Agrociencia Uruguay 2025 | Volume 29 | Article e1468
DOI: 10.31285/AGRO.29.1468
ISSN 2730-5066

Sugarcane production and nutrient accumulation in commercial plantations under vinasse irrigation

del Pino, A. [1]; Hernández, J. [1]; Casanova, O. [1]; Takata, V. [1]; Panissa, G. [2]

[1]*Universidad de la República, Facultad de Agronomía, Departamento de Suelos y Aguas, Montevideo, Uruguay*
[2]*ALUR, Artigas, Uruguay*

Editor

Marco Dalla-Rizza
Instituto Nacional de Investigación Agropecuaria (INIA), Canelones, Uruguay

Received *04 Apr 2024*
Accepted *17 Dec 2024*
Published *3 Apr 2025*

Correspondence

Amabelia del Pino
amabelia@fagro.edu.uy

Abstract

Vinasse is a liquid byproduct of ethanol production used as fertilizer for sugarcane (*Saccharum officinarum* L). Although the nutrient concentration of vinasse is relatively low, it is considered a valuable source of nutrients. Currently, in Uruguay undiluted vinasse is applied in fields close to the ethanol industrial facilities (ALUR, Bella Union), but its effect on soil and crops has been scarcely studied. This work, carried out between 2014 and 2017, evaluated the production and absorption of nutrients in 21 commercial plantations receiving vinasse (doses between 26.5 and 150 m^3 ha^{-1}) to assess its contribution to the crop nutrition and sustainability of the production system. In each plantation the production of biomass and content of nutrients were analyzed (N, P, K, Ca, Mg, Na, Cu, Fe, Mn, and Zn). The yield varied from 34.4 to 125.3 Mg ha^{-1}, (average 64.7 Mg ha^{-1}), while average aerial biomass production was 33.1 Mg ha^{-1} of dry matter. The highest accumulation of nutrients for the crop corresponded to K (average 216, 154 and 157 kg ha^{-1} in 2015, 2016 and 2017, respectively), which highlights the importance of vinasse as a K source. However, in some fields a low efficiency of K utilization was estimated. It is concluded that the application of vinasse makes an important contribution of nutrients (N, P and K) to the crop, which allows achieving high yields, as well as saving commercial fertilizers.

Keywords: ethanol production, nutrient use efficiency, luxury consumption of K, Uruguay

Producción de caña de azúcar y acumulación de nutrientes en plantaciones comerciales bajo irrigación con vinaza

Resumen

La vinaza es un subproducto líquido de la producción de etanol utilizado como fertilizante para la caña de azúcar (*Saccharum officinarum* L). Aunque su concentración de nutrientes es relativamente baja, se considera una valiosa fuente de nutrientes. Actualmente, en Uruguay se aplica vinaza sin diluir en campos cercanos a las instalaciones industriales de etanol (ALUR, Bella Unión), pero su efecto sobre el suelo y los cultivos ha sido poco estudiado. Este trabajo, realizado entre 2014 y 2017, evaluó la producción y la absorción de nutrientes en 21 plantaciones comerciales que recibieron vinaza (dosis entre 26,5 y 150 m^3 ha^{-1}) para evaluar su aporte a la nutrición del cultivo y la sostenibilidad del sistema productivo. En cada plantación se analizaron la producción de biomasa y el contenido de nutrientes (N, P, K, Ca, Mg, Na, Cu, Fe, Mn y Zn). El rendimiento varió de 34,4 a 125,3 Mg ha^{-1}, (promedio 64,7 Mg ha^{-1}), mientras que la producción promedio de biomasa aérea fue 33,1 Mg ha^{-1} de materia seca. La mayor acumulación de nutrientes para el cultivo correspondió a K (promedio de 216, 154 y 157 kg ha^{-1} en 2015, 2016 y 2017, respectivamente), lo que resalta la importancia de la vinaza como fuente de K. Sin embargo, en algunos campos se estimó una baja eficiencia de utilización de K. Se concluye que la aplicación de vinaza realiza un importante aporte de nutrientes (N, P y K) al cultivo, lo que permite alcanzar rendimientos altos, así como ahorrar fertilizantes comerciales.

