Mín = 34 kg AS ha^{-1}. $^4\hat{y} = 4.567 - 0.00402x + 0.000036^{**}x^2$ $R^2 = 0.98$ Mín = 56 kg AS ha^{-1}. $^5\hat{y} = 42.394 - 0.14774x + 0.000284^{**}x^2$ $R^2 = 0.98$ Mín = 260 kg AS ha^{-1}. $^6\hat{y} = 4.708 - 0.0029 + 0.000036^{*}x^2$ $R^2 = 0.75$ Mín = 40 kg AS ha^{-1}. †OM = organic matter; CEC = cation exchange capacity; V% = base saturation; W-oats = White oats; B – oats = Black oats; F – turnip = Forage turnip. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, respectively, by the analysis of variance.

With regard to the organic matter in 2007 and 2008 (Table 1), the study treatments did not produce significant variation in these averages. However, although not significant, black oat treatment resulted in an increase in soil organic matter in the years evaluated because its root system is more aggressive (SANTI et al., 2003), showing the largest amount of dry matter produced in both years (especially in 2006) compared with white oat (black oat 1,950 and 2,145 kg ha^{-1} MS and white oat 1,720 and 2,104 kg ha^{-1} MS in 2006 and 2007, respectively).

Regarding the soil CEC values at the 0.0-0.05 m depth in 2008, significant increases were observed with increasing AS doses. The CEC values varied from 89.8 (control plot) to 106.7 $mmol_c$ dm^{-3} (450 kg AS ha^{-1}) (Table 1). For the same year, even with the CEC values increasing as a function of AS levels, significant increases were was not observed at the other depths studied.

The cover crops did not significantly affect the base saturation (V%) values at different soil depths in 2007, even with the increasing ammonium sulfate rates. However, in 2008 at 0.05-0.10 m depths, the V% significantly decreased with increasing SA doses up to 300 kg ha^{-1}. The highest V% value was found in the control plot (42%, Table 1).

The interaction partition of the treatment components for the V% values in 2008 (Table 2) indicated that the V% was higher in the plot with 150 kg ha^{-1} AS under forage turnip, significantly different from the value obtained under black oat. According Schlindwein et al. (2003), forage turnip has a greater ability to reduce the toxicity of aluminum than black oat and common vetch, possibly due to a higher concentration of calcium and magnesium in the area of the rhizosphere and the organic compounds produced which form a complex with aluminum in solution.

Table 2. Cation exchange capacity (CEC) - 2007 and bases saturation (V) - 2008, both at 0.0-0.05 m depth in the soil under cotton Delta Opal cultivar, increasing ammonium sulfate doses and cover crops for two years and three depths. Selvíria, Mato Grosso do Sul State, Brazil.

	CEC			V(%)		
	Cover Crops					
Ammonium sulfate	W-oats	B-oats	F-turnip	W-oats	B-oats	F-turnip
0	66.25	63.66	67.81^{*1}	44.33	54.66^{**2}	46.00^{*3}
150	61.49b	74.79a	61.16b	33.00ab	22.00b	48.00a
300	60.96	64.93	57.61	35.00	30.33	14.66
450	57.68b	62.74ab	74.29a	35.00	38.66	22.33
CV%	17.38			32.10		

Polinomial Equations

$^1\hat{y} = 68.667 - 0.10604x + 0.00032^{**}x^2$ $R^2 = 0.90$ Min. = 207 kg AS ha^{-1}. $^2\hat{y} = 52.616 - 0.23144x + 0.00056^{**}x^2$ $R^2 = 0.85$ Min. = 207 kg AS ha^{-1}. $^3\hat{y} = 48.400 - 0.06954^{**}x$ $R^2 = 0.75$. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, respectively, by the analysis of variance. Means followed by the same letters in the horizontal line do not differ by Tukey test ($p < 0.05$).

The comparison among cover crops showed that in the plots with forage turnip, the linear decrease in the V% values related to the increasing AS doses was due to ammonium nitrification through acidification of the soil (CANTARELLA; MONTEZANO, 2010) and a reduction in the base saturation of the soil layer at the 0.0 to 0.05 m depth. The plots with black oat had higher V% values at 150 kg ha^{-1} AS.

The soil chemical analyses of samples from the 0.0-0.05, 0.05-0.10, and 0.10-0.20 m depths in 2007 and 2008 (Table 3) showed increasing soil S concentrations with increasing AS doses. All evaluations showed an average linear increase in the S content of the soil and an R^2 equal to or greater than 84%. Such adjustments and increases were due to the AS fertilizer present, which was composed of 24% S. Thus, the major values for sulfur in the soil were found at the 0.0-0.05 m depth in 2008. Although N fertilizer was applied to the soil surface, significant increases in S concentrations were found at the 0.10-0.20 m depth. The total S content did not change much along the profile (Table 3), showing nutrient mobility and contact with the roots.

With respect to different cover crops, forage turnip provided a higher S concentration than the black oat in two of the three depths measured in 2007 (Table 3). Rheinheimer et al. (2005) found that the wild radish crop showed an increase in dry matter and the S concentration in plant tissues according to the sulfur rates in the soil. The increase in DM is very important for the recycling of sulfate because wild radish has a deep root system and high sulfur uptake capacity. It was not possible to verify the significant effects of the cover crops on the levels of sulfur in the soil in relation to the other ratings.

The potential acidity (H+Al) measured in 2008 linearly increased with the AS rates from 46.1 and 49.5 $mmol_c\ dm^{-3}$ in the controls to 81.6 and 79.8 $mmol_c\ dm^{-3}$ in the plot with the highest AS rate at depths of 0.0-0.05 m and 0.05-0.10 m, respectively (Table 3).

Similarly, increasing Al^{3+} values were found with increasing AS doses at the 0.0-0.05 m and 0.05-0.10 m depths in 2007, varying from 3.1 and 3.7 (controls) to 8.0 and 7.7 $mmol_c\ dm^{-3}$ (the highest AS dose), respectively (Table 3). In 2008, the soil chemical analysis at a depth of 0.0-0.05 m also indicated a significant linear increase for the contents of Al^{3+} up to 12.6 $mmol_c\ dm^{-3}$. These results corroborated those of Pires et al. (2008) at the 0.0-0.05 and 0.05-0.10 m depths when using broadcasted N fertilizer.

The Al-saturation (m%) values at the 0.0-0.05 and 0.05-0.10 m depths in 2008 significantly increased with increasing AS doses at the soil surface. The results showed the highest m% values (34.7 and 31.1%, respectively) in the plots with 450 kg ha^{-1} AS (Table 3).

In 2008, the cover crops did not cause significant changes in the soil H+Al, Al^{3+} or m% values after cotton crop cultivation at the different depths analyzed.

Table 3. Sulfur (S), potential acidity (H+Al), aluminum (Al^{3+}) and Al-saturation (m) in the soil under cotton Delta Opal cultivar, increasing ammonium sulfate doses and cover crops for two years and three depths. Selvíria, Mato Grosso do Sul State, Brazil.

		S† (mg dm^{-3})		**H+Al† ($mmol_c\ dm^{-3}$)**		**Al^{3+}† ($mmol_c\ dm^{-3}$)**		**m† (%)**	
		2007	2008	2007	2008	2007	2008	2007	2008
0 – 0.05 m									
Cover Crops (c)	W-oats	34.0^{*}ab	48.0	-	62.2	6.6	6.0	23.3	17.4
	B-oats	30.0 b	43.5	-	65.7	4.4	6.8	14.7	18.6
	F-turnip	46.3 a	53.5	-	70.8	6.1	8.7	23.1	24.1
Ammonium sulfate (a)	0	15.1^{**1}	15.4^{**2}	-	46.1^{**3}	3.1^{*4}	1.4^{**5}	9.5	3.8^{**6}
	150	40.0	39.7	-	64.0	5.1	6.0	25.4	17.2
	300	41.2	60.4	-	73.3	6.5	8.7	24.1	24.4
	450	51.9	77.6	-	81.6	8.0	12.6	22.5	34.7
CV%		40.81	45.21	-	29.45	61.11	82.27	81.36	84.41
0.05 – 0.10 m									
Cover Crops (c)	W-oats	40.3	45.0	35.4	62.4	6.6	7.1	19.7	20.2
	B-oats	44.6	49.6	33.5	67.0	5.4	6.3	14.4	19.6
	F-turnip	48.2	49.0	35.8	63.0	6.1	6.8	20.0	19.7
Ammonium sulfate (a)	0	18.6^{**7}	14.3^{**8}	32.4	49.5^{**9}	3.7^{*10}	2.6	9.9	7.1^{*11}
	150	38.2	48.3	38.1	66.5	6.1	7.8	21.3	24.2
	300	41.2	44.1	33.3	60.6	6.4	5.7	18.2	17.1
	450	79.4	84.8	35.8	79.8	7.9	10.7	22.8	31.1
CV%		35.92	51.35	21.74	25.01	56.63	89.61	77.14	87.14
0.10 – 0.20 m									
Cover Crops (c)	W-oats	32.3^{*}b	33.3	30.1	51.8	-	3.5	-	10.2
	B-oats	30.0 b	38.6	31.2	51.8	-	3.0	-	8.8
	F-turnip	44.1 a	39.5	32.1	52.8	-	4.2	-	11.7
Ammonium sulfate (a)	0	22.6^{**12}	17.3^{*13}	32.1	44.8	-	1.6	-	5.3
	150	31.5	39.2	32.8	59.5	-	5.6	-	16.3
	300	35.6	40.1	30.1	55.0	-	3.8	-	10.6
	450	52.1	52.1	29.7	51.2	-	3.3	-	8.7
CV%		38.04	55.75	15.45	27.03	-	71.10	-	79.90

Polinomial Equations

[1]$\hat{y} = 20.239 + 0.0736^{**}x$ $R^2 = 0.84$. [2]$\hat{y} = 22.400 + 0.1152^{**}x$ $R^2 = 0.89$. [3]$\hat{y} = 51.377 + 0.0662^{**}x$ $R^2 = 0.95$. [4]$\hat{y} = 3.349 + 0.0106^{**}x$ $R^2 = 0.99$. [5]$\hat{y} = 2.922 + 0.0191^{**}x$ $R^2 = 0.88$. [6]$\hat{y} = 8.200 + 0.0528^{**}x$ $R^2 = 0.89$. [7]$\hat{y} = 16.626 + 0.1235^{**}x$ $R^2 = 0.88$. [8]$\hat{y} = 29.033 + 0.0839^{**}x$ $R^2 = 0.87$. [9]$\hat{y} = 57.166 + 0.0311^{*}x$ $R^2 = 0.90$. [10]$\hat{y} = 3.712 + 0.0099^{*}x$ $R^2 = 0.91$. [11]$\hat{y} = 14.355 - 0.0245^{*}x$ $R^2 = 0.98$. [12]$\hat{y} = 21.631 + 0.0616^{**}x$ $R^2 = 0.93$. [13]$\hat{y} = 25.011 + 0.0541^{*}x$ $R^2 = 0.98$. †S = sulfur; H+Al = potential acidity; Al^{3+} = aluminum; m% = Al-saturation. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, respectively, by the analysis of variance. Means followed by the same letters in the columns do not differ by Tukey test ($p < 0.05$).

Significant interactions among treatments with regard to the potential acidity values at the 0.0-0.05 m depth varied among plots treated with the highest AS doses and reached maximum values under the forage turnip cover crop (14.08 $mmol_c$ dm^{-3}) when compared to the white oat. Plots under black oat showed potential acidity values fitting a quadratic equation with a maximum at the AS dose of 195 kg ha^{-1} (Table 4).

From the results shown in Table 4, it can also be noted that there were significant interactions among AS doses and cover crops with regard to Al concentration, as the concentration in plots under white oat was 300 kg ha^{-1} AS, followed by the treatment with forage turnip at 450 kg ha^{-1} AS. The plots under white oat showed decreasing Al^{3+} concentrations as the AS doses increased. However, the plots under forage turnip presented significant Al increases at 115 kg ha^{-1} AS.

The Al saturation values (m%) for different cover crops at the highest AS dose were 1.9, 5.06 and 14.11% for white oat, black oat and forage turnip, respectively. The plots under forage turnip showed a decrease in the m% as the AS doses increased, up to 122 kg ha^{-1} AS, followed by a significant increase in the m% at the highest AS dose. However, the plots under white oat showed decreased m% values with increasing AS levels (Table 4).

According to Franchini et al. (1999), black oat extract was more effective in extracting soil exchangeable calcium, while oil seed radish extract was more effective in extracting soil exchangeable aluminum. The degree of neutralization of the Al toxicity of an organic acid is determined by the stability of the organic complex formed. Hue et al. (1986) classified the main organic acids with regard to the softening capacity of Al toxicity to cotton plants as follows: a) strong: citric, oxalic, tartaric, b) moderate: malic, malonic, salicylic, and c) poor: succinic, lactic, formic, phthalic, acetic. Amaral et al. (2004) found that trans-aconitic acid was the most important acid in black oat, and citric and malic acids were the most important acids in oil seed radish.

The soil chemical analysis data obtained for the 0.05-0.10 m depth indicated significant differences for the soil P concentrations among the cover crops (Table 5). The plots under black oat presented higher soil P concentrations than those under forage turnip. The low mobility and accumulation of P in the surface layers could also be connected with residue deposition, which favors the redistribution of the organic forms that are less susceptible to degradation (SANTOS; TOMM, 2003). Nevertheless, no effect of the increasing AS doses on the soil P was observed at any depth analyzed in 2007 and 2008, demonstrating that this element was only slightly influenced by fertilizer application.

As nitrate anions are lixiviated, they are followed by their counter ions (K^+, Ca^{2+}, or Mg^{2+}); meanwhile, the protons released during ammonium or organic matter nitrification remain in the superficial soil layer, resulting in a potential acidity (HELYAR, 1991).

According to the analysis of soil samples in 2007 at the 0.0-0.05, 0.05-0.10, and 0.10-0.20 m depths, as shown in Table 5, it can be seen that both cover crops and coverage AS levels did not significantly affect the K^+ and Ca^{2+} soil averages. In 2008, a significant effect of the increasing AS doses on the soil K^+ concentrations was shown the 0.0-0.05 m depth, which decreased from 5.3 (control) to 3.7 $mmol_c$ dm^{-3} (highest AS rate). In the same manner, the Ca^{2+} concentrations at the 0.0-0.05 m and 0.05-0.10 m depths decreased with the AS doses, mainly with the 234 and 172 kg ha^{-1} AS doses, where the Ca^{2+} concentrations decreased from 21.6 to 12.1 $mmol_c$ dm^{-3} and 20.6 to 13.8 $mmol_c$ dm^{-3}, respectively.

Table 4. Potential acidity (H+Al) 0.0-0.05 m, aluminum (Al^{3+}) 0.10-0.20 m and Al-saturation (m) 0.10-0.20 m depths in the soil under cotton Delta Opal cultivar, increasing ammonium sulfate doses and cover crops for two years and three depths. Selvíria, Mato Grosso do Sul State, Brazil, 2007.

