




Nitrogen sufficiency index for estimating nitrogen fertilizer requirement of irrigated rice

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ABSTRACT

The proper nitrogen management is required to achieve high irrigated rice yield. This study aimed to determine the rice response to nitrogen topdressing doses and calibrate the chlorophyll meter reading. Three experiments were conducted in a randomized block design. In the first experiment, five N rates (0, 30, 60, 90, and 120 kg ha⁻¹) were evaluated as the first, and 30 kg ha⁻¹ N as the second topdressing, which were combined with the application of 30 kg ha⁻¹ N as the first and five N rates, as the second topdressing. The other experiments assessed the application of 30 kg ha⁻¹ of N, as the first, and four N rates (0, 40, 80, and 120 kg ha⁻¹), as the second topdressing. There was a response to N application, with maximum technical efficiency reaching 33 kg ha⁻¹ in the first and between 40 and 50 kg ha⁻¹ in the second topdressing. The chlorophyll meter was sensitive to estimate the amount of N to be applied in topdressing, using the nitrogen sufficiency index (NSI). To each percent unit of NSI below 95%, one should apply 10 kg ha⁻¹ of N as the first and 2-3 kg ha⁻¹ of N as the second topdressing.

Keywords: *Oryza sativa* L.; N management; grain yield; nitrogen topdressing; chlorophyll meter.

INTRODUCTION

Conservation and sustainability of crop grain yield require good management practices of soil fertility. Nitrogen (N) is the nutrient of greatest metabolic demand by plants, and its deficiency is usually a limiting factor for crop growth. The molecule chlorophyll contains nitrogen and has a significant participation in the increase of leaf area of the plant, which increases the interception of solar radiation and the photosynthetic rate, resulting in higher grain yield (Fageria & Stone, 2003).

Rice cultivated in the flooded irrigation system is highly demanding for nutrients, and N is among those required in greatest amount, since it is an important factor to determine its productive potential (Fageria *et al.*, 2008; Fageria, 2014). The lower grain yield of irrigated rice in the tropical region than in subtropical areas can be

attributed to the reduction in the crop cycle and the lower response to fertilizers, especially N (Santos, 2004). N deficiency in irrigated rice occurs frequently in tropical floodplain soils. The main reasons for this occurrence are soil ammonia volatilization losses, gaseous losses of nitrogen oxides (NO₂, N₂O, NO) and elemental nitrogen (N₂), soil nitrate leaching out of the reach of roots, NH₃ losses by the shoots (Fageria & Baligar, 2005; Damin & Soler-Silva, 2016), and decrease in the organic matter content from successive crops (Munda *et al.*, 2018). In this context, a good N management is fundamental, both for reducing production costs and minimizing the effects of environmental pollution. N has an extremely complex dynamics in irrigated rice farming, with great variability in its chemical forms due to soil water content (aerobic or anaerobic conditions), which directly reflects the efficiency of nutrient utilization by the crop.

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Because most farmers have no access to plant analysis or other guidance method, mineral nitrogen fertilization is quantified by empirical visual analysis or based on traditional recommendations. Therefore, correct N diagnosis in the plant is essential for a proper management. Most of the methods available for this assessment are costly, destructive, and time consuming.

To date, no routine laboratory method has been developed that provides a satisfactory evaluation of the soil's ability to supply N to plants and recommendations, given the complexity and interactions between the transformation processes of this nutrient in the soil and climatic conditions (Fageria *et al.*, 2019). Most of the N in the soil is in the organic form, which must be mineralized to be released and made available to plants. Thus, it is not possible to establish a calibration curve for this nutrient, and N recommendations are made based on the dose response curve.

The lack of synchronicity between the time of application and the time of the highest demand provides a low N recovery efficiency by the irrigated rice. These pre-established nitrogen doses may lead to underestimation or overestimation of fertilizer requirements. On the one hand, this can result in drop in grain yield and, on the other hand, in increased costs due to the unnecessary fertilizer amounts, leading to a decrease in the farmer's profit and a negative impact on the environment due to nitrate leaching and higher gas emissions by nitrification, i.e., the risk of environmental pollution. For a better synchronization of application and demand times, it has been suggested the monitoring of leaf N and chlorophyll levels as an alternative to conventional methods for the diagnosis. The handheld device chlorophyll meter (SPAD unit) provides readings corresponding to the content of the pigment in the leaf and has been used to estimate the N leaf content, since chlorophyll and N correlate positively in the same crop (Carvalho *et al.*, 2012; Pcojeski *et al.*, 2012) and with grain yield.

The chlorophyll meter monitors indirectly and non-destructively the nutritional status of N in the crop and can be used to estimate the need for nitrogen topdressing at different growth stages.

Several biotic and abiotic factors may affect the chlorophyll meter measurements of the intensity of green color in the leaf. In order to minimize this influence, a method has been recommended for normalizing the chlorophyll meter readings for each area, cultivar, growth stage, edaphoclimatic condition, and management practice (Hussain *et al.*, 2000; Godoy *et al.*, 2003; Rambo *et al.*, 2007). One way to normalize the readings is to determine the N sufficiency index (NSI) by dividing the average of the readings done in the treatments to be fertilized by that done in a Reference Area. The Reference Area is a strip of

the crop, with the same cultivar, fertilized with a much higher amount of N than the rest of the crop, so that in theory there is no N deficiency. The most frequently used NSI value is 0.95. Therefore, when the value of NSI in the sample is below 95% of the reading in the Reference Area, nitrogen fertilization is necessary (Godoy *et al.*, 2003; Rambo *et al.*, 2007).

Santos *et al.* (2011, 2017) and Carvalho *et al.* (2018) conducted studies in the tropical region performing chlorophyll readings from the growth stages V3 - V4 to V11 - V12. The SPAD units or relative chlorophyll content of plants that received N increased to reach maximum values at the V7 - V8 stages and, afterwards, decreased and stabilized until the last reading. In these studies, the NSI values of the stages V3 - V4 and V7 - V8 indicated the need for N application.

The objective of this study was to determine the agronomic performance of irrigated rice as affected by N doses applied as the first (V3 - V4 stage) and as the second (V7 - V8 stage) topdressing and calibrate the chlorophyll meter reading with the crop response curve for the management of nitrogen fertilizer in tropical lowlands.

MATERIAL AND METHODS

The study was conducted in the experimental field of Palmital Farm, belonging to Embrapa Rice & Beans, located in the municipality of Goianira, GO, between coordinates 16°26'45" S and 49°23'31" W, 729 m altitude, in the 2014-15 and 2016-17 harvest years. Three experiments were carried out in a Neofluvisolic Eutrophic Ta Haplic Gleysol, medium/medium-coarse texture, A moderate, phases flat relief, Stony III, hydrophilic floodplain (Oliveira & Rodrigues, 2012). According to the Köppen-Geiger climatic classification (Kottek *et al.*, 2006), the climate is "Aw", with annual average rainfall of 1,485 mm and annual average relative humidity of 71%.

The first experiment tested the effects of five N doses applied as the first topdressing and a fixed dose of 30 kg ha⁻¹ N applied as the second topdressing combined with the application of 30 kg ha⁻¹ N as the first topdressing and five N doses as the second topdressing, in the form of urea, on the performance of irrigated rice. The doses 0, 30, 60, 90, and 120 kg ha⁻¹ of N were applied at the vegetative growth stage V3 - V4 (pre or early tillering) and at the V7 - V8 (effective tillering), according to the scale of Counce *et al.* (2000).

Prior to fertilizer applications, we used the SPAD-502 (Minolta, 1989) (SPAD-Soil Plant Analysis Development) chlorophyll meter to monitor the N status in 25 plants. The readings were taken on the middle third of the last fully expanded leaf of the rice plants, from 9:00 to 10:00 a.m.

In order to normalize the readings obtained by the chlorophyll meter, we established a Reference Area which received 180 kg ha⁻¹ N as three applications of 60 kg ha⁻¹ N, corresponding to twice the recommended dose, which is 90 kg ha⁻¹ N, to ensure no deficiency of nitrogen. Using these data, we determined NSI with the formula:

$$\text{NSI (\%)} = \frac{\text{average values of readings in plants of the area to be fertilized with N}}{\text{average values of readings in plants of the Reference Area}} \times 100$$

The second and third experiments tested the effects of 30 kg ha⁻¹ N applied as the first N topdressing and four doses of 0, 40, 80, and 120 kg ha⁻¹ of N as the second topdressing on the performance of irrigated rice.

The three experiments were carried out with cv. BRS Catiana for the irrigated condition, with long and thin grains, and average cycle of 121 to 135 days. It is recommended for the majority of states with significant irrigated rice production in the tropical region. The cultivar stands out for its translucent grains, low incidence of chalky grains, and good cooking quality with soft and loose grains. It has wide adaptation, high productive potential and tolerance to lodging, with the stay-green phenotype showing later senescence. In addition, it also stands out for the excellent grain quality and moderate resistance to the main diseases that attack irrigated rice crops (Morais *et al.*, 2016)

The three experiments were arranged in a randomized block design, with four replications. Land was prepared by harrowing and leveling of the area. At sowing, 20 kg ha⁻¹ of N, 40 kg ha⁻¹ of P₂O₅, and 55 kg ha⁻¹ of K₂O were applied according to the recommendation based on soil fertility analyses. The chemical analyses and grain size of soil samples collected at the beginning of the study in the 0-0.20 m layer showed the following characteristics: pH (H₂O): 5.2 and 5.2; Ca²⁺: 29.5 and 22.7 mmol_c dm⁻³; Mg²⁺: 14.6 and 6.5 mmol_c dm⁻³; Al³⁺: 2.8 and 4.6 mmol_c dm⁻³; P: 37.6 and 49.8 mg dm⁻³; K⁺: 79.8 and 65.5 mg dm⁻³; Cu: 1.7 and 7.4 mg dm⁻³; Zn: 2.2 and 5.9 mg dm⁻³; Fe: 268.3 and 364.2 mg dm⁻³; Mn: 19 and 24 mg dm⁻³; Clay: 414 and 238 g dm⁻³; Silt: 254 and 242 g dm⁻³, and Sand: 331 and 519 g dm⁻³, in the experiments 1 and 2/3, respectively.

Sowing was performed on dry soil, using rows spaced 0.17 m apart and 80 seeds per meter. Flooding started shortly after the first topdressing fertilization at the V3 - V4 stage. During irrigation, the water depth was uniformly maintained at about 0.12 m. Interruption of irrigation occurred only at the R8 - R9 stage, at complete grain maturation.

Plant samples collected at harvest were separated into straw (leaves + sheaths + stems) and grain, and dried in an oven at 60 °C to determine the straw dry mass

(DMstraw) and total shoot dry mass (Biomass). Still, at harvest time, the following variables were recorded: number of tillers and panicles in 1 m², grain number and empty spikelets per panicle, 100-grain weight, and plant height, determined in ten panicles, and grain yield, expressed as kg ha⁻¹ after moisture adjusted to 13%. Spikelet fertility was determined by dividing the number of grains per panicle by the total number of spikelets and expressing the result as percentage. Grain harvest index (GHI) was obtained by the ratio between the grain yield and Biomass in 1 m². N use efficiency was calculated by the formula: Agronomic Efficiency of N (AEN) = (PG_{wf} - PG_{wof})/(QN_a) expressed as kg kg⁻¹, where PG_{wf} is the production of grains with nitrogen fertilizer; PG_{wof} is the production of grains without nitrogen fertilizer; QN_a is the quantity of N applied in kilograms (Fageria & Baligar, 2005; Fageria, 2014).

Data were analyzed by analysis of variance and the effects of N doses by regression analysis. After estimation of maximum grain yield (MEY) based on the N response curve, the maximum technical efficiency (MET) was determined. As an economic criterion for fertilizer recommendation, MET is normally considered to be 90% of MEY (Fageria *et al.*, 2007; Fageria *et al.*, 2008). However, due to the importance of N for irrigated rice, in this study MET was considered equal to 0.95MEY.

RESULTS AND DISCUSSION

N rates influenced differently some agronomic traits of cv. BRS Catiana (Table 1). In the first experiment, the number of panicles per area increased linearly with the N doses applied at early tillering. This indicates that application of N at the pre- or early tillering stage results in a higher number of panicles per area, which is defined in the vegetative phase and contributes the most to grain yield (Fageria, 2007). This yield component had similar behavior with the second topdressing in the third experiment. Therefore, a larger number of panicles per area can also be obtained with nitrogen fertilizations carried out at the effective tillering stage. Camargo *et al.* (2008) reported that the formation of rice panicles increases with N addition prior to booting. Fageria (2007), Fageria *et al.* (2007), and Fageria & Santos (2015) found that the number of panicles of irrigated rice increased with N fertilization.

The number of grains per panicle was not influenced by nitrogen fertilization, while the 100-grain weight decreased in the first experiment and increased in the third experiment, with the N rates applied as the second topdressing. Fageria *et al.* (2007) and Santos *et al.* (2016) found no effect of N doses on grain weight of irrigated rice genotypes. However, Fageria *et al.* (2007) reported that

grain weight and grain yield shown a positive, but not significant, correlation, which demonstrates its less importance for increasing yield in the rice crop.

The spikelet fertility decreased linearly with the increase in the N doses applied as first and second topdressing. Fageria *et al.* (2007) stated that in irrigated rice the spikelet sterility is a genotype characteristic and can be modified by using N.

The N doses influenced DMstraw and rice biomass in the first experiment, showing quadratic effects in the first topdressing, with peaks at the doses 111 and 86 kg ha⁻¹ of N, respectively, and increasing linearly in the second topdressing. In the second experiment, there was a linear response of DMstraw and quadratic of biomass, peaking at 87 kg ha⁻¹ N. In the third experiment, these agronomic traits responded linearly to the N doses, increasing 4.3 and 6.6 g m⁻² in dry matter per each kg of N applied, respectively. Fageria *et al.* (2008) evaluated the performance of irrigated rice genotypes to nitrogen fertilization and found a quadratic association between biomass and grain yield.

The dry matter yield responses to N doses were reflected in the height of the plants, which increased linearly. GHI showed linear negative response to the increasing doses of N applied as the first and second topdressing, indicating that the increase in straw dry matter was greater than the increase in grain yield.

In this study, we found N sufficiency indices (NSI) below 95%, indicating, therefore, the time of greatest need for N application, which is similar to the results obtained by Santos *et al.* (2011, 2017) and Carvalho *et al.* (2018), who verified the need for N application at the V3 - V4 and V7 - V8 stages of rice growth.

Considering the crop response to the application of nitrogen in field conditions, in the first experiment, the maximum grain yields of 9,791 and 10,040 kg ha⁻¹ were estimated (MEY) at doses of 74 and 77 kg ha⁻¹ of N as first and second topdressing, respectively (Table 2).

Furthermore, studies on plant nutrition have been using the maximum technical efficiency (MTE) as an economic criterion for fertilizer recommendations. MTE corresponds to the same yield obtained by using a smaller

Table 1: Regression equations of agronomic traits of irrigated rice cultivar BRS Catiana as a function of N doses applied as topdressing and determination coefficients (R²), in three experiments

Trait	Regression equation	R ²
First experiment		
First topdressing		
Panicle (n° m ⁻²)	y = 567.69 + 1.5294x	0.621*
Spikelet fertility (%)	y = 86.30 - 0.0889x	0.838*
DMstraw (g m ⁻²)	y = 626.88 + 11.5080x - 0.0518x ²	0.942**
Biomass (g m ⁻²)	y = 1450.45 + 22.3354x - 0.1293 x ²	0.903**
Plant height (cm)	y = 85.63 + 0.1723x	0.993**
GHI	y = 0.57 - 0.0010x	0.990**
Second topdressing		
100-grain weight (g)	y = 2.88 - 0.0022x	0.860**
Spikelet fertility (%)	y = 81.74 - 0.0732x	0.767**
DMstraw (g m ⁻²)	y = 721.43 + 3.7199x	0.720**
Biomass (g m ⁻²)	y = 1505.40 + 7.8992x	0.709**
Plant height (cm)	y = 88.46 + 0.1252x	0.886**
Second experiment		
DMstraw (g m ⁻²)	y = 647.64 + 2.0868x	0.794**
Biomass (g m ⁻²)	y = 1313.56 + 12.1656x - 0.0699 x ²	0.996**
Plant height (cm)	y = 81.08 + 0.0831x	0.934**
Third experiment		
Panicle (n° m ⁻²)	y = 503.53 + 1.6508x	0.914**
100-grain weight (g)	y = 2.64 + 0.0019x	0.431**
Spikelet fertility (%)	y = 78.48 - 0.0231x	0.635**
DMstraw (g m ⁻²)	y = 581.94 + 4.2851x	0.931**
Biomass (g m ⁻²)	y = 1292.93 + 6.6201x	0.955**
Plant height (cm)	y = 78.67 + 0.1330x	0.979**
GHI	y = 0.55 - 0.0007x	0.955**

* and ** Significant at 5% and 1% probability level.

quantity of production factors or at least one of them, above which there is no response from the crop that justifies increasing the amount of the nutrient. Considering the MEY obtained by the response curve of the irrigated rice cv. BRS Catiana, MTE, that is, 95% of the MEY, was determined on the same curve, and the doses 33 and 42 kg ha⁻¹ of N were estimated to be applied as first and second topdressing, respectively.

Based on the chlorophyll meter readings, NSI were calculated for the first experiment:

$$\text{First topdressing NSI (\%)} = (34.91 / 38.07) \times 100 = 91.69\%$$

$$\text{Second topdressing NSI (\%)} = (26.78 / 38.00) \times 100 = 70.47\%$$

In the normalization of the chlorophyll meter readings, N well-nourished plants are considered to have 95% NSI. With this, it is necessary to establish the factor to be used for determining the N dose to be applied as the first topdressing, based on the chlorophyll meter. This was done by dividing 33 kg ha⁻¹ of N that was estimated on the response curve by the difference between 95% and the calculated NSI, which was 91.69%, that is:

$$\text{Factor for determination of N dose} = \text{MTE} / (95 - \text{NSI}).$$

The result obtained is factor 10, that is, $33/3.3 = 10$.

Similarly, the N dose to be applied in the second nitrogen topdressing, based on chlorophyll meter readings, was determined by dividing 42 kg ha⁻¹ N calculated on the response curve by the difference between 95% and the NSI, which was 70.47%. Thus, factor 2 is obtained as a whole number, that is, $42/24.53 = 2$. With this methodology, the doses calculated to be applied to the irrigated rice crop are 33 and 49 kg ha⁻¹ of N as first and second topdressing, which corresponds to 10 and 2 kg ha⁻¹ of N per each percentage point below 95% of NSI. On the other hand, to calculate the maximum estimated yield (MEY) of 9,791 kg ha⁻¹ grain, the factor used to determine the nitrogen fertilization should be changed from 2 to 3, which would imply the application of 74 kg ha⁻¹ of N as the second topdressing.

In the second experiment, considering cv. BRS Catiana's response curve, the maximum yield of 8,040 kg ha⁻¹ grain was estimated (MEY) at the dose 81 kg ha⁻¹ N and MTE of 7,638 kg ha⁻¹ grain was calculated at the dose of 47 kg ha⁻¹ N as the second topdressing (Table 3). Using the NSI obtained from 78.25% and, therefore,

Table 2: Maximum grain yield estimated (MEY) based on the response curve of the irrigated rice cultivar BRS Catiana, maximum technical efficiency (MTE) (95% MEY) and calculation of N dose based on NSI, in the first experiment

First topdressing					
Regression equation					R ²
Grain yield	$y = 8154.51 + 44.2859x - 0.2996x^2$				0.841**
MEY (kg ha ⁻¹)	9791		N Dose (kg ha ⁻¹)	74	
MTE (kg ha ⁻¹)	9302		N Dose (kg ha ⁻¹)	33	
Calculation of N dose in the first topdressing based on NSI ¹					
Chlorophyll meter reading	NSI (%)	95 - NSI (%)	Factor	Dose de N (kg ha ⁻¹)	
Reference Area	Area to be fertilized				
38.07	34.91	91.69	3.30	10	33
Second topdressing					
Regression equation					R ²
Grain yield	$y = 7645.10 + 62.3186x - 0.4054x^2$				0.958**
MEY (kg ha ⁻¹)	10040		N Dose (kg ha ⁻¹)	77	
MTE (kg ha ⁻¹)	9538		N Dose (kg ha ⁻¹)	42	
Calculation of N dose in the second topdressing based on NSI					
Chlorophyll meter reading	NSI (%)	95 - NSI (%)	Factor	N Dose (kg ha ⁻¹)	
Reference Area	Area to be fertilized				
38.00	26.78	70.47	24.53	2	49
				3	74

¹N sufficiency index

** Significant at 1% probability

a difference of 16.75% below 95% of the reading in the Reference Area, which is a value that takes into account N well-nourished plants, we obtained the factor 3, as a whole number, that is, $47/16.75$. With this methodology, the dose estimated to be applied to the irrigated rice crop as the second topdressing is $50 \text{ kg ha}^{-1} \text{ N}$, which corresponds to $3 \text{ kg ha}^{-1} \text{ N}$ per each percentage point below 95% of NSI.

In the third experiment, the maximum yield of $8,236 \text{ kg ha}^{-1}$ grain was estimated (MEY) at the dose $97 \text{ kg ha}^{-1} \text{ N}$ and MTE of $7,824 \text{ kg ha}^{-1}$ grain was calculated at the dose $52 \text{ kg ha}^{-1} \text{ N}$ as the second topdressing (Table 3). Using the NSI obtained from 78.83% and, therefore, a difference of 16.17% below 95% of the reading in the Reference Area, a value that takes into account N well-nourished plants, we obtained the factor 3, as a whole number, that is, $52/16.17$. Therefore, the dose estimated to be applied as the second topdressing is $49 \text{ kg ha}^{-1} \text{ N}$, which corresponds to $3 \text{ kg ha}^{-1} \text{ N}$ per each percentage point below 95% of NSI. This dose allows the production of grain yields very close to those estimated by MTE.

Grain yield increased with increasing N, but the agronomic efficiency of N (AEN) decreased because of the plant's lower capacity for nutrient uptake and utilization (Table 4).

This decrease is also related to relatively smaller increases with the successive increments of N doses, as well as the possibility of higher N losses through different processes (Fageria, 2014). AEN declined linearly with N doses increasing in the range from 50 to 180 kg ha^{-1} . There was a negative linear relationship between N dose and AEN in the first and second topdressing, as well as in the total N application. On average, AEN varied from 29 to 41 kg grain produced per kg of total N applied, which corroborates the findings of Fageria *et al.* (2013), who reported an average of 40 kg grain per kg of N applied. Maximum N agronomic efficiencies were 56 and 65 kg of grain produced per kg of N applied, which was obtained with 30 kg ha^{-1} of N as first and second topdressing, and 55 kg grain obtained with up to 90 kg of total N applied. Santos *et al.* (2017) and Carvalho *et al.* (2018) obtained higher N use efficiencies in irrigated rice with nitrogen

Table 3: Maximum grain yield estimated (MEY) based on the response curve of the irrigated rice cultivar BRS Catiana, maximum technical efficiency (MTE) (95% MEY) and calculation of N dose based on NSI, in the in the second and third experiments

Second Experiment					
Regression equation					R ²
Grain yield		$y = 5729.38 + 57.0446x - 0.3521x^2$			0.999**
MEY (kg ha ⁻¹)		N Dose (kg ha ⁻¹)			
8040		81			
MTE (kg ha ⁻¹)		N Dose (kg ha ⁻¹)			
7638		47			
Calculation of N dose in the second topdressing based on NSI ¹					
Chlorophyll meter reading	NSI (%)	95 – NSI (%)	Factor	N Dose (kg ha ⁻¹)	
Reference Area	Area to be fertilized				
44.25	34.63	78.25	16.75	2	34
				3	50
Third experiment					
Regression equation					R ²
Grain yield		$y = 6348.71 + 38.8383x - 0.1998x^2$			0.985**
MEY (kg ha ⁻¹)		N Dose (kg ha ⁻¹)			
8236		97			
MTE (kg ha ⁻¹)		N Dose (kg ha ⁻¹)			
7824		52			
Calculation of N dose in the second topdressing based on NSI					
Chlorophyll meter reading	NSI (%)	95 – NSI (%)	Factor	N Dose (kg ha ⁻¹)	
Reference Area	Area to be fertilized				
36.05	28.42	78.83	16.17	2	32
				3	49

¹N sufficiency index

** Significant at 1% probability

fertilizer applied according to chlorophyll meter readings than with N applied according to the local recommendation, which is based on pre-fixed times. Higher N use efficiency may contribute to increase grain yield (Fageria *et al.*, 2007).

The chlorophyll meter readings were sensitive to estimate N content in the irrigated rice, allowing a response adjusted to the maximum technical efficiency (MTE) determined by the crop response curve to the application of N in field conditions.

The factors estimated to reach the appropriate level (95%) were 10 and 2 to 3 kg ha⁻¹ of N in the first and second topdressing applications, respectively, per each percentage unit of increase in NSI.

Several studies to monitor N status in the rice crop have been carried out successfully different of countries (Balasubramanian *et al.*, 2000; Hussain *et al.*, 2000; Santos *et al.*, 2011; Pcojeski *et al.*, 2012) as an alternative to conventional methods of topdressing fertilization.

Table 4: Grain yield of the irrigated rice cultivar BRS Catiana and agronomic efficiency of N (AEN) as a function of N dose in both topdressing applications and total N

N Dose (kg ha ⁻¹)		Grain yield (kg ha ⁻¹)	AEN (kg kg ⁻¹)	
First experiment				
First topdressing	N total		First topdressing	N total
0	60	7969	-	54
30	90	9652	56	55
60	120	9530	26	40
90	150	9546	18	32
120	180	9273	11	25
Mean			28	41
Regression				
N Dose in the first topdressing x AE N= 63.68 – 0.4807x. R ² =0.869**				
Total N x AEN = 72.79 – 0.2650x. R ² = 0.936**				
Second topdressing	N total		Second topdressing	N total
0	60	7514	-	46
30	90	9457	65	52
60	120	9791	38	42
90	150	9841	26	34
120	180	9373	16	26
Mean			36	40
Regression				
N Dose in the second topdressing x AE N= 76.03 – 0.5334x. R ² = 0.944**				
Second experiment				
Second topdressing	N total		Second topdressing	N total
0	36	5734	-	30
40	76	7434	43	37
80	116	8053	30	29
120	156	7495	15	18
Mean			29	29
Third experiment				
Second topdressing	N total		Second topdressing	N total
0	50	6468	-	55
40	90	7401	23	41
80	130	8884	30	40
120	170	8144	14	26
Mean			22	41
Regression				
Total N x AE N= 64.65 – 0.2202x. R ² = 0.923*				

* and ** Significant at 5% and 1% probability level.

CONCLUSIONS

This study has shown that cultivar BRS Catiana responds in a quadratic manner to N fertilization, with maximum technical efficiency (MTE) achieved with 33 kg ha⁻¹ applied as first topdressing and between 40 and 50 kg ha⁻¹ as second topdressing.

The nitrogen sufficiency index (NSI) obtained with the chlorophyll meter readings allows the efficient estimation of the N amount to be topdressed to the irrigated rice.

The amount of 10 kg ha⁻¹ of N should be applied as the first topdressing and 2 to 3 kg ha⁻¹ of N as the second topdressing per each percentage unit of increase in NSI in order to reach the appropriate level (95%).

The chlorophyll meter has proved to be a practical alternative to conventional methods for the determination of the N requirement of irrigated rice in tropical lowlands.

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