Palabras clave: producción de etanol, eficiencia de uso de nutrientes, consumo de lujo de K, Uruguay

Produção de cana-de-açúcar e acúmulo de nutrientes em plantios comerciais sob irrigação de vinhaça

Resumo

A vinhaça é um subproduto líquido da produção de etanol, utilizado como fertilizante para a cana-de-açúcar (*Saccharum officinarum* L). Embora a concentração de nutrientes da vinhaça seja relativamente baixa, ela é considerada uma valiosa fonte de nutrientes. Atualmente no Uruguai a vinhaça pura é aplicada em lavouras próximas às instalações industriais de etanol (ALUR, Bella Union), mas seu efeito no solo e nas lavouras tem sido pouco estudado. Este trabalho, realizado entre 2014 e 2017, avaliou a produção e absorção de nutrientes em 21 lavouras comerciais recebendo vinhaça (doses entre 26,5 e 150 m^3 ha^{-1}) a fim de avaliar sua contribuição para a nutrição da cultura e sustentabilidade do sistema de produção. Em cada plantação foi analisada a produção de biomassa e o teor de nutrientes (N, P, K, Ca, Mg, Na, Cu, Fe, Mn e Zn). A produtividade variou de 34,4 a 125,3 Mg ha^{-1}, (média de 64,7 Mg ha^{-1}), enquanto a produção média de biomassa aérea foi de 33,1 Mg ha^{-1} de matéria seca. O maior acúmulo de nutrientes para a cultura correspondeu ao K (média de 216, 154 e 157 kg ha^{-1} em 2015, 2016 e 2017, respectivamente), o que evidencia a importância da vinhaça como fonte de K. No entanto, em alguns campos foi estimada uma baixa eficiência de utilização de K. Conclui-se que a aplicação de vinhaça traz importante aporte de nutrientes (N, P e K) para a cultura, o que permite alcançar altas produtividades, além de economizar fertilizantes comerciais.

Palavras-chave: produção de etanol, eficiência de utilização de nutrientes, consumo de luxo de K, Uruguay

1. Introduction

Sugarcane (*Saccharum officinarum*) crop is mainly distributed in tropical climate zones, where it expresses its great growth potential, even under conditions of water deficiency or nutritional limitations. In most of Uruguay the climatic conditions are unfavorable for this crop, therefore, its production is restricted to the northwest zone, the warmest in the country. Sugarcane is planted both in autumn and spring, in fields systemized to allow furrow irrigation during summer. This crop is considered semi perennial, allowing several harvests of the same plantation. In Uruguay the crop stalk harvest is performed manually once a year, in the period from May to October, after burning the senescent leaves to facilitate cutting. The stem of sugarcane is utilized for sugar and ethanol production. The yield of plantations in ALUR, which is the company producing ethanol from sugarcane in Uruguay, is 55 Mg ha^{-1} in average.

The vigorous growth is accompanied by high nutrient absorption, mainly of N and K, but the crop also uptakes important amounts of P, Ca, Mg, S and micronutrients[(1)(2)]. The growth and absorption dynamics of nutrients along the year have been described by a sigmoidal curve[(3)]. In their work, conducted in Florida (USA), these authors found that after planting, or after cut, comes a period of slow growth and absorption of nutrients (approximately 150 days). This is followed by a period of rapid growth and absorption, which they called GGP (grand growth period), until a plateau is reached approximately at 300 days. While the time lapse for growth or absorption varies in the different production zones, this model is generally accepted to describe growth and nutrient uptake by sugarcane. The nutrient accumulation curve also follows a sigmoidal trend, but precedes that of biomass[(1)(4)].

In plantations of Bella Union the fertilization N - K is applied during the fast growth stage, while the phosphate fertilizer is applied generally prior to planting. The dosage of fertilizer is set taking into consideration the results of soil analysis and the expectation of nutrients´ removal by the crop.

At industrial level, the production of ethanol from sugarcane generates many byproducts and waste, which must be managed suitably to avoid negative impacts to the environment[(5)]. However, if they are properly handled, they represent an opportunity to transform an environmental liability into a source of nutrients for the crop itself[(6)]. Vinasse is one of the byproducts of the fermentation and distillation of juice from sugar cane, generating up to 20 L of stillage per liter of ethanol produced, according to Wilkie and others[(7)]. Currently, in ALUR industry in Uruguay about 7 L of vinasse are generated per liter of ethanol. Because it is a liquid residue, vinasse is difficult to handle, and is generally stored in large pools.

Given its potential contribution of nutrients, vinasse can be used for the nutrition of the sugarcane crop, which allows a substantial saving of fertilizers. This residue also contains an organic fraction, which promotes microbial activity when applied to the soil[(8)(9)]. Although it is accepted that vinasse has become a component of the production system of ethanol from sugar cane as biofertilizer[(10)(11)], the application method and timing generally vary from one region to another. In Uruguay, vinasse is applied prior to sowing, and on recently cut crops. This operation is intended to prevent the storage for prolonged periods of large volumes of the effluent. Additionally, the application of vinasse after cutting has the purpose of ensuring the availability of nutrients, especially K, for the regrowth. Because vinasse is supplied early in the season, when irrigation is not required, it is applied directly by aspersion without any dilution.

