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SOIL AND CROP FACTORS TO SITE-SPECIFIC NITROGEN MANAGEMENT ON SUGARCANE FIELDS

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Abstract.

Nitrogen (N) is one of the most widely used fertilizers in crops and the most harmful to the environment. The increased consumption of nitrogen fertilizers is one of the main factors that affect the sustainability of the bioenergy production process from sugarcane. Currently, N recommendations in sugarcane are based only on the expected yield. However, several factors of the plant, soil and climate can affect the response of sugarcane to N fertilization. In this context, the objective of the present study was to investigate what are the main soil and plant factors that affect the N response to sugarcane in researches available in the literature using multivariate and meta-analysis, aiming to guide models for nitrogen site-specificific management. A wide literature review (130 experiments) showed that 60% of the total evaluated experiments were responsive to N. The general average of the N optimal rate (Nopt) of the responsive experiments was 118.20 (kg N) ha-1. The results showed that soils with low yield potential (< 70 t ha-1) presented higher Nopt when compared to soils with high yield potential (> 100 t ha-1); Nopt = 120.18 and 111.80 (kg N) ha-1, respectively, for soils with low and high yield potential. Among the factors of the plant assessed, the crop variety, the N application rate and the geolocation of the field are the three factors that most affect the N resposiveness. About soil factors, the soil texture and the organic matter content are the ones that most impact the crop's response to N.

Keywords.
Saccharum spp., ratoon; fertilization, green cane, sustainability.

Introduction

Nitrogen fertilization in agriculture contributes significantly to N_2O emissions (Crutzen et al., 2008; de Vries and Bardgett, 2012; Soares et al., 2015), corresponding to 310 times than GHG emission power of CO_2. Furthermore, there are no reliable diagnostic methods for characterizing the availability of nitrogen (N) in agricultural soils. The recommendation of N fertilization for sugarcane fields is based exclusively on the concept of expected yield (Spironello et al., 1997). Some authors point out that, in order to meet the nutritional needs of sugarcane, it is recommended to apply between 120 and 200 kg ha^{-1} of N under Brazilian conditions (Cantarella and Rossetto, 2014). However, these values are high when compared to the doses usually recommended in commercial areas. Furthermore, it is evident that the optimal N rate may depend on several factors, such as soil characteristics (pH, CEC, organic matter, clay content, soil aeration and compaction), climatic conditions (temperature and rainfall) and agronomic practices (preparation and crop rotation) (Subbarao et al., 2006). The methodology proposed by Khan et al. (2001) and Mulvaney et al. (2001), called the “soil based N approach for guiding N recommendation” (Mulvaney et al., 2006), despite not being used in practice, has been sought for decades as a strategy to optimize the nitrogen fertilization recommendation of crops, a since the soil is the main reservoir of N for crops (Dourado-Neto et al., 2010; Franco et al., 2011). However, using soils from 21 field experiments, Mariano et al. (2017) showed unfavorable results in using chemical indices to identify the responsiveness of sugarcane to N. As there is still no consensus in the literature on the possibility of using chemical methods to diagnose soil N status, another strategy is to evaluate factors that affect the responsiveness of sugarcane to N. Otto et al. (2016) observed that the response of sugarcane to N fertilization in Brazil is low, being attributed by the authors to the cultivation conditions of the crop, such as preservation of straw on the surface, reuse of industrial waste (filter cake, straw and vinasse) and the crop rotation, which increase the N availability in the soil and, consequently, decrease its responsiveness. Therefore, it is necessary to revisit studies on the response of sugarcane to N, listing which soil and plant factors may be associated with the responsiveness of sugarcane to N, allowing these parameters to be included in more efficient models of recommendation, seeking maximum economic return and environmental sustainability within the context of localized management and precision agriculture. The present study aims to evaluate the soil and plant factors that affect the response of sugarcane to N in studies available in the literature, using multivariate analysis and meta-analysis, aiming to guide the construction of models for site-specific crop management.

Material & Methods

Fourteen studies published in the literature were reviewed (Table 1), totaling 130 experiments and 586 experimental plots of sugarcane response to N fertilization. Information on the region of the experiment, variety used, N rates applied, cutting time, clay content, organic matter (OM), soil cation exchange capacity (CEC) and yield of the experimental plots were extracted. All the reviewed works come from the state of São Paulo, the largest producer of sugarcane in Brazil (CONAB, 2019), with Ribeirão Preto, Piracicaba and São José do Rio Preto being the main regions where the works were developed (Figure 1 - a). Most of the works reviewed were developed after 2010, with green sugarcane harvesting (Figure 1 – b). Second and third ratoons were the sugarcane age in more than 80% of the works reviewed (Figure 1 – c). The two most used varieties in the studies were IAC955000 (25%) and SP813250 (20%) (Figure 1 – d).

Data analysis

The assessment of the sugarcane response to N fertilization, as a function of soil and plant parameters, was carried out in stages (Figure 2). First, the main soil and plant information from all experiments evaluated were extracted. For each set of experimental plots, linear and quadratic models of N rates were adjusted as a function of yield. A significance of 5% ($\alpha = 0.05$) was adopted as a parameter. When none of the adjustments was significant, the experiment was classified as non-responsive to N. For significant adjustments, the optimal N rate (N_{opt}) and the required nitrogen ($N_{req.}$ – Equation 1) were calculated. For the quadratic model the N_{opt} corresponds to the inflection point of the curve. For the linear model, N_{opt} was adopted as 80% of the maximum dose of the experiment.

$$N_{req.} = N_{opt.} / \text{Yield} \qquad \textbf{(1)}$$

where: $N_{req.}$ – Nitrogen requirement [(kg N) t^{-1}], N_{opt} – Nitrogen optimal rate [(kg N) ha^{-1}]; Yield – Yield at N_{opt} [t ha^{-1}].

Table 1. Survey of N-response curve trials in sugarcane fields assessed.

Trial	N_{trial}	N_{plots}	Reference
1 - 8	8	37	Otto et al. (2013)
9 - 10	2	10	Prado and Pancelli (2008)
11 - 25	15	60	Rosseto et al. (2010)
26 - 46	21	94	Mariano (2015)
47 - 54	8	32	Fortes (2010)
55	1	4	Vieira et al. (2010)
56 - 59	4	24	Castro (2012)
60	1	4	Penatti et al. (2001)
61 - 72	12	36	Orlando Filho et al. (1999)
73 - 84	12	36	Moreira (2017)
85 - 114	30	150	Castro (2016)
115 - 120	6	30	Leite (2016)
121 - 129	9	63	Boschiero (2017)
130	1	6	Vitti et al. (2007)

N_{trial} – number of experiments; N_{plots} – number of plots.

The average of the N_{opt} and N_{req} parameters were then calculated according to established classes of yield potential (low: yield <70 t ha^{-1}; medium: yield 70-100 t ha^{-1} and high: yield >100 t ha^{-1}). To establish the classes of yield potential, the yield of the control experimental plots (N rate = zero) was adopted. To identify which are the main soil and plant parameters that directly impact the response to N, Random Forest (RF) multivariate analysis was applied (Breiman, 2001). Two approaches were used for this analysis. In the first approach, the N_{req} was used as the response variable according to Eq. 1, which is a numerical attribute. In the second approach, the response variable was the crop's responsiveness to N, thus being a binary attribute with values “YES” and “NO”. For both approaches, a set of 100 decision trees were used and all soil and plant attributes were evaluated. For training and testing, 70% and 30% of the total data were used, respectively. Finally, the importance graph of the attributes was evaluated to identify those that most directly impact the N requirement and the culture's responsiveness.

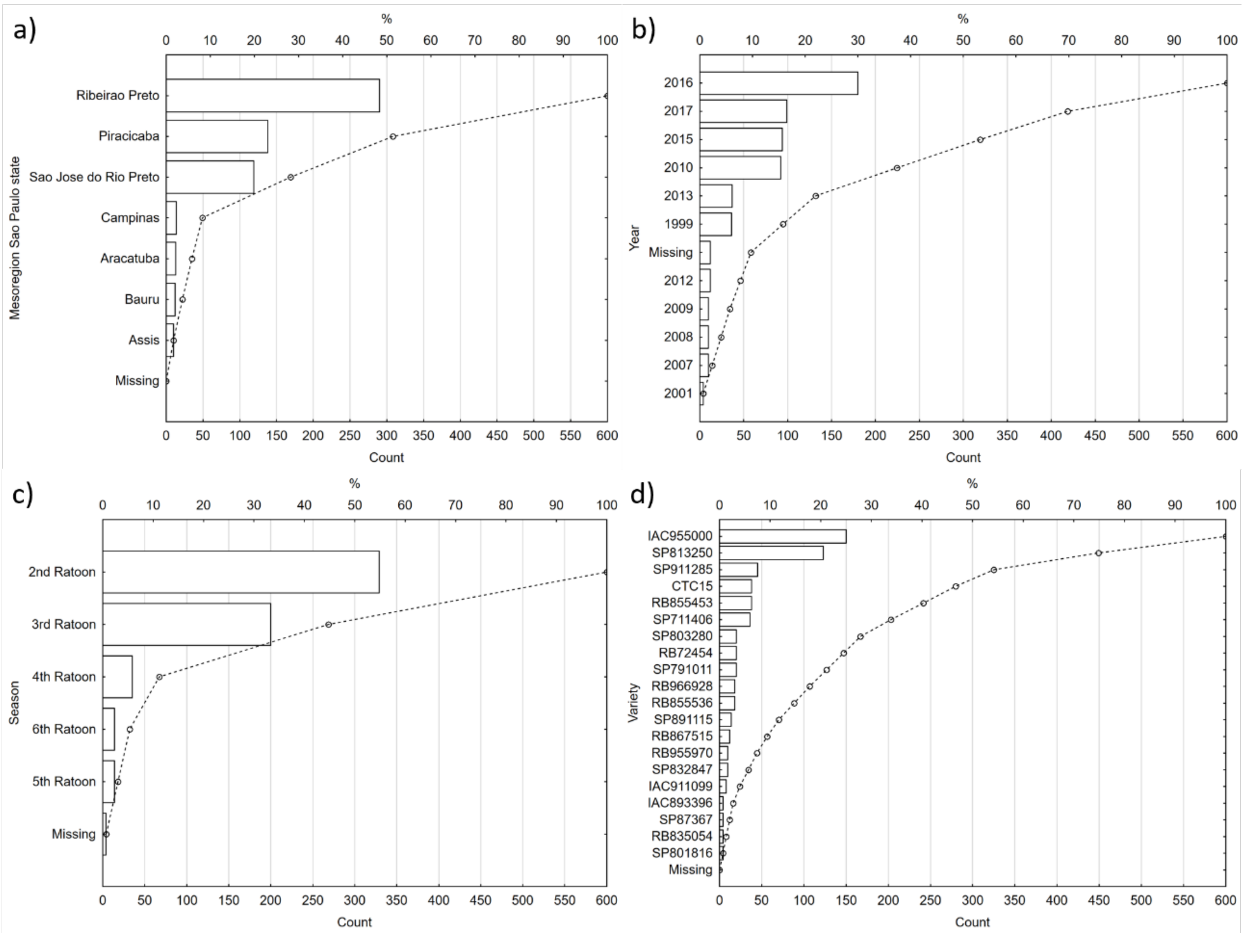

Fig 1. Characterization of dataset of N-response curve trials in sugarcane fields by mesoregion (a), year (b), ratoon (c) and variety (d).

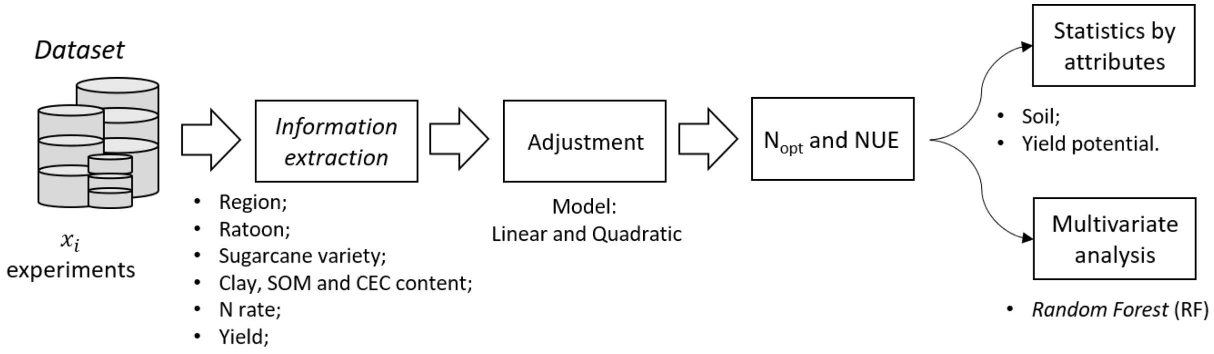

Fig 2. Steps on data analyses process.

Results & Discussion

From the total number of experiments assessed in the present review, 79 were responsive to N application, corresponding to ~60% of the total. Otto et al. (2016) in a comprehensive review found that 51% and 24% of the evaluated experiments were moderately and highly responsive to N, respectively. The overall average of N_{opt} and $N_{req.}$ of the 79 responsive experiments was 118.2 (kg N) ha^{-1} and 1.21 (kg N) t^{-1}, respectively. Some authors point out that, in order to meet the nutritional needs of sugarcane, it is recommended to apply between 120 and 200 kg ha^{-1} of N under Brazilian conditions (Cantarella and Rossetto, 2014), which is higher than the average of the experiments evaluated here. This fact shows that to meet the nutritional requirements of sugarcane, rates can be lower than those currently recommended. The intensive adoption of mechanization of the sugarcane harvest, which has been providing the maintenance of large amounts of straw in the field, may explain the lowest optimal dose found. According to Menandro et al. (2017), sugarcane straw is composed of 60% of dry leaves and 40% of green leaves, with green leaves corresponding to 70% of the concentration of N, P and K in the straw. According to the authors, 5.6 t ha^{-1} of green leaves have the potential to recycle 48, 15 and 80 kg ha^{-1} of N, P_2O_5 and K_2O. In this way, the amounts of N recycled by the straw can promote a lower need for mineral fertilizers, especially N, to meet the nutritional requirements of the plant. This low response to N was also attributed by Otto et al. (2016) for the preservation of straw on the surface, reuse of industrial waste (filter cake, ash and vinasse) and the planting of legumes in rotation.

As reported by Subbarao et al (2006), nitrogen use efficiency (NUE) depends on several characteristics, such as soil attributes, climatic conditions (temperature and rainfall) and agronomic practices (crop preparation and rotation). The results show that soils with lower yield potential, that is, yield below 70 t ha^{-1}, showed N_{opt} and N_{req} values (120.18 (kg N) ha^{-1} and 1.57 (kg N) t^{-1}, respectively) higher when compared to soils with greater yield potential (111.80 (kg N) ha^{-1} and 0.92 (kg N) t^{-1}, respectively). This fact shows that the attributes of soil texture, OM and CEC, determining factors for defining the yield potential of crops (Sanches et al., 2019b), can directly impact N_{opt} and $N_{req.}$ In this context, the results presented show that the N recommendation can be linked to the parameters that define the yield potential of the soil. Within precision agriculture technologies, soil apparent electrical conductivity (EC_a) has been shown to be a successful method of quickly, high-resolution and low-cost assessment of fertility variability (Sudduth et al., 2005) and of the yield potential of soils (Sanches et al., 2019; Corwin and Lesch, 2005). Some authors have also investigated the use of EC_a for N applications in crops (Wong and Asseng, 2006; Cockx et al., 2005). However, the literature still does not provide results on how this information can be used in sugarcane fields to optimize the application of N. Thus, the results presented here show great potential for the use of EC_a to delimit the yield potential of the soil to guide more efficient nitrogen fertilization.

Table 3. Nitrogen optimal rate (N_{opt}), N requeriment ($N_{req.}$) and yield gain according yield potential.

		N_{opt}	$N_{req.}$	Yield gain	
		(kg N) ha^{-1}	(kg N) t^{-1}	%	t ha^{-1}
Yield Potential	Low	120.18	1.57	30.59	17.33
	Medium	122.03	1.21	24.39	20.56
	High	111.80	0.92	11.24	12.15

The yield potential of the crop is directly linked to the $N_{req.}$ The 79 N-responsive experiments evaluated in the present study showed that the crop yield was inversely proportional to the $N_{req.}$ (Table 3). As one of the most used recommendations by sugarcane producers, Raij et al. (1997) mention that ratoon cane fertilization should vary from 60 to 120 (kg N) ha^{-1}, with the recommended dose being directly proportional to the expected yield. For yields greater than 100 t ha^{-1}, the authors recommend a N rate of 120 (kg N) ha^{-1}, that is, 1.2 kg N for each ton of cane produced. However, the results of the present research show that the recommendation for N application may be lower for crops with higher yield potential, reducing the recommendation proposed by Raij et al. (1997) of 1.20 (kg N) t^{-1}. In this way, crops with high yield potential can receive smaller amounts of N, contributing to a more environmentally sustainable application. The extinction of the burning of Brazilian sugarcane fields and the consequent shift to more intensive mechanization of harvesting (Franco et al., 2018) are factors that may explain the lower need for N in high-yield crops. The great availability of straw on the soil surface, as reported by Menandro et al. (2017), have been causing a change in the availability of N in soils, promoting lower needs for N supplementation via mineral fertilization; unlike the scenario of the 90's when the recommendations were proposed, and the fields still suffered the burning of straw to harvest the crop. Thus, it is necessary to review the N application recommendations in crops. On the other hand, the results found in the present research may also contribute to the reduction of GHG emissions. While sandy soils (with less yield potential) emit less N_2O, regardless of the N source used for fertilization, compared to clayey soils (Zhu et al., 2013), the results show that it is possible to apply less N in clay soils (greater productive potential), contributing to the reduction of GHGs.

The crop parameters assessed showed greater importance in the N requirement when compared to the soil parameters (Figure 3). Among the parameters evaluated, the variety of the crop had the greatest impact on $N_{req.}$ (Figure 3 – a) and the crop responsiveness (Figure 3 – b). Kolln (2016) evaluating 18 sugarcane genotypes concluded that the N requirement is directly impacted by the crop variety, concluding that the current N application recommendations are imprecise because they do not consider the NUE of the commercially available genotypes. The N rate was the second parameter that most impacted the N_{req}. Thorburn et al. (2017) investigating the parameters that guide the NUE in Australian sugarcane fields showed that the N rate was also one of the main factors in several simulations conducted, collaborating with the results presented here. The experiment region was the third most important parameter, both for $N_{req.}$ as for the crop responsiveness. The region's water availability, a parameter not evaluated in the present work, may be one of the reasons that explain the region's importance to N_{req}. Castro et al. (2019), evaluating the application of N at different times of the year (beginning, middle and end of harvest season) concluded that the lower water availability in the middle of the harvest season directly impacted $N_{req.}$, leading to a decrease in this. The authors also conclude that applications greater than 150 (kg N) ha^{-1} may not be economically viable. Among the three soil factors analyzed, clay content was more important when compared to OM and CEC content for $N_{req.}$. When talking about responsiveness, soil CEC becomes more important when compared to texture, base saturation (BS) and OM. Future works should investigate the impact of these soil attributes on $N_{req.}$, allowing greater assertiveness in the current N recommendations in sugarcane. Finally, the results of the present research show that N recommendations in sugarcane should not be based only on expected yield, but also on variety parameters and soil factors.

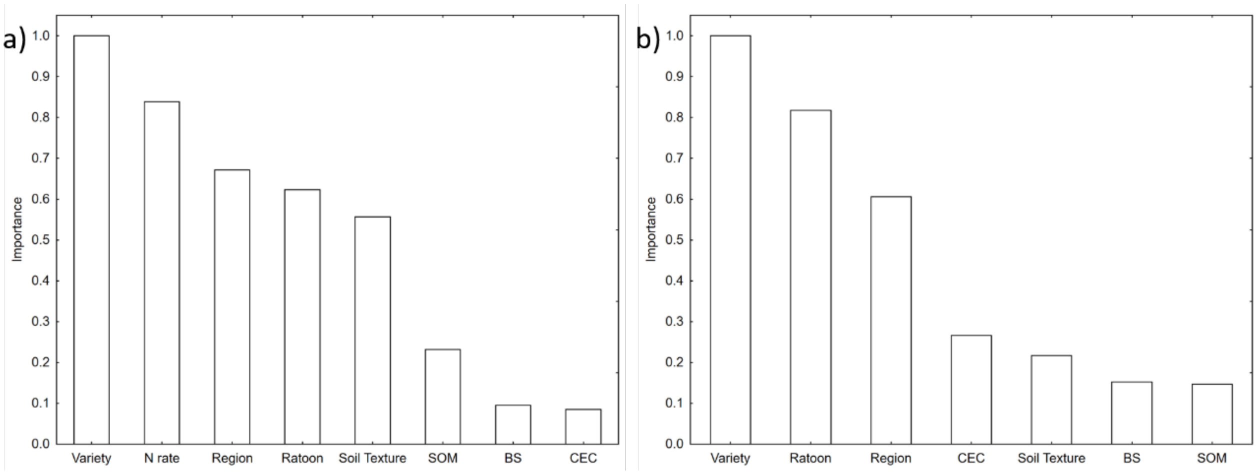

Fig 3. Importance plot from random forest (RF) algorithm applied to nitrogen requirement (a) and nitrogen responsiveness (b) from survey of N-response curve trials.

Conclusion

Current recommendations for N application only take into account the yield potential of crops, neglecting plant and soil factors that allow maximizing NUE. The recommendations propose even higher rates of application in crops with greater yield potential, in opposition to the results of the present research. Future recommendation models should include variety parameters and soil attributes to rationalize N fertilization. The findings show that it is possible to rationalize the application of N for production sustainability. An extensive review showed that fields with high yield potential allow smaller applications of N to express their maximum potential yield.

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