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N-Fertilization Adjustment in Sugarcane Crop Cultivated in Intensive Mechanization

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Abstract

Currently sugarcane is cultivated in Brazil in intensive mechanization during all cultural practices, since planting, harvesting until fertilizer applications. In this sense, to increase the sugarcane yield which it was stagnant along the last 5 years, it is necessary looking for alternatives to management the crop and maximize the yield gain. One alternative is through the adjustment the N-fertilization in green cane crop according to the IPNI guidelines—“4R Nutrient Stewardship System” (International Plant Nutrition Institute—IPNI) program which seeks to apply fertilizer in the right location, at the right time, in the right amount and the right source. Therefore, the main goal of this chapter is shows these alternatives and the yield gains that it was obtained in researches during 2013–2017.

Keywords: nitrogen, *Saccharum* spp., green cane, fertilizer

1. Introduction

According to statistical surveys conducted in the last decade by the International Plant Nutrition Institute [1], the largest consumer market for NPK fertilizers was Asia (57%), followed by the Americas (25%), Europe (13%), Africa (3%), and Oceania (2%). In 2015, approximately 183.2 million tons of NPK fertilizers were consumed, being the most consumed nitrogen fertilizers with 60% of total (110.4 million tons), followed by phosphorus (22% (40.7 million tons)) and potassium (18% (32.1 million tons)). In the Americas, the largest consumers were the United States and Brazil, with Brazil showing a significant increase in fertilizer consumption during the last decade, representing a consumption of approximately 14 million tons of NPK fertilizers in 2015. This value was 50% higher than obtained in the previous decade [1]. This large demand resulted in a financial movement of approximately R\$ 19.5 billion per year, originating from the internal sale of NPK fertilizers [2].

In Brazil, the main crops (soybean, maize, and sugarcane) use approximately 6.2 million tons of NPK fertilizers during 2015. The sugarcane crop represents 22.6% of this amount, with consumption of 1.4 million tons of NPK fertilizers, which generated investment higher than R\$ 2 billion per year. Within this billion-dollar market of fertilizers for sugarcane, potassic fertilizers were the most used (609 thousand tons), followed by nitrogen fertilizers (573 thousand tons) and phosphates fertilizers with 195 thousand tons used [2].

Most of the NPK fertilizer market in the Brazilian sugarcane sector is based on four sources, such as potassium chloride (source of K), urea and ammonium nitrate (N sources), and simple superphosphate (P source). Although the industry is a large and efficient waste recycler, such as filter cake that is rich in phosphorus and potassium-rich vinasse, the high demand for the importation of these raw materials shows the risk in our food and energy security.

Brazil is the world's largest producer of sugarcane with approximately 640 million tons [3], grown in an area of 9 million hectares, followed by India and China, respectively, with 352 and 126 million tons [4]. Despite this, the increase in the sugarcane area, which was 5.8 million hectares during the last 10 years, not took place increase in stalk productivity, which remains stagnant (72 Mg ha^{-1} —crop season 2016/2017) compared to the Brazilian historical series, which has already reached an average of 80 Mg ha^{-1} [3].

The IPNI has established a Best Practices Fertilizer Management (BPFM) program. This program shows the practical actions necessary to provide a better economic, social, and environmental performance of crops, in order to adapt the supply of nutrients to the needs of the crop minimizing the losses of its nutrients in the soil-plant-atmosphere continuum [5]. In the focus of plant nutrition and fertilizer use, BPFM encompasses the 4R principle: (1) applying the right nutrient source, (2) taking the right amount, (3) at the right place, and (4) in the correct time (right time). In this context, the present text aims to address aspects related to the nutrition of the sugarcane crop, focusing on nitrogen fertilization, showing the challenges and bottlenecks for increasing the efficiency of use of these nutrients by sugarcane.

2. Nitrogen fertilization: definition of the correct source, applied time, application mode, and right dose

The N is the nutrient that has the highest interaction in the environment due to the numerous reactions, mediated by microorganisms, that occur in the soil, being affected by temperature and humidity [6]. In addition, there are several routes of N losses (leaching, volatilization, and immobilization), promoting only about 26% of the N applied by fertilizer that is used by the plant [7]. For other crops this value usually is higher than 50% [8]. The large N stock in the soil, representing more than 95% of the total N, comes from organic matter. However, organic N is not directly utilized by plants, requiring their mineralization to produce ammonium, which can be absorbed or transformed into nitrate (nitrification process) that will be absorbed by plants [6].

In general, it is recommended to apply $30\text{--}60 \text{ kg ha}^{-1}$ of N in plant cane, applied in the planting furrow. In ratoon the dose can vary from 80 kg ha^{-1} N, for yields between 60 and 80 tons of stalks per hectare (TSH), up to 140 kg ha^{-1} N, in areas where it is expected to produce above 140 TSH [9]. There is no doubt about the importance of nitrogen fertilization for productivity gains in sugarcane cultivation, especially in ratoon areas. In a very good literature review made by Otto et al. [7], the authors found that in 75% of the total number of papers reviewed, there was an increase in TSH due to nitrogen fertilization. In 30% of papers, the gain in stalk yield was higher than 25% in relation to the control.

The most common nitrogen fertilizers used in Brazilian sugarcane fields are ammonium nitrate (33% N), urea (45% N), and ammonium sulfate (21% N). It is interesting to note that each option has positive and negative aspects, such as (i) ammonium nitrate has N in two forms: nitrate (NO_3^-) and ammonium (NH_4^+), in which ammonium has been reported to be a mineral preferential form uptake by

sugarcane [10]. In addition, there is not losses due the volatilization of ammonia by this N source (ammonium nitrate) in tropical soils. However, it can lead to nitrate leaching losses [11]. Also since it is a raw material for explosive devices, it must be restricted in its commercialization in the coming years around the world; (ii) urea is the fertilizer with the highest N content in its composition, making it possible to reduce the relative cost of its acquisition (R\$ per kg of N). Nevertheless, with the advent of mechanized harvesting of sugarcane, which generated straw covers in sugarcane fields and currently 85% of all sugarcane cultivated area in Brazil is harvested this mode [12], the application of urea over the straw implies in higher losses of NH_3 by volatilization; (iii) ammonium sulfate, although it is the option with lower concentration of N, presents in its composition approximately 24% of sulfur (S). This fact makes this fertilizer an excellent option, especially in areas where there is no application of vinasse, as it is able to supply nitrogen and sulfur at the same time to the plant. However, it has a high salinity index. When it is applied locally, in high amounts and in periods of low soil moisture, it can cause problems in the plant growth.

One of the major limitations to increase the productivity of sugarcane in Brazil is the availability of adequate amounts of nutrients in soils, especially N [13]. This is due to the many factors that affect nitrogen utilization efficiency (EUN), such as soil characteristics (pH, cation exchange capacity (CEC), organic matter, texture, clay, aeration, and compaction), climatic conditions (temperature and rainfall), and agronomic practices (cultivation, soil preparation, and crop rotation) [14]. Due to the difficulty to define the dose of N to be applied in sugarcane due to the lack of a laboratory methodology that allows quantification of N available for plants into the soil, the dose of N is often defined according to the expected productivity [15]. This fact causes sub or super estimates of the N doses to be applied to the crop. In this scenario, new works [7, 16] seek the development of strategies for the management of nitrogen fertilization in sugarcane plantations, aiming to increase nitrogen fertilization efficiency.

In addition, the presence of straw over the soil surface and the harvesting season (wet or dry season) should be considered for the proper management of sugarcane. This can be justified by analyzing the average productivity obtained over four harvests—2015, 2016, 2017, and 2018 (**Figure 1**), where the same variety of sugarcane (IACSP95-5000) was harvested at different crop season (beginning, middle, and end of the harvest corresponding to the months of April, August, and October, respectively). Comparing the fertilizations (same dose) made in wet season and dry season, the results show that the fertilizations carried out in the humid season always promoted the highest yields (**Figure 1**). In general, the area harvested at the beginning of the harvest had the highest average yield of stalks (107 TSH), followed by the middle area (95 TSH) and the final harvest (77 TSH). Therefore, the best time to apply the N in the sugarcane ratoon should be when there is moisture in the soil, regardless of the period in which the harvest was performed. This contrasts with the traditional management of sugarcane, in which fertilization was done when the plant had a significant canopy (number of green leaves) and tillering [15].

Other possibilities for increasing the efficiency of nitrogen fertilization in sugarcane, together with increases in yield of stalks, are related to the application forms. Regarding the forms of nitrogen fertilizer application, this can be done in several ways (**Figure 2**): (1) application incorporated to the soil by cultivation in the interrow (“triple operation”), (2) superficial application in band, (3) application under the straw in band, (4) application made in both sides of the ratoon, (5) surface application in total area, and (6) surface application with liquid fertilizer (a) and foliar application (b).

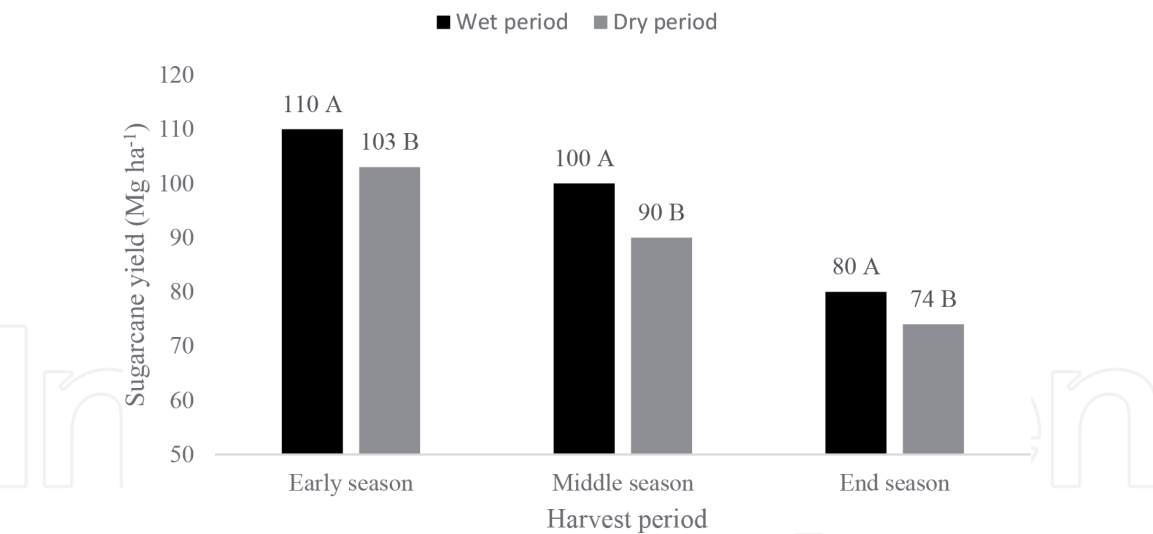


Figure 1. Effect of the nitrogen fertilizer application time according to the sugarcane harvest season. Source: Castro [17]. Note: Capital letters differ from each other within each harvest season.



Figure 2. Alternatives of N-fertilizer application methods in sugarcane ratoon. Source: Castro et al. [18].

The N-fertilizer applications made through the interrow are the most traditional in Brazil sugarcane fields. This is because the cultivation had been widely used in the burned cane—in the past. Regardless, in the currently years, with the adoption of the green cane cultivation (without fire in the harvest), the surface application has greater operational in sugarcane fields, where the straw layer resulting from the harvest can disrupt the scarification of the interweaving when opted for cultivation. Castro et al. [19] showed that no effect was obtained on crop productivity by the adoption of interlaced cultivation (**Table 1**).

The absence of alterations in TSH in sugarcane yield shows that the cultivation operation may not be necessary, mainly because sugarcane does not exploit the interleaving region [20, 21], even in areas where the traffic of machines in this region did not occur [22]. The application performed by the triple operation (number 1 in **Figure 2**), despite being incorporated in the soil, presents lower yields of TSH (**Figure 3**) due precisely to the distance at which the fertilizer is positioned in relation to the stump of the plant, and the area covered the root system, which in the middle of the interline is very small [20].

On the other hand, some studies show increases in TSH when incorporating the nitrogen fertilizer at 0.1 m depth [23], on both sides of the sugarcane ratoon: on average 0.2–0.3 m of the cane row (**Figure 2** (no. 4)). The deposition of N-fertilizer near the root

Treatments	2008	2009	2010	2011	Mean
With tillage	125 ^{bs} *	112 ^a	85 ^a	81 ^a	101 ^a
Without tillage	131 ^a	112 ^a	88 ^a	81 ^a	103 ^a

* Means with the same letter in column did not differ according to the “Tukey” test ($p>0.05$)

Table 1.
Sugarcane yield (TSH) associated to the performance or not of the mechanical cultivation of the interrow of crop (adapted Castro et al. [18]).

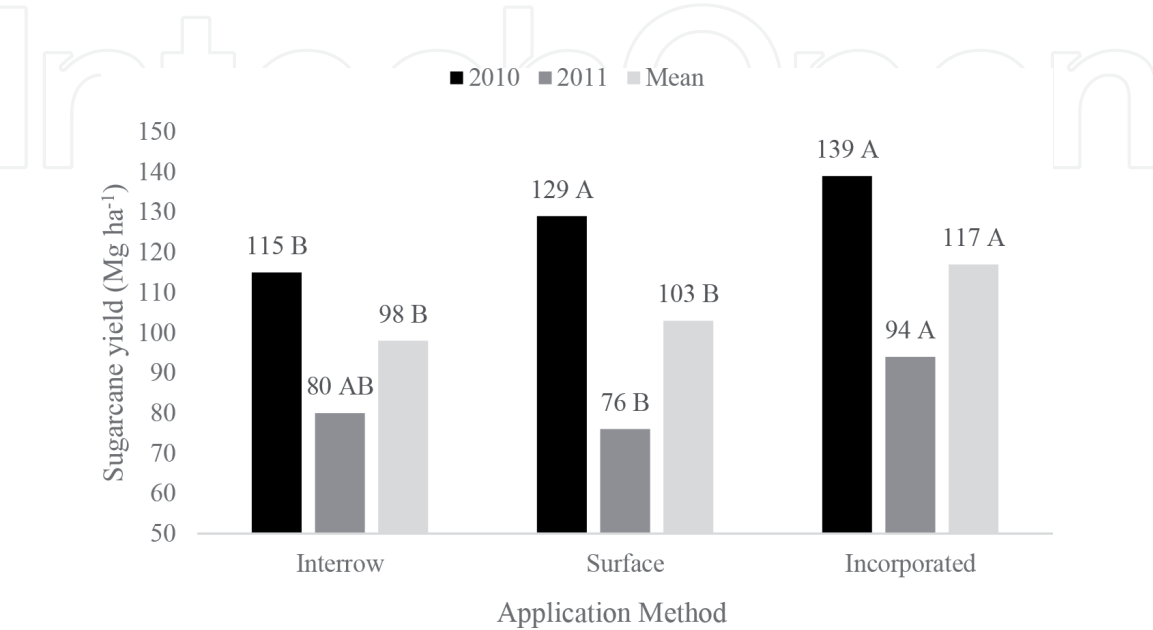


Figure 3.
Effect of the N-fertilizer application method in sugarcane yield. Source: Castro et al. [23]. Note: Capital letters differ from each other within each treatment evaluated in each year.

system of the plant can facilitate its absorption, improving the TSH of the crop. This aspect also explains the difference between the incorporated application and the surface application; because when applied on the soil surface, the fertilizer needs to transpose the layer of straw which often occurs with the rains, and because it is not constant, a temporal difference in N uptake and plant development when compared to the incorporated application. In general, the incorporation of N-fertilizer presented an increase in sugarcane yield of 14% (28 TSH) and 19% (38 TSH) when compared, respectively, to the superficial application and the interrow, which did not differ between them.

Due to the large extension of sugarcane cultivated areas and the short interval of time for fertilization (adequate soil moisture conditions), alternatives that allow higher operational yield (hectares h⁻¹) are necessary. In this sense, one of the options is the application of the nitrogen fertilizer by means of machines such as the Uniport of the Jacto manufacturer, which deposits the fertilizer below the layer of straw (**Figure 3** (n°3)), due to the fertilizer granules were applied with a pressure which these granules are able to transpose the straw layer. In a research conducted by Brazilian Bioethanol Science and Technology Laboratory (CTBE) [24], three forms of application of nitrogen fertilizer in sugarcane ratoon were compared, being application under straw and in strip and surface application in strip and application incorporated to the soil. The results showed that the yield of the crop was higher when the fertilizer was applied in an incorporated form or under the straw compared to the surface application (**Figure 4**). Considering the average productivity obtained in the two agricultural years (**Figure 4**), the application incorporated to the soil and under the straw provided increases in the TSH of 16% (26 TSH) and 13% (21 TSH), respectively, when compared to surface application.

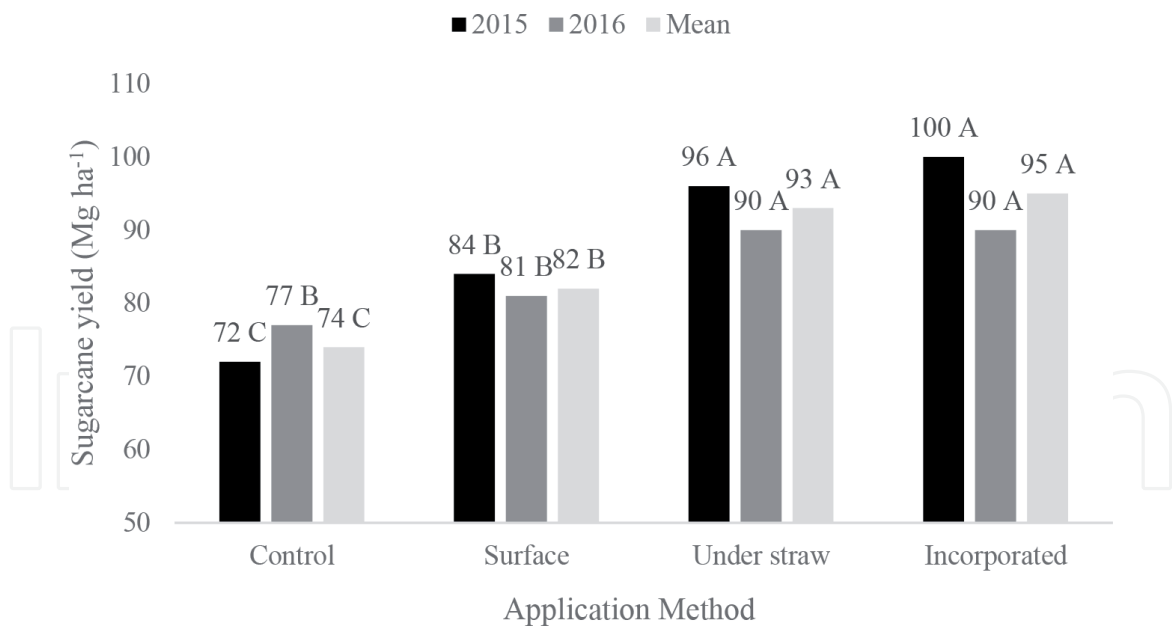


Figure 4. Effect of N-fertilizer application forms in sugarcane yield. Source: Franco et al. [24]. Note: Letters compare the forms of application in each of the years.

Therefore, in nitrogen fertilization, one must consider the choice of a source that allows lower losses or minimized if such losses exist, for example, by adjusting the mode of application. It is also convenient to adapt the time of application of N-fertilizer, in which, if there are operational conditions, nitrogen fertilizer should be applied when there is moisture in the soil, recommending the application incorporated in both sides of the cane row or application under the straw. Considering the management of the time and method of application of the nitrogen fertilizer in sugarcane, associated to the fact that in the south central region of Brazil, crop harvest occurs from March to December, thus an extended period for the accomplishment of cultural

Sugarcane Price (U\$ Mg ⁻¹)	N fertilizer price (U\$ Mg ⁻¹)					
	200	225	250	275	300	325
N economical rate (base line 120 kg N ha ⁻¹)						
	Early	Middle	End	Early	Middle	End
10						
13	-25%	-13%	-25%	-30%	-25%	-30%
15						
18						
20	+10%	0%	+15%	-15%	-5%	-15%
23						

Ps: Price of sugarcane according to Consecana Brasil; Nitrogen fertilizer price according to Anda [2].

Table 2. N-economic rate to be applied in the sugarcane crop according to the harvesting season associated with the price of the raw material and the N-fertilizer.

treatments; it is possible to adjust the N dose to be applied (variation of 30%) without loss of productivity (**Table 2**). In this sense, the investment made in the acquisition of the nitrogen fertilizer must be removed by increasing productivity, then that high doses can obtain a gain which is not enough to pay off the investment [17].

3. Conclusion

The adoption of the best technologies (IPNI—Best Practices Fertilizer Management (BPFM)) to apply the N-fertilizer in sugarcane crop cultivated in intensive mechanization is possible to have an increase in the yield and a reduction in the application cost. It is possible with the choice of the right N rate, associated with the right application method and right time to perform this operation. In this context, the average yield gain is near 30%, as well as the production cost reduced near 15%.

Considering the sugarcane (green cane) cultivated in central south region of Brazil, where the harvest season occur between March and November, the best time to apply the N-fertilizer is in wet period. The best application method is incorporated at 0.1 m depth in both sides of the sugarcane row. With this adoption is possible have a reduction in the N rate applied in the sugarcane ratoon, as well as, there is an environmental sustainability in the nitrogen fertilization in sugarcane crop, due there is not adopt the high N rate in the fields.

The absence of alterations in TCH in sugarcane yield shows that the cultivation operation may not be necessary, mainly because sugarcane does not exploit the interleaving region [20, 21], even in areas where the traffic of machines in this region did not occur [22]. The application performed by the triple operation (number 1 in **Figure 2**), despite being incorporated in the soil, presents lower yields of TCH (**Figure 3**) due precisely to the distance at which the fertilizer is positioned in relation to the stump of the plant and the area covered by the root system, which in the middle of the interline is very small [20].

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