The management of vinasse as biofertilizer has scarce documented history in Uruguay. Consequently, information regarding its effect on the soil and the crop productivity is limited. An incubation experiment under controlled conditions[(12)] observed that the application of vinasse to the soil in doses of up to 300 m^3 ha^{-1} can make an important contribution of nutrients (N, P, K, Ca, M g, Cu, Fe, Mn, Zn). In coincidence with international bibliography, it was found that the highest nutrient concentration corresponds to K, which is immediately available[(13)(14)], while N and P are probably insufficient for the crop requirements. Other macro and micronutrients that are added to the soil with vinasse, but are not normally included in fertilizer recommendations, may contribute to the sustainability of the production system.

Because vinasse application to sugarcane crops is recent in Uruguay, the cumulative effects of this practice have not been investigated. However, long-term studies in other countries have shown positive effects of the application of vinasse on various properties of the soil, as well as on crop productivity[(15)(16)]. Currently, for soil and cultivation conditions in Uruguay, there is not a reliable set of data to confirm whether the use of vinasse is feasible from the productive and environmental point of view. To assess this question a monitoring program of farms that apply vinasse to sugarcane crops is being conducted. In the framework of this monitoring we evaluated, during the first three years, sugarcane production and extraction of N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn in 21 commercial farms receiving vinasse application. To characterize the nutrient use efficiency of the crop, and the proportion of extracted nutrients off site, will contribute to evaluate the long-term sustainability of the production of sugarcane with vinasse irrigation.

2. Materials and methods

2.1 Study sites

For the purposes of monitoring, 24 sites were selected in 2014, with soils representative of the area planted with sugarcane, in their morphological, chemical, and physical characteristics. The sites were chosen in plantations of commercial production in which vinasse is applied. For the present work we utilized information from the 21 sites that received vinasse during the period 2014-2016 (harvested from 2015 to 2017).

The sites are in a relatively small area, close to the industrial plant (in the range of longitude 57° 31' 13.0" to 57° 38' 47.2" W and latitude 30° 17' 34.8" to 30° 26' 42.4" S). The climate of this zone is characterized by a mean temperature of the coldest month (June) of 13 °C, while in the warmest month (January) the mean temperature is 25 °C, and the average annual rainfall is 1268 mm distributed over the year, although highly irregular.

The initial characterization of the soil in each site was taken as a baseline for monitoring. All the selected soils belong to Mollisols and Vertisols. **Table 1** presents an overview of the physicochemical characteristics of the A horizon of the soils at the beginning of the study.

Table 1. Characteristics of A Horizon of the soils at the beginning of the study. Mean, standard deviation, variation coefficient, minimum and maximum values (n = 21)

Properties	Mean	Std	VC (%)	Min	Max
pH (H_2O)	5.6	0.4	8	4.5	6.4
CE (dS m^{-1})	0.190	0.090	47	0.056	0.359
OC (g kg^{-1})	17	6	33	6	27
P Bray 1 (g kg^{-1})	30	25	83	8	152
Ca ($cmol_c$ kg^{-1})	13	5	41	3	22
Mg ($cmol_c$ kg^{-1})	3.4	1.8	53	0.7	7.5
K ($cmol_c$ kg^{-1})	0.39	0.21	54	0.09	1.03
Na ($cmol_c$ kg^{-1})	0.31	0.16	32	0.16	0.84
CEC ($cmol_c$ kg^{-1})	22	8	36	8	41
BS (%)	72	7	10	46	79
Sand (g kg^{-1})	427	152	36	240	810
Silt (g kg^{-1})	250	82	3 3	40	410
Clay (g kg^{-1})	323	102	3 2	150	510

CE: Electrical conductivity, CEC: cation exchange capacity, BS: base saturation.

2.2 Vinasse irrigation

In the industrial plant, right after the vinasse is generated, it is stored in a large lagoon, from which it is pumped for irrigation. Periodically during the storage, samples are analyzed. According to the information provided by the company, the composition showed variations between years and sampling dates within the year. In the period between 2014 and 2017, on average the pH of vinasse was 4.7 ± 0.1, while the content of N was 479 ± 52 mg L^{-1}, the content of P was 57 ± 19 mg L^{-1} and that of K was 2269 ± 32 mg L^{-1}.

Table 2 presents the number of vinasse applications and the total volume applied in the three studied periods. The acronym identifying sites refers to the location in the study area, but it is desirable to maintain this identification, as it is currently utilized for monitoring of soil properties in the long term.

The survey was made in commercial plantations, hence different strategies of vinasse application were utilized. In consequence, the fields received one, two or three vinasse applications. In all sites vinasse was applied without dilution shortly after harvest, by spreading from a tank.

To estimate the annual dose of nutrients provided by the stillage, its average composition in each growing season was used. Although the composition of vinasse is variable in time, as it is generally for residues and byproducts, we consider that this estimation permits, in general terms, to characterize nutrient application in the different fields. The percentage of N, P and K applied with the stillage respect to the total (sum of the application with vinasse and fertilizers) was in average 15, 63 and 69%, respectively.

Table 2. Number of applications of vinasse, total volume and estimation of the amount of N-P-K applied with vinasse in the study plantations. Crop periods: 2014/15, 2015/16 and 2016/17

Site	Vinasse application		Estimated annual dose applied with vinasse		
	Nº	Total amount	N	P_2O5	K_2O
		(m^3 ha^{-1})		(kg ha^{-1})	
V1	3	212	34	11	200
V2	3	212	34	11	200
V3	3	212	34	11	200
V5	3	212	34	11	200
V10	2	182	30	9	173
V11	3	212	34	11	200
V12	2	182	30	9	173
V14	2	200	33	10	189
V15	1	27	5	2	25
V16	3	327	50	17	305
V17	2	177	26	9	164
V18	2	200	33	10	189
BV1	1	150	21	8	138
BV2	2	251	39	12	235
BV3	1	142	25	6	136
BV5	2	246	38	12	230
BV6	1	96	17	4	92
C2	2	100	17	5	95
C3	2	100	17	5	95
RS2	1	100	17	4	96
S3	2	60	13	5	83
Mean	2	171	28	9	163

2.3 Sampling and plant analysis

The production of sugarcane was evaluated in three growing seasons (2014/15, 2015/16 and 2016/17) in fields receiving vinasse at least once. In 2017 three of the sites (V10, V11 and V12) were not harvested, because excessive rainfall in the area caused flooding of the fields under monitoring.

To quantify the yield and biomass of the crop, prior to the commercial harvest 1 m section was manually harvested from 4 rows, collecting all aboveground biomass. The biomass was weighed in the field, and three plants (stalks with leaves) were taken per 1 m section, in which stalks were separated from the straw (including leaves and sprouts), weighing them separately. Both fractions were cut into small pieces (15 cm). From each fraction (stalk and straw) a subsample was taken, dried in a forced-air-circulating oven at 60 ºC, and ground (< 0.5 mm) for chemical analysis.

In the stalk and straw samples, the total content of N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn was determined, calculating the amount extracted in each fraction as the average of the 4 samples per site. The total content of N was determined by a modification of the Kjeldahl method[(17)]. To analyze total P the sample was calcinated at 550 ºC, dissolving the ashes with hydrochloric acid (HCl) and determining P content in the extract colorimetrically[(18)]. In the same extract the content of Ca, Mg, Cu, Fe, Mn, and Zn was measured by atomic absorption spectrometry, while K and Na were determined by emission spectrometry[(19)].

2.4 Calculations and statistical analysis

Sugarcane yield, in fresh basis (Mg ha^{-1}), was calculated from the proportion of stalk (average of three plants) of each of the 4 subsamples, and their total fresh weight. The content of dry matter (DM) of the subsamples was used to calculate the biomass production, as well as the accumulation of nutrients, multiplying the concentration of each nutrient by the DM amount of the different fractions.

Descriptive statistics was performed (average, standard deviation, maximum and minimum) of sugarcane yield, aboveground biomass, and nutrient (N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn) accumulation for the 21 sites. We also examined the relationship of yield and aboveground biomass production with the amount of accumulated nutrients by Pearson correlation analysis.

As an indicator of the efficiency of utilization of N, P, K, Ca, and Mg the amount of nutrients in aboveground biomass per harvested product was calculated, expressed in kg Mg^{-1}, and is interpreted as the higher use efficiency, the lower the index.

3. Results

3.1 Yield and nutrient accumulation by sugarcane crop

The highest yield of the three growing seasons was obtained in the harvest of 2015 and the lowest in 2016 (**Table 3**). There was a wide variation in the parameters, both among sites and between years in each site. In general, the 2015 harvest showed greater performance, regarding yield and the absorption of P, K, Ca, and Mg, compared to the other harvests. It was observed that the absorption of micronutrients (Cu, Fe, Mn and Zn) showed a wider range of values compared with macronutrients. Data of nutrient concentration in straw and stalks is presented in the Supplementary material (**Table S1**).

The different plantations also showed great variability in terms of the efficiency of nutrient use, although the averages of the different harvests were in relatively limited ranges (**Table 4**).

Although close relationships between yield and biomass production were observed (**Table 5**), considering all sites and the three years of study, the correlation of growth parameters (yield and biomass) with the amount of macronutrients was generally moderate, while Na and micronutrients´ accumulation showed lower relationships (data not presented). The biomass production was highly correlated to the extraction of N, but sugarcane yield showed greater correlation with the amounts of Mg, Ca, and K. As for the relationship between the absorption of different nutrients, high correlation was observed between the amounts of P, Ca, and Mg accumulated in the biomass.

Table 3. Sugarcane yield and amount of nutrients accumulated in aboveground biomass in three growing seasons. For each period, mean and standard deviation in parenthesis is presented. The last three columns show overall mean, minimum, and maximum for each parameter

Season	2015	2016	2017	Mean	Min	Max
Nº of sites	20	21	18			
Yield (Mg ha^{-1})	80.7 (16.4)	54.0 (12.5)	60.1 (14)	64.7	34.4	125.3
Biomass (Mg ha^{-1})	35.0 (5.1)	29.1 (5.1)	34.5 (5.8)	33.1	19.0	52.0
N (kg ha^{-1})	122 (30)	120 (34)	148 (38)	130	59	214
P (kg ha^{-1})	22 (7)	19 (6)	14 (4)	18	9	44
K (kg ha^{-1})	213 (89)	150 (43)	154 (45)	173	56	430
Ca (kg ha^{-1})	71 (23)	49 (22)	43 (18)	54	10	115
Mg (kg ha^{-1})	37 (11)	24 (8)	20 (8)	27	10	53
Na (kg ha^{-1})	3 (1)	6 (2)	4 (1)	4	1	12
Cu (g ha^{-1})	76 (35)	109 (44)	79 (54)	89	7	242
Fe (kg ha^{-1})	3 (1)	4 (2)	3 (1)	3	1	9
Mn (kg ha^{-1})	2 (1)	2 (1)	2 (1)	2	1	6
Zn (g ha^{-1})	300 (115)	411 (189)	366 (155)	360	105	815

Table 4. Nutrient utilization efficiency of sugarcane (kg of nutrient in aerial biomass per Mg of stalk). Numbers in parentheses correspond to the standard deviation. The last three columns show overall mean, minimum, and maximum for each parameter

	2015	2016	2017	Mean	Min	Max
N° of sites	20	21	18			
N (kg Mg^{-1})	1.51 (0.30)	2.29 (0.75)	2.56 (0.75)	2.11	0.99	3.97
P (kg Mg^{-1})	0.27 (0.07)	0.36 (0.13)	0.24 (0.07)	0.29	0.15	0.82
K (kg Mg^{-1})	2.59 (0.88)	2.95 (0.87)	2.63 (0.79)	2.73	0.85	4.82
Ca (kg Mg^{-1})	0.87 (0.20)	0.90 (0.41)	0.71 (0.26)	0.83	0.17	1.73
Mg (kg Mg^{-1})	0.46 (0.12)	0.44 (0.10)	0.34 (0.13)	0.41	0.16	0.76

Table 5. Results of the Pearson correlation analysis between yield, aboveground biomass, and accumulation of nutrients in sugarcane (all sites and harvest years). Correlation coefficient (r) ≥ 0.25 corresponds to P <0.05

	Biom.	N	P	K	Ca	Mg
Yield	0.78	0.26	0.52	0.61	0.61	0.64
Biom.	1.00	0.60	0.39	0.50	0.55	0.56
N		1.00	0.12	0.30	0.14	0.29
P			1.00	0.43	0.66	0.59
K				1.00	0.38	0.31
Ca					1.00	0.83
Mg						1.00

3.2 Exportation of biomass and nutrients

Although most of the aboveground biomass was exported from the site with the stalks of sugarcane, an important amount was not removed with the product. This fraction was in average 13.7 Mg ha^{-1} of dry matter (range from 6.4 to 26.5 Mg ha^{-1}). This material, mainly composed by senescent leaves, and the apical portion of the plant, represented in average 42% of the total biomass.

The proportion of nutrients accumulated in the aerial biomass that was exported with the commercial product, however, did not always follow biomass patterns (**Figure 1**). While the exported fraction of K was similar, or even higher than that of the biomass, Ca presented low extraction, remaining in the field about two thirds of the total accumulated amount. Regarding N, approximately half of the accumulated amount was exported with the stalks. Considering all sites and harvests the average nutrient extraction with stalks was 61, 11, 113, 19 and 15 kg ha-1 for N, P, K, Ca, and Mg, respectively.

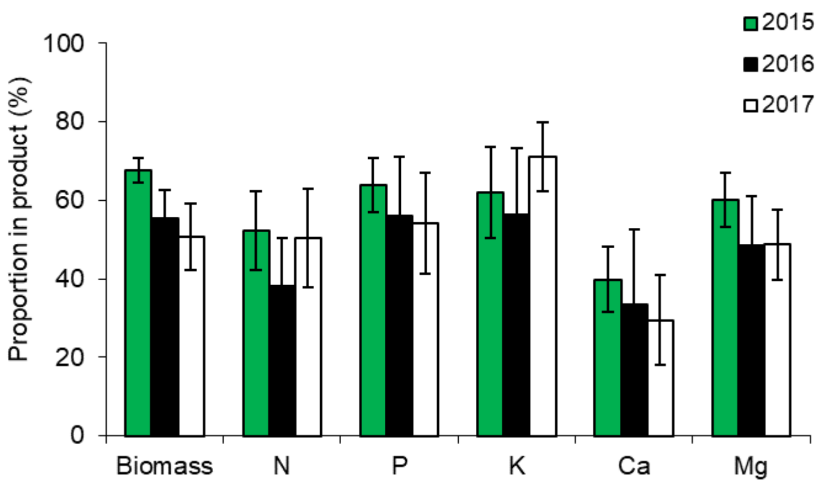

Figure 1. Proportion of harvested biomass and nutrients exported with the products (stalks) in different seasons. Vertical bars indicate standard deviation

4. Discussion

4.1 Biomass and nutrient accumulation

The area in which sugarcane is planted in Uruguay is characterized by a varied mosaic of soils, attributed to the diverse geological material of the region. While in the area near the Uruguay river the parent material consists of fluvial sediments of different lithology, in more distant areas soils derived from material resulting from alteration of basaltic rocks predominate[20]. The various parent materials generated soils with important differences in texture and fertility, which frequently present rock fragments and rolling stones in the soil profile. This fact makes the selection of a representative set of soils a difficult task; however, the wide range of properties in the monitoring sites confirms that a substantial part of soil variability was included in this study, where Mollisols and Vertisols are the dominant soils of the area.

The yield of sugarcane fields with application of vinasse was in average higher than the long-term average recorded by ALUR (55 Mg ha^{-1}). This suggests that the vinasse was able to replace partially or totally the supply of nutrients that are usually applied with synthetic fertilizers. The great volume of biomass accumulated each season corroborates that sugarcane has a much higher growth potential, compared to other crops in Uruguay. Due to its physiological characteristics, and because it is produced under irrigation with fertilizer application, sugarcane makes a very efficient use of radiation. Hence it is likely that this factor is important in determining the differences in production between seasons, provided that nutrition and water availability were not limiting factors.

Despite the wide accumulation range of the different nutrients in the aerial biomass, the variability in the annual average was moderate, especially for macronutrients, which gives robustness to the overall mean as representative of their extraction by the crop of sugarcane in this area. Coale and others[3] for sugarcane production in Florida, USA (average yield of 103 Mg ha^{-1}), cite extractions of 142, 38, 554, 142 and 68 kg ha^{-1} of N, P, K, Ca, and Mg, respectively. These values, except for the case of N, are above the averages of this work, probably due to higher growth. In coincidence[21], comparing different varieties in Pernambuco, Brazil, they obtained significantly higher nutrient extractions than those of our work, for average yields of 195 Mg ha^{-1}. On the other hand, in Alagoas, Brazil[2], for four varieties, with average yields of 102 Mg ha^{-1} in first ratoon crops (first regrowth), they cite macronutrient removals in line with those of our work. They obtained an average accumulation in aerial part of 118, 18, 191, 52 and 42 kg ha^{-1} of N, P, K, Ca, and Mg, respectively.

Da Silva and others[2] also examined the removal of micronutrients, reporting total amounts of 46, 3143, 579 and 268 g ha^{-1} of Cu, Fe, Mn, and Zn, respectively, which are lower than the mean values of our study. For plantations in Venezuela[1], they found higher micronutrient accumulation, except for Mn, compared to our study (121, 5241, 1142 and 876 g ha^{-1} of Cu, Fe, Mn, and Zn, respectively). It should be noted that the availability and absorption of micronutrients is highly influenced by soil characteristics, such as parental material, texture, and pH. Therefore, it is not expected to find coincidences in their accumulation in plantations from different regions.

In most of the farms, vinasse was the main source of K, which accounts for the greatest quantity among nutrients, and it was the only source in 5 of the fields. The K amounts applied with vinasse were in the range of 25 to 305 kg ha^{-1} of K_2O per harvest, exceeding in many cases the amount of K accumulated in the crop's aerial biomass. It has been observed[22] that sugarcane makes a very efficient extraction of K from the soil, even beyond its needs (luxury consumption), which can lead to the depletion of the nutrient in the soil without improvements in the yields[23]. Although luxury consumption of K could have occurred in our study, the amount of this nutrient in aerial biomass showed a high correlation with cane yield, confirming its importance for crop nutrition.

The N content of the vinasse was relatively low, and the amount applied was insufficient for the crop, averaging 28 kg ha^{-1} per year, a quantity lower than that accumulated (average 130 kg ha^{-1}). Moreover, part of the N in the vinasse is in organic form, therefore it should be mineralized to be available for the crop[(16)]. In most of the farms, high doses of N fertilizer were applied, resulting in the addition of vinasse accounting for only 15% of the total supply.

The amount of P applied with the vinasse (average 9 kg ha^{-1} of P_2O_5 per harvest) represented a small proportion of the amount accumulated in the biomass. Previous studies[(10)(12)(24)] showed that a great part of the P from vinasse is readily available to plants, hence it could be absorbed by the crop. Given that a large dose of phosphate fertilizer is usually applied prior to planting, the vinasse contribution for the following re-growth can be significant, even if it were insufficient to replace the P absorbed by the crop. Moreover, it has been observed that the application of vinasse increases soil pH and decreases exchangeable Al in the long term[(10)(25)], which enhances the availability of P in acid soils.

4.2 Nutrient use efficiency

Although there are different methodologies to evaluate nutrient use efficiency[(26)], one of the most used indices for sugarcane production is calculated as the amount of nutrients in the crop's aerial biomass per unit of harvested product. A higher value of this index implies a lower efficiency in the use of nutrients, therefore this index allows detecting situations of nutrient deficiency, as well as situations of excessive consumption[(27)]. Based on data from different countries (Australia, India, Brazil, South Africa and Hawaii, USA)[(22)], average efficiencies for sugarcane of 1.16, 0.19, 2.00, 0.36 and 0.31 kg Mg^{-1} for N, P, K, Ca, and Mg, respectively, can be cited, which are within the range of this work, although they are lower than the average. In the comparison of four varieties in Brazil[(2)], mean values lower than those of our study were obtained (0.98, 0.17, 1.83, 0.57 and 0.46 kg Mg^{-1} for N, P, K, Ca, and Mg, respectively), suggesting that these crops make a more efficient use of nutrients, probably due to their higher growth potential. In comparison with our results[(3)], higher utilization efficiencies for N and P were obtained (0.76 and 0.22 kg Mg^{-1}, respectively), but lower efficiency in the use of K (3.33 kg Mg^{-1}). On the other hand, in high-yield sugarcane plantations in Pernambuco, Brazil[(4)], utilization efficiencies within the ranges found in our study were reported (between 1.3 and 1.6 kg Mg^{-1} for N, between 0.21 and 0.28 kg Mg^{-1} for P, and between 2.4 and 3.2 kg Mg^{-1} for K).

In the 2015 harvest, N and K were more efficiently used than in the other growth periods. This suggests that, in general, the availability of nutrients was not limiting production, although in certain sites this might have occurred. In the case of K, its utilization efficiency was highly variable between sites and between harvests for the same site. The importance of K availability for this crop lies mainly in its role in the metabolism of sugars, and it has been detected as one of its greatest nutritional limitations worldwide[(22)(23)]. Across fields and seasons one third of the cases presented K efficiency indexes higher than 3.0 kg Mg^{-1}. These high values of the K efficiency index in many of the sites, in comparison with the bibliography, suggest that there was luxury consumption by the crop, although high values of the efficiency index could not be related to large doses of this nutrient, either through the application of stillage or fertilization.

4.3 Nutrient export with product and remaining amount in residues

The large extraction of nutrients with the product (stalks) reaffirms the need of nutrient restoration, not only to achieve higher sugarcane yields, but also to ensure the sustainability of the production system, avoiding depletion of soil nutrients in the long term. It should be noticed that the average N and P extraction with the product was lower than the average amount applied with vinasse, but this byproduct provided a larger amount of K than that exported with stalks. Potassium export represented in average 63% of the accumulated total, resulting higher in comparison with an average biomass extraction of 58%. In contrast, the lowest removal corresponds to Ca, reaching an average of 34%, probably due to the low translocation of this nutrient within the plant. Although the removal of secondary and micronutrients (Ca, Mg, Cu, Fe, Mn, and Zn) showed great variability, and the quantities extracted were relatively small, their removal becomes relevant in the long term. In this context, the application of vinasse constitutes a management practice that ensures sustainability in the replacement of these nutrients, which are not incorporated through fertilization. On the other hand, P and N needs are not likely to be fulfilled through vinasse application, therefore these nutrients should be complemented with fertilizer applications.

The amounts of harvest residues were in the range reported by Digonzelli and others(28) for plantations in Tucumán, Argentina, as well as in Brazil(29). The crop residues that remain in the field fulfill various functions. In addition to the recycling of nutrients, they can contribute to the control of erosion, water retention and conservation of soil organic matter(5)(29)(30). Because in Uruguay dry leaves are burned prior to harvest, probably some nutrients suffer losses (mainly N and S), although in our work these losses were not quantified. However, after the harvest it was possible to observe partially burned residues and ash accumulated on the site, representing a reservoir of nutrients for the next production cycle, and offering some protection to the soil surface. On the other hand, in countries where mechanized harvest is carried out, it has been found that residues´ accumulation on the surface can negatively affect regrowth(31). This could justify the removal of part of the material for energy production, leaving a lower, and easier to handle, mass on the soil surface(32).

Our results suggest that although burning is undesirable from the environmental point of view, its abandonment in the plantations of Uruguay will require technological solutions to manage the large mass of residues left by sugarcane.

5. Conclusions

In view of the high levels of yield, the amounts of nutrients accumulated in the aerial biomass of the crop, and the large proportion exported from the site with the stalks, it is concluded that the supply of nutrients from the vinasse will contribute to the sustainability of the production system. In parallel, the use of this byproduct will enable saving important amounts of fertilizers (NPK), avoiding potential environmental hazards due to industrial residues mismanagement.

Acknowledgements

The authors would like to acknowledge ALUR for the financial support. We also thank the Laboratory from Departmento de Suelos y Aguas, Facultad de Agronomía, for the analysis of plant and soil material.

Transparency of data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author contribution statement

del Pino, A.: Conceptualization, Methodology, Investigation, Writing – original draft.

Hernández, J.: Conceptualization, Methodology, Investigation, Writing – review & editing.

Casanova, O.: Conceptualization, Methodology, Investigation, Writing – review & editing.

Takata, V.: Investigation, Writing – review & editing.

Panissa, G.: Conceptualization, Investigation, Writing – review & editing.

References

[1] Rengel M, Gil F, Montaño J. Crecimiento y dinámica de acumulación de nutrientes en caña de azúcar. Bioagro. 2011;23(2):135-40.

[2] da Silva VSG, de Oliveira MW, Ferreira VM, Oliveira TBA, de Brito Santana M, Galvão ER. Stalk yield and nutrients accumulation of sugarcane varieties in three crop cycles. Rev Bras Cienc Agrar. 2018;41(2):415-23.

[3] Coale FJ, Sanchez CA, Izuno FT, Bottcher AB. Nutrient accumulation and removal by sugar cane grown on everglades histosols. Agron J. 1993;85:310-15.

[4] Leite JM, Ciampitti IA, Mariano E, Vieira-Megda MX, Trivelin PC. Nutrient partitioning and stoichiometry in unburnt sugarcane ratoon at varying yield levels. Front Plant Sci. 2016;7:466. Doi: 10.3389/fpls.2016.00466.

[5] de Oliveira Bordonal R, Carvalho JLN, Lal R, de Figueiredo EB, de Oliveira BG, La Scala N. Sustainability of sugarcane production in Brazil: a review. Agron Sustain Dev. 2018;38(2):13. Doi: 10.1007/s13593-018-0490-x.

[6] Contreras AM, Rosa E, Pérez M, Van Langenhove H, Dewolf J. Comparative life cycle assessment of four alternatives for using by – products for cane sugar production. J Clean Prod. 2009;17:772-9.

[7] Wilkie AC, Riedesel KJ, Owens JM. Stillage characterization and anaerobic treatment of ethanol stillage from conventional and cellulosic feedstocks. Biom Bioener. 2000;19(2):63-102.

[8] Senatore D, Quirolo A, Wajswol S, Bajsa N. Monitoreo de la aplicación de vinaza como fertilizante en caña de azúcar con indicadores microbianos del suelo. INNOTEC. 2017;13:92-7.

[9] Lourenço KS, Suleiman AKA, Pijl A, van Veen JA, Cantarella H, Kuramae EE. Resilience of the resident soil microbiome to organic and inorganic amendment disturbances and to temporary bacterial invasion. Microbiome. 2018;6(1):142. Doi: 10.1186/s40168-018-0525-1.

[10] Soobadar A. Application of vinasse to sugarcane. In: Webb E, editor. Sugarcane: production, consumption & agricultural management systems. New York: Nova Science Publishers; 2014. p. 329-58.

[11] Ortegón GP, Arboleda FM, Candela L, Tamoh K, Valdes-Abellan J. Vinasse application to sugar cane fields: effect on the unsaturated zone and groundwater at Valle del Cauