Research, Society and Development, v. 9, n. 11, e6779119409, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9409

Effect of Trinexapac-ethyl associated with nitrogen fertilization on upland rice nutritional status and grain yield

Efeito do Trinexapac-ethyl associado com adubação nitrogenada afeta o estado nutricional e a produtividade de arroz de terras altas

Efecto de Trinexapac-etil asociado con la fertilización con nitrógeno en el estado nutricional del arroz de secano y el rendimiento de grano

Received: 10/18/2020 | Reviewed: 10/25/2020 | Accept: 11/26/2020 | Published: 11/29/2020

Samuel Ferrari
ORCID: https://orcid.org/0000-0001-8542-204X
São Paulo State University, Brazil
E-mail: samuel.ferrari@unesp.br
Luis Fernando dos Santos Cordeiro
ORCID: https://orcid.org/0000-0001-7238-5518
São Paulo State University, Brazil
E-mail: luiscordeirolfc@gmail.com
Luís Guilherme Delovo Carara
ORCID: https://orcid.org/0000-0002-4964-6684
São Paulo State University, Brazil
E-mail: luis.guilherme97@hotmail.com
Vagner do Nascimento
ORCID: https://orcid.org/0000-0003-0169-203X
São Paulo State University, Brazil
E-mail: vagner.nascimento@unesp.br
Paulo Renato Matos Lopes
ORCID: https://orcid.org/0000-0003-4886-5292
São Paulo State University, Brazil
E-mail: prm.lopes@unesp.br
Evandro Pereira Prado
ORCID: https://orcid.org/0000-0001-7616-0471
São Paulo State University, Brazil
E-mail: evandro.prado@unesp.br

Ronaldo da Silva Viana
ORCID: https://orcid.org/0000-0001-6819-5092
São Paulo State University, Brazil
E-mail: ronaldo.viana@unesp.br

Abstract

Trinexapac-ethyl spraying time and proper nitrogen rate are essential to reduce plant height and lodging at harvest, without affecting rice yield and nutritional balance. This study aimed to evaluate trinexapac-ethyl spraying time and N contents as topdressing for upland rice paddies. The experiment was carried out in a randomized block design and a 4x5 factorial scheme, with four replications. Treatments consisted of four trinexapac-ethyl spraying times, in the phenological stages of tillering, floral differentiation, between tillering and floral differentiation, and a control (without spraying), and five nitrogen rates (0, 50, 100, 150, and 200, kg ha^{-1}) as topdressing. As nitrogen topdressing rates increased, leaf contents of N, Fe^{++}, and Zn^{++} increased, while S and Mn^{++} decreased; however, contents of P, Ca^{++}, Mg^{++}, B, and Cu^{++} were little influenced. When trinexapac-ethyl was applied, leaf contents of N, P, S, B, and Zn^{++} were little influenced, while P, Ca^{++}, Mg^{++}, Fe^{++}, and Mn^{++} increased, and Cu^{++} decreased. Trinexapac-ethyl can be applied at tillering without decreasing rice yield. Upland rice increased grain yield by 58 and 46% in two consecutive crop years due to application of about 120 kg N ha^{-1} as topdressing.

Keywords: *Oryza sativa* L.; Nitrogen rates; Gibberellin; Growth regulator; Leaf diagnosis.

Resumo

O momento de aplicação do trinexapac-ethyl e a dose de nitrogênio (N) adequada são fundamentais para propiciar a redução da altura e acamamento das plantas no momento da colheita, sem afetar a produtividade e o desequilíbrio nutricional das plantas de arroz. O objetivo do estudo foi avaliar época de aplicação de trinexapac-ethyl e doses de nitrogênio em cobertura no arrozeiro de terras altas. O delineamento experimental foi em blocos casualizados em esquema fatorial 4x5, com quatro repetições, sendo quatro épocas de aplicação de trinexapac-ethyl realizadas nos estádios fenológicos de perfilhamento (P), diferenciação floral (DF), entre o P-DF e controle sem aplicação, e cinco doses de N, 0, 50, 100, 150 e 200 kg ha^{-1} em cobertura. Conforme acrescentado as doses de nitrogênio em cobertura, o teor foliar de N, Fe^{++} e Zn^{++} aumentou, P, Ca^{++}, Mg^{++}, B e Cu^{++} pouco foram influenciados, e houve diminuição nos teores de S e Mn^{++}. Quando aplicado trinexapac-ethyl os teores foliares de N, P, S, B e Zn^{++}

foram pouco influenciados; P, Ca^{++}, Mg^{++}, Fe^{++} e Mn^{++} aumentaram e Cu^{++} diminuiu. A aplicação de trinexapac-ethyl no perfilhamento do arrozeiro pode ser realizada sem diminuir a produtividade. O arroz de terras altas incrementou a produtividade de grãos em 58 e 46% em duas safras respectivamente devido à aplicação de aproximadamente 120 kg ha^{-1} de N em cobertura.

Palavras-chave: *Oriza sativa* L.; Doses de nitrogênio; Giberelina; Regulador de crescimento; Diagnose foliar.

Resumen

El tiempo de pulverización de trinexapac-etil y la tasa de nitrógeno adecuada son esenciales para reducir la altura de la planta y el alojamiento en la cosecha, sin afectar el rendimiento del arroz y el equilibrio nutricional. Este estudio tuvo como objetivo evaluar el tiempo de aspersión de trinexapac-etilo y el contenido de N como cobertura para arrozales de secano. El experimento se llevó a cabo en un diseño de bloques al azar y un esquema factorial 4x5, con cuatro repeticiones. Los tratamientos consistieron en cuatro tiempos de aspersión de trinexapac-etil, en las etapas fenológicas de macollamiento, diferenciación floral, entre macollamiento y diferenciación floral, y un control (sin aspersión), y cinco dosis de nitrógeno (0, 50, 100, 150 y 200, kg ha^{-1}) como cobertura. A medida que aumentaron las dosis de aplicación de nitrógeno, aumentaron los contenidos foliares de N, Fe^{++} y Zn^{++}, mientras que S y Mn^{++} disminuyeron; sin embargo, los contenidos de P, Ca^{++}, Mg^{++}, B y Cu^{++} fueron poco influenciados. Cuando se aplicó trinexapac-etil, los contenidos foliares de N, P, S, B y Zn^{++} se vieron poco afectados, mientras que P, Ca^{++}, Mg^{++}, Fe^{++} y Mn^{++} aumentaron y Cu^{++} disminuyó. El trinexapac-etil se puede aplicar en el macollamiento sin disminuir el rendimiento del arroz. El arroz de secano aumentó el rendimiento de grano en un 58 y un 46% en dos años de cosecha consecutivos debido a la aplicación de aproximadamente 120 kg de N ha^{-1} como cobertura.

Palabras clave: *Oryza sativa* L.; Dosis de nitrógeno; Giberelina; Regulador de crecimiento; Diagnóstico foliar.

1. Introduction

Rice is a staple food and of great economic, social, and food importance, integrating daily eating habits of about 2.4 billion people worldwide. Estimates for 2050 point to the need to serve twice as many of this population (Silva et al., 2019). In Brazil, annual per-capita consumption of rice ranges between 25 and 50 kg inhabitant^{-1} year^{-1} (Fao, 2011). This grain is not only an excellent natural source of carbohydrates, but also proteins, minerals (mainly phosphorus, iron, and calcium), and B-complex vitamins such as B1 (thiamine), B2 (riboflavin), and B3 (niacin). For the crop year of 2019/2020, it has been estimated a total area of 1.7 million hectares, production of 10.6 million tons of grain, and average yield of 6,300 kg ha^{-1} for rice crops in Brazil (Conab, 2020).

High grain yield and quality for rice are associated with plant nutrition, and nitrogen (N) is the most needed. This macronutrient, besides increasing yield, is also responsible for improving grain nutritional value and plays roles in the absorption of other nutrients. The application of high N rates can increase protein contents in rice grains by up to 7% (Chandel et al., 2010).

However, the supply of water and nutrients, mainly N, without proper criteria can increase plant lodging in rice fields, and hence harvesting losses (Peron et al., 2019). Lodging occurs mainly due to a low resistance to rupture in lower internodes, as plants grow longer after an excess N application (Zhang et al., 2016).

One of the ways to reduce elongation of lower internodes and plant heights, and therefore lodging, is the use of growth regulators (Alvarez et al., 2016). This may favor rice farming systems since they allow the application of high N rates to achieve maximum yields, without losses due to lodging (Hashem et al., 2016).

Rates, sources, times, and modes of application of growth regulators influence absorption, translocation, and redistribution of nutrients in plant shoots. When applied in rice fields, they improve Fe^{++} and Mn^{++} absorptions (Guo et al., 2015). Moreover, nutrient contents in leaf tissue increase because of less accumulation of dry matter (Marolli et al., 2017).

Spraying of 150 g trinexapac-ethyl per upland rice ha^{-1} reduced plant height, lodging, and grain yield. However, doses of up to 120 kg ha^{-1} increased yield (Peron et al., 2019). Since the spraying of trinexapac-ethyl decreases plant height, its productivity could be reduced (Alvarez et al. 2014). In oats, a dose of 450 mL trinexapac-ethyl ha^{-1} decreased plant lodging without reducing grain yield, even with application of high N topdressing rates and in both climatically favorable and unfavorable years (Marolli et al., 2017).

Based on the above, trinexapac-ethyl can be a promising approach to minimize lodging at harvesting for irrigated upland rice fertilized with high N topdressing rates. But further studies are still needed to better understand such technology (Corbin et al., 2016). Although several studies have reported beneficial results from the use of growth regulator in rice crops, there is still no consensus on suitable rates and timing, mainly when associated with N fertilization. Furthermore, little is known about effects of such agricultural practice on plant mineral nutrition and grain yield in rice crops.

Therefore, the objective was to evaluate the effects of trinexapac-ethyl spraying time associated with different N topdressing rates on leaf contents of nutrients and grain yield in upland rice crops**.**

2. Material and Methods

Experiments were performed in Registro city, São Paulo state, Brazil, at geographical coordinates of 24° 31' South and 47° 51' West and altitude of 25 m above sea level. The climate type according to Koppen classification is humid subtropical with hot summers (Cfa). The average annual temperature is 27 °C with an annual rainfall of 1,500 mm (Table 1).

Table 1. Mean monthly rainfall and air temperature for the 2011/12 and 2012/13 growing seasons and the 35-year average at Registro, São Paulo State, Brazil.

Month	Rainfall (mm)			Temperature (^{0}C)		
	2011/12	2012/13	35-year average[a]	2011/12	2012/13	35-year Average
September	05	42	33	18.2	20.3	19.4
October	225	108	118	21.6	22.4	21.5
November	102	97	117	20.9	22.1	21.3
December	234	198	181	23.3	26.6	24.4
January	277	224	210	23.6	24.5	24.6
February	185	132	150	26.4	25.8	25.7
March	71	153	95	23.4	24.2	24.1
April	93	47	73	22.5	22.7	22.3
May	121	71	61	19.7	21.2	20.8
June	240	138	126	18.1	20.1	19.3
Total	1553	1210	1184	-	-	-

[a]Average for the 35-year period 1978-2013. Source: Authors.

The soils are described as alluvial and clayey soils of Eutrophic Cambisols type (Santos et al., 2013) that correspond to Eutrophic Inceptisol (Usda, 1999). Soil samples were collected in June 2011 and July 2012 for characterization of chemical properties from the depth of 0 to 20 cm with four replicates being collected: 5 and 6 mg dm^{-3} of P (resin); 28 and 23 g dm^{-3} of organic matter (OM); 4.2 and 4.9 of pH ($CaCl_2$); K^+, Ca^{++}, Mg^{++}, H+Al, BS and CEC equal of 0.7 and 0.6, 12 and 20, 4 and 12, 64 and 35, 13 and 0; and 81 and 68 mmol$_c$ dm^{-3}, respectively; and 21% e 48% of base saturation, 2011 e 2012, respectively.

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An experiment was carried out in a randomized block design and 4x5 factorial scheme, with four replications. Treatments consisted of four trinexapac-ethyl spraying times: at rice tillering (T), at its floral differentiation (FD), and between T-FD (V_4, R_1 and V_8 according to the scale of Counce et al. (2000)), plus a control (absence of spraying). These were associated with five nitrogen (N) rates (0, 50, 100, 150, and 200 kg N ha^{-1}) applied as topdressing at 30 days after emergence (DAE).

Each experimental plot had five 7.0m long planting rows, spaced at 0.35 m intervals. However, the plot area used for sampling, and grain harvest was comprised of the center 6.0 m and only for the three central rows.

The soil was tilled in August 2011 by one plowing at 0.30 m depth and one medium-disk harrowing. Based on soil analysis and recommendations by Neto and Villela (2014), a rate of 2,600 kg ha^{-1} dolomitic limestone ($CaCO_3$; TNP of 75%) was spread by hand, aiming to raise soil base saturation to 50%. After application, it was incorporated to a depth of 0.2 m, using a disk harrow. In August 2012, the same areas received a second application of 600 kg ha^{-1} dolomitic limestone ($CaCO_3$; TNP of 75%), which was also spread by hand and incorporated to the soil using a disc harrow at 0.20 m depth. Before rice sowing in December 2011 and 2012, a harrowing was carried out for soil leveling and weed control.

Upland rice was sown mechanically on December 11, 2011 and December 10, 2012 (Ferrari et al., 2018). The cultivar IAC 202 was used for its modern plant architecture, upright leaves, and small size (average 0.96 m), which is also resistant to lodging and has an average cycle of 112 days and 50% flowering at 69 days (Regitano Neto et al., 2013). Seeds were treated just before sowing by carbofuran and carboxin + thiram at 1500- and 300-mL commercial product (cp) per 100 kg seeds, respectively. Certified seeds were used and sown at a population of 180 plants m^{-2} in both crop years (2011/12 and 2012/13). Seedling emergence occurred uniformly, nine days after planting (DAP), in both crop years.

Seeding fertilization was applied in-furrow at 600 kg ha^{-1}, using a 04-14-08 NPK formulation, as recommended by Neto and Villela (2014). Increasing topdressing rates were applied at 30 DAE, in both cultivation years, using urea (45% N) as source.

In both crop years, trinexapac-ethyl was sprayed at three different times: in the phenological stages of tillering (25 DAE); between tillering and floral differentiation (35 DAE); and floral differentiation (45 DAE), which were defined as T, T-FD, and FD, respectively; plus a control (absence of spraying). A single rate of 150 g active ingredient (ai) ha^{-1} was applied by driven jet, using a CO_2-pressurized backpack sprayer with aluminum bar, constant pressure,

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empty conical jet nozzles, and spraying volume of 200 L ha^{-1}. Sprays were performed between 8 and 9 am to avoid high temperatures.

Weeds were controlled by herbicides and manual weeding. Other cultural and phytosanitary treatments followed recommendations for upland rice farming in the region.

Leaf contents of nutrients in upland rice were determined in a sample of 30 flag leaves at full bloom (R4). After collection, samples were placed to dry in a forced-air oven at 65 ºC, then ground and sent to the laboratory for analyses (Bataglia et al., 1983).

A manual harvest was conducted when approximately 90% of the panicles had grains of a typical mature coloration (R_9) in 6.30 m^2 in each plot. The panicles were dried in the sun for 2 days. The grain yield (unhulled grain weight was correcting their moisture content to 130 g kg^1 wet basis and converting to kg ha^1) was evaluated. The harvest of upland rice was carried out at 125 e 130 days after emergence respectively in 2011/12 e 2012/13 agricultural year.

In all data results, two-way ANOVA was run using the statistical software package SISVAR (Ferreira, 2019). The blocks and all of the block interactions were considered as random effects. Nitrogen rates and growth regulator were considered as fixed effects. Significant effects of quantitative factors were evaluated by polynomial regression analysis, and qualitative ones by the Tukey's test. The effects on leaf contents of macro- and micronutrients and grain yields were considered significant at 5% probability ($p \leq 0.05$).

3. Results

Spraying times of trinexapac-ethyl influenced differently the absorption of primary macronutrients in each crop year (Table 2). When compared to the control, no effect was observed on N and P leaf contents in the 2011/12 crop year. Conversely, in the 2012/13 crop year, the spraying at T-FD increased N and P absorptions, respectively, by 15 and 13% but decreased K contents by 11%.

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Table 2. Average values of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, zinc in the leafe and grain yield of upland rice as a function of nitrogen (N) coverage and season application of trinexapac-ethyl, Registro-SP, Brazil, 2011/12 and 2012/13.

	Nitrogen ($g\ kg^{-1}$)		**Phosphor** ($g\ kg^{-1}$)		**Potassium** ($g\ kg^{-1}$)		**Calcium** ($g\ kg^{-1}$)	
	11/12	12/13	11/12	12/13	11/12	12/13	11/12	12/13
	N rates							
0	24[1]	25[2]	1.7[3]	1.7	-	18	4.7	4.8
50	26	26	1.5	1.6	-	18	4.8	4.9
100	28	29	1.6	1.6	-	18	4.3	4.5
150	31	32	1.5	1.5	-	19	4.3	4.1
200	33	34	1.5	1.5	-	17	4.3	4.1
	Application time of trinexapac-ethyl							
Control	29	28 b	1.6	1.6 ab	-	17 a	4.3 b	4.0 b
P	29	29 b	1.5	1.5 b	-	18 a	4.5 ab	5.1 a
P-DF	29	32 a	1.6	1.7 a	-	16 b	4.3 b	4.0 b
DF	27	28 b	1.6	1.6 ab	-	19 a	4.9 a	4.8 a
CV%	10.2	10.7	9.7	10.3	11.4	9.6	13,0	18.9
	Magnesium ($g\ kg^{-1}$)		**Sulfur** ($g\ kg^{-1}$)		**Boron** ($mg\ kg^{-1}$)		**Copper** ($mg\ kg^{-1}$)	
	N rates							
0	2.8	2.8	4.0[4]	3.4[5]	14	15	6	6
50	2.8	2.9	3.2	2.7	14	15	6	6
100	2.8	3.0	2.7	2.2	15	16	5	6
150	3.0	3.0	2.7	2.1	14	14	6	6
200	3.2	3.4	2.6	2.0	14	15	6	6
	Application time of trinexapac-ethyl							
Control	2.7 b	2.5 b	3.0	2.4 ab	13 b	15	6 a	6 a
P	2.7 b	3.2 ab	2.9	2.2 b	13 b	15	6 a	5 ab
P-DF	2.7 b	2.7 b	3.2	2.6 ab	15 a	16	6 ab	5 ab
DF	3.6 a	3.7 a	3.1	2.8 a	15 a	16	5 b	5 b
CV%	15.4	22.5	10.7	22.3	12.5	17.3	22.11	24.3
	Iron ($mg\ kg^{-1}$)		**Manganese** ($mg\ kg^{-1}$)		**Zinc** ($mg\ kg^{-1}$)		**Grain yield** ($kg\ ha^{-1}$)	
	N rates							
	[6]		[7]	[8]	[9]	[10]	[11]**	[12]**
0	74	90	374	353	19	17	2789.28	2704.84
50	81	87	398	360	21	19	3852.36	3692.86
100	88	85	221	294	22	23	4365.47	3840.48
150	94	92	230	280	24	24	4057.38	3683.93
200	99	90	279	282	23	23	4032.07	3329.76
	Application time of trinexapac-ethyl							
Control	87 ab	87 ab	230 b	219 b	20	21	3961.6a	3764.3 a
P	92 a	91 a	285 b	252 b	23	23	4012.5a	3450.1ab
P-DF	88 ab	92 a	266 b	208 b	22	24	4024.4a	3185.7 b
DF	82 b	82 b	420 a	378 a	21	22	3302.7b	3401.4ab
CV%	9.6	17.2	37.5	28.3	14.9	11.6	16.2	13.1

Any mean followed by the same lowercase letters are not significantly different (P value > 0.05). ** significant $p<0.01$; * significant $0.01<p<0.05$; Corrected data following the equation $(x+0.5)^{0.5}$; [1] $Y=23,531+0,048x+0.000x^2$; [2] $Y=24,201+0.04x$; [3] $Y=1,646-0.0008x$; [4] $Y=3,739500-0,006x$; [5] $Y=3.342-0.014x+0.00004x^2$; [6] $Y=73,833+0,150x-0,0001x^2$; [7] $Y=372,041-0,717x$; [8] $Y=366,127-$

0,487x; [(9)]Y=19,145+0.023; [(10)]Y=18,224+0,085x; [(11)]Y= 2837.592 + 23.893x -0.095x^2 ; [(12)]Y=2772.648+19.371x-0.079x^2. Source: Authors.

N leaf contents increased linearly with increasing N rates in both crop years (Table 2). By contrast, raising N rates reduced P contents in upland rice leaves, which was only registered in the 2011/12 crop year. Yet, N rates had no significant effect on K contents in the 2012/13 crop year (Table 2).

No interaction was observed between N rates and K leaf contents in the 2011/12 crop year (Table 3). A rate of 100 kg N ha^{-1} increased K leaf contents by 28% compared to the control. However, 50 kg N ha^{-1} reduced K contents by 20% when the growth regulator was sprayed at T-FD, compared to the control. In the absence of trinexapac-ethyl, increasing N rates linearly decreased K contents in rice leaves.

Table 3. Development of significant interaction for the leaf potassium (K^+) content of upland rice as a function of nitrogen (N) coverage and season application of trinexapac-ethyl, Registro-SP, Brazil, 2011/12.

N rates (kg ha^{-1})	**Application time of trinexapac-ethyl**			
	FD	T-FD	T	Control
	Leaf K^+ Content (g kg^{-1})			
0	16	18	17	18[(1)]
50	17 a	14 b	18 a	17 a
100	20 a	17 b	18 ab	15 b
150	16	17	17	15
200	18 a	15 b	17 ab	16 b

Any mean followed by the same lowercase letters are not significantly different (P value > 0.05). Corrected data following the equation $(x+0.5)^{0.5}$; [(1)]Y=17.467-0.012x. Source: Authors.

Trinexapac-ethyl spray increased Ca^{++}, Mg^{++}, and S in the 2011/12 crop year, and contents of Ca^{++} and Mg^{++} in the 2012/13 crop year (Table 2). The highest Ca^{++} contents were observed in sprayings at FD in both crop years, and at T in the 2012/13 crop year. The highest leaf contents of Mg^{++} were observed in sprays at FD, which was also observed for S in the 2012/13 crop year (Table 2).

Increasing N rates linearly reduced S contents in upland rice leaves by 35 and 40% in the 2011/12 and 2012/13 crop years, respectively. Moreover, N rates had no effect on Ca^{++} and Mg^{++} contents (Table 2).

B leaf contents were lower when trinexapac-ethyl was sprayed at T and in the control treatment (2011/12). But, if compared to the spraying at FD, Cu^{++} contents in control were 40

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and 34% higher in the 2011/12 and 2012/13 crop years, respectively. Moreover, N rates had no effect on B and Cu^{++} contents (Table 2).

Fe^{++} leaf contents reduced when trinexapac-ethyl was sprayed in the first crop year. Conversely, the highest Mn^{++} contents were observed when trinexapac-ethyl was applied at FD, without differences with the other spraying times. Zn^{++} leaf contents did not differ among the trinexapac-ethyl spraying times (Table 2). Also, increasing N rates linearly increased leaf contents of Fe^{++} and Mn^{++} in the first crop year and Zn^{++} in both crop years, but linearly reduced those of Mn^{++} in the second crop year (Table 2).

Lastly, trinexapac-ethyl spraying time had no influence on upland rice grain yield. Sprays at FD in the 2011/12 crop year and between T-FD in the 2012/13 crop year decreased grain yields by 20 and 18%, respectively (Table 3). Maximum yields of upland rice crops were reached at N fertilization rates of 126 and 123 kg ha^{-1} in the 2011/12 and 2012/13 crop years, respectively. Average grain yield in the 2011/12 crop year was 10% higher compared to the following crop year (Table 2).

4. Discussion

In contrast to sandy, clayey soils have lesser demand for N fertilization due to their higher organic matter contents and N availability. In these soils, high N rates associated with frequent irrigation can increase plant lodging at harvest, which reduces harvesting efficiency and increases grain yield losses (Nascimento et al., 2009). In addition, it can reduce plant absorption of some nutrients such as P, S, and Mn^{++} (Table 2). However, balanced N fertilization may improve N, P, K^{+} absorption by upland rice plants, increasing phytomass and grain yields (Liu et al., 2017).

Pan et al., (2016) emphasized that proper and balanced N fertilization can improve rice root growth, benefiting nutrient absorption by plants, mainly K^{+}. The same was not observed in our study since increasing N rates decreased K^{+} contents in upland rice crops (Table 3). This may be related to an increase in dry matter contents. But, despite this, K^{+} contents shown in our study are within the suitable range (13-30 g kg^{-1} K^{+}) for good rice development, as by Raij et al., (2011).

An increase in N rates linearly reduced S contents in upland rice leaves (Table 2). Such a decrease may be because of a rise in protein synthesis (Jamal et al., 2010; White, 2016; Reis et al., 2018). Therefore, increases in N fertilization rates must be lined up with a proper S supply, aiming at greater fertilization efficiency. Despite the S reduction, our findings are within the suitable range (1.4-3.0 g kg^{-1} S) for good rice development, as by Raij et al., (2011).

Likewise, P leaf contents decreased with increasing N rates (Table 2), as already reported by Yan et al., (2015). This might be due to an increase in C uptake by crops and, consequently, higher photosynthetic rates with more P consumption for adenosine triphosphate synthesis (Agren, 2004). Rice plants had moderate P deficiency, regardless of trinexapac-ethyl use and N rate, with contents between 1.5 to 1.7 g P kg^{-1}, which are below the suitable (1.8- 3.0 g kg^{-1} P) for good plant development, according to Raij et al., (2011).

In upland farming environments with organic matter contents above 2%, rice crops responded better to N topdressing at rates around 125 kg N ha^{-1}. Moreover, in the crop year with more rains and uniform rainfall distribution, plants tended to respond better to higher N rates in terms of rice production potential. It is known that increasing N rates can raise rice grain yields by up to 35% (Arf et al., 2005).

Mostly, growth regulator spraying increased leaf contents of nutrients, mainly the structural ones (N, Ca^{++}, and Mg^{++}), and the micronutrients B and Mn^{++} (Table 2). This might have occurred due to a plant growth reduction in terms of shoot phytomass (Marolli et al., 2017). Therefore, nutrient absorption had similar results, showing higher leaf content and accumulation in upland rice plants. It is worth noting that N topdressing up to 50 kg ha^{-1} provided moderate deficiency in rice plants, with N leaf contents from 24 to 26 g N kg^{-1} (Table 2), i.e., below the suitable (27-35 g N kg^{-1}) for good rice development (Raij et al., 2011).

Although Ca^{++}, Mg^{++}, B, Cu^{++}, Fe^{++}, Mn^{++}, and Zn^{++} had different absorption levels, contents were within the suitable range (2.5-10.0 g Ca^{++}; 1.5-5.0 g Mg^{++}; 4-25 mg B; 3-25 mg Cu^{++}; 70-200 mg Fe^{++}; 70-400 mg Mn^{++}; and 10-50 mg Zn^{++}, kg^{-1}) for good development of rice plants (Raij et al., 2011).

The spraying of a growth regulator that inhibits gibberellin biosynthesis had no effect on grain yield of upland rice crops (Table 2). This finding corroborates other studies (Arf et al. 2012; Alvarez et al., 2012; Peron et al., 2019) and may be due to a reduced plant shoot growth, and hence less light energy uptake (Song et al., 2013).

5. Conclusion

As nitrogen topdressing rate increased, leaf contents of nitrogen, iron, and zinc increased, while sulfur and manganese contents decreased; however, contents of phosphorus, calcium, magnesium, boron, and copper showed little change.

Trinexapac-ethyl spraying had little influence on the leaf contents of nitrogen, phosphorus, sulfur, boron, and zinc; while contents of phosphorus, calcium, magnesium, iron, and manganese increased, those of copper decreased.

Trinexapac-ethyl can be sprayed at rice tillering without decreasing grain yield.

Upland rice grain yield increased by 58 and 46% in the 2011/12 and 2012/13 crop years, respectively, with an application of about 120 kg N ha^{-1} as topdressing.

Conflicts of Interest

Competing Declaration of Interests. The authors declare no competing interests.

Acknowledgment

To FAPESP for financial aid. Process: 2011/20504-8. To São Paulo State University (Unesp), Campus of Registro for the infrastructure and human resources available.

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Percentage of contribution of each author in the manuscript

Samuel Ferrari – 30%

Luis Fernando dos Santos Cordeiro – 15%

Luís Guilherme Delovo Carara – 15%

Vagner do Nascimento – 14%

Paulo Renato Matos Lopes – 10%

Evandro Pereira Prado – 8%

Ronaldo da Silva Viana – 8%