	H+Al			**Al^{3+}**			**m**		
	Cover Crops								
Ammonium sulfate	W-oats	B-oats	F-turnip	W-oats	B-oats	F-turnip	W-oats	B-oats	F-turnip
0	33.11	28.84^{*1}	37.16	3.58^{**2}	1.62	1.59^{*3}	12.63^{**4}	4.73	5.48^{*5}
150	39.35	46.77	33.58	3.10	2.36	1.44	9.02	7.14	4.01
300	37.84	36.04	36.45	3.15a	0.30 b	1.47 ab	9.55	1.40	5.58
450	33.38b	34.55ab	47.46a	0.61b	1.71ab	4.20 a	1.90b	5.06b	14.11a
CV%		20.05			57.85			42.74	
				Polinomial Equations					

[1]$\hat{y} = 30.741 + 0.10121x - 0.00026^{*}x^2$ $R^2 = 0.86$ Max. = 195 kg ha^{-1} AS. [2]$\hat{y} = 3.943 - 0.0059^{*}x$ $R^2 = 0.90$. [3]$\hat{y} = 1.719 - 0.00916x + 0.00004^{**}x^2$ $R^2 = 0.94$ Min. = 115 kg ha^{-1} AS. [4]$\hat{y} = 13.027 - 0.02108^{**}x$ $R^2 = 0.87$. [5]$\hat{y} = 5.679 - 0.03172x + 0.00013^{**}x^2$ $R^2 = 0.98$ Min. = 122 kg ha^{-1} AS. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, espectively, by the analysis of variance. Means followed by the same letters in the horizontal line do not differ by Tukey test (0.05).

Table 5. Available phosphorus (P), exchangeable cations (K^+, Ca^{2+} e Mg^{2+}) and sum of bases (SB) in the soil under cotton Delta Opal cultivar, increasing ammonium sulfate doses and cover crops for two years and three depths. Selvíria, Mato Grosso do Sul State, Brazil.

		P† (mg dm^{-3})		K^{+}† (mmol$_c$ dm^{-3})		Ca^{2+}† (mmol$_c$ dm^{-3})		Mg^{2+}† (mmol$_c$ dm^{-3})		SB† (mmol$_c$ dm^{-3})	
		2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
0 – 0.05 m											
Cover Crops (c)	W-oats	10.2	8.0	4.3	4.2	13.6	15.2	7.6	10.3	25.6	29.8
	B-oats	13.6	11.5	5.0	4.7	16.1	16.5	8.6	10.8	29.9	32.1
	F-turnip	12.3	7.1	4.7	3.9	14.0	15.7	7.7	8.5	26.5	28.2
Ammonium sulfate (a)	0	13.1	10.4	5.3	5.3^{**1}	17.4	21.6^{*2}	10.1^{*3}	12.7^{*4}	32.8	39.7^{*5}
	150	13.0	8.1	4.7	4.4	13.6	14.1	7.5	10.1	25.9	28.6
	300	11.1	7.5	4.4	3.7	12.7	12.3	7.1	7.2	24.3	23.3
	450	10.9	9.4	4.4	3.7	14.6	16.2	7.3	9.5	26.4	29.5
CV%		50.94	60.86	24.63	27.34	29.61	35.12	29.86	38.61	26.23	32.36
0.05 – 0.10 m											
Cover Crops (c)	W-oats	6.8	5.5*ab	3.0	3.5	16.0	16.3	8.0	8.4	26.6	28.3
	B-oats	9.3	8.0a	3.2	4.6	17.9	15.1	8.1	8.0	29.4	27.9
	F-turnip	7.3	4.6b	3.5	4.3	15.2	15.0	7.7	9.2	26.3	28.6
Ammonium sulfate (a)	0	7.7	7.3	3.4	4.7	15.7	20.6^{*6}	10.1^{**7}	10.4^{*8}	28.4	35.8^{*9}
	150	9.0	5.1	3.2	4.3	16.3	12.1	7.6	7.8	27.1	24.3
	300	7.8	6.4	3.6	3.7	15.8	11.6	7.0	7.0	26.6	22.4
	450	6.8	5.5	2.9	3.9	17.5	17.6	7.1	9.0	27.5	30.4
CV%		51.77	44.03	28.36	29.66	31.08	45.85	24.29	30.00	22.45	32.81
0.10 – 0.20 m											
Cover Crops (c)	W-oats	9.2	6.6	2.3	2.8*b	16.3	18.0	9.7	10.5	28.4	31.4
	B-oats	14.7	6.7	2.9	4.0a	17.0	17.1	10.6	9.8	30.6	31.0
	F-turnip	11.5	4.9	3.0	3.0ab	16.2	17.7	10.0	10.6	29.3	31.4
Ammonium sulfate (a)	0	10.8	6.2	2.4	2.9	15.7	18.3	9.7	11.1	27.9	32.4
	150	10.9	6.1	2.5	3.3	18.5	18.1	10.4	9.1	31.5	30.6
	300	14.8	5.0	3.0	3.6	16.0	17.1	10.1	10.3	29.1	31.1
	450	10.7	7.1	2.9	3.2	15.8	19.6	10.4	10.7	29.2	33.6
CV%		65.76	39.97	42.03	36.04	36.30	26.89	18.57	24.18	23.73	22.89
Polinomial Equations											

[1]$\hat{y} = 5.140 - 0.00364^{**}x$ $R^2 = 0.86$. [2]$\hat{y} = 20.811 - 0.0748x + 0.00016^{*}x^2$ $R^2 = 0.99$ Min. = 234 kg AS ha^{-1}. [3]$\hat{y} = 8.240 - 0.00592^{*}x$ $R^2 = 0.84$. [4]$\hat{y} = 11.800 - 0.00837^{*}x$ $R^2 = 0.71$. [5]$\hat{y} = 40.322 - 0.11714x + 0.00026^{*}x^2$ $R^2 = 0.97$ Min. = 225 kg AS ha^{-1}. [6]$\hat{y} = 20.583 - 0.07912x + 0.00023^{**}x^2$ $R^2 = 0.99$ Min. = 172 kg AS ha^{-1}. [7]$\hat{y} = 9.425 - 0.00639^{**}x$ $R^2 = 0.98$. [8]$\hat{y} = 10.505 - 0.02628x + 0.00006^{*}x^2$ $R^2 = 0.98$ Min. = 219 kg AS ha^{-1}. [9]$\hat{y} = 35.005 - 0.1107x + 0.0002^{**}x^2$ $R^2 = 0.99$ Min. = 277 kg AS ha^{-1}. †P = phosphorus (resin); K^+ = potassium; Ca^{2+} = calcium; Mg^{2+} = magnesium; SB = sum of bases. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, respectively, by the analysis of variance. Means followed by the same letters in the columns do not differ by Tukey test ($p < 0.05$).

Similarly, in 2007 and 2008, increasing AS doses induced decreasing concentrations of Ca^{2+} and Mg^{2+} at depths of 0.0-0.05 and 0.05-0.10 m. The averages presented a linear adjustment at the 0.0-0.05 m depth and a quadratic adjustment with minimal values at 234 kg ha^{-1}AS at the 0.05-0.10 m depth.

As expected, at the 0.0-0.05 and 0.05-0.10 m depths in 2008, the sum of the bases decreased with the increasing AS doses, reaching minima of 27.1 and 19.7 mmol$_c$ dm^{-3} for the 225 and 277 kg ha^{-1} AS levels, respectively. However, no significant differences were found for the average SB in plots under different cover crops (Table 5).

This result corroborated the statement of Helyar (1991), who indicated that Mg^{2+} is required as the counter ion for nitrate lixiviation from the superficial soil layers, and with Serafim et al. (2012), who found lower Mg^{2+} concentrations in the upper soil layer, while Mg in the bottom soil layer increased with increases in gypsum doses, due to leaching with sulfate. According to Moraes et al. (2007), the organic acids of radish or black oat crop residues were rapidly metabolized or adsorbed into the soil colloidal fraction, having a small effect on cation mobilization.

The correlation of the cotton yield with increasing AS doses may have contributed to the higher uptake of soil bases, reducing the soil content. Aquino et al. (2012) found that cotton required high amounts of bases (K^+, Ca^{2+}, and Mg^{2+}).

Nevertheless, no significant differences among different cover crops were found for the soil attributes at the 0.0-0.05 m depths (Table 5).

Significant increases in seed cotton yields in both harvesting years were found in response to AS treatments and cover crops (Table 6). In 2006 and 2007, a higher seed cotton yield was observed in the forage turnip plot than in the two other cover crop plots. Such a yield increase might be due to installing the no-tillage system. The smaller C/N ratio in the forage turnip DM compared with that of oat may have promoted a smaller N immobilization and less competition from microorganisms and can be recommended for preceding the cotton crop. Moreover, significant increases in the Delta Opal cultivar productivity were also observed with increasing AS doses, with yield increments up to the highest N rate applied, demonstrating that in a no-till system where grass species were involved, the cotton crop responds significantly to applied N and that the pre-sowing fertilization was able to provide nutrients and increase yield. The seed cotton yields varied from 2,231.54 kg ha^{-1} (control plot) to

2,945.27 kg ha^{-1} (plot with 450 kg ha^{-1} AS) with an overall increment of 713.73 kg ha^{-1}.

Table 6. Yields of seed cotton Delta Opal cultivar, under increasing ammonium sulfate doses and different cover crops. Selvíria, Mato Grosso do Sul State, Brazil.

		Yield (kg ha^{-1})	
		2006/07	2007/08
Cover Crops (c)	White oats	2412.42^{**} b	2762.24
	Black oats	2363.31 b	2898.61
	Forage turnip	2988.12 a	2868.45
Ammonium sulfate (a)	0	2231.34^{**1}	2430.00^{*2}
	150	2230.08	2807.13
	300	2707.37	3027.25
	450	2945.27	3108.52
CV%		14.62	16.60
Polinomial Equations			

$^1\hat{y} = 2231.0485 + 1.5871^{**}x$ $R^2 = 0.99$. $^2\hat{y} = 2504.9111 + 1.5036^{**}x$ $R^2 = 0.92$. **, *Significant F test, at $p < 0.05$ and $p < 0.01$, respectively, by the analysis of variance. Means followed by the same letters in the columns do not differ by Tukey test ($p < 0.05$).

During the year 2007/2008, no significant effect of the cover crops was observed on seed cotton yields under these field experiment conditions. Nevertheless, linear positive effects of increasing N doses on seed cotton yields were obtained, with an overall increment between the control and the highest N rate of 678.52 kg ha^{-1} (Table 6).

The experimental results demonstrated that broadcast ammonium sulfate fertilization applied prior to no-till cotton sowing is a facile and rapid practice that enhances cotton productivity.

In accordance with these results, Teixeira et al. (2008), when studying the effects of increasing doses of ammonium sulfate and urea on cotton yields, observed a maximum yield (3,633 kg ha^{-1}) with 131 kg ha^{-1} of N applied in equal doses broadcasted at sowing compared to the control (3,362 kg ha^{-1}). Additionally, Lamas and Staut (2005) observed significant increases in cotton yields with increasing N doses up to 150 kg ha^{-1}.

The 2007/2008 harvest was superior to that of 2006/2007; this relationship might also be attributed to the adequate amount of rainfall occurring in 2007/2008, indicating that there was enough water for cotton growth and development. The rainfall between November 2006 and April 2007 accumulated 1,158.34 mm of water, lower than that in the following year. In 2007/2008, the rainfall accumulated 1,376.22 mm of water (Figure 1) over the same period as that in 2006/2007.

Conclusion

The application of increasing doses of ammonium sulfate induced lower soil pH and lower Ca and Mg concentrations in the superficial soil layers, as well as higher exchangeable Al^{3+}, H+Al, m% and S concentrations up to a depth of 0.20 m.

Using forage turnip as a cover crop provided an increased cotton yield, and this practice can be recommended.

The application of broadcast AS fertilization over cover crop dry biomass and before no-till cotton sowing resulted in significant increases in seed cotton yields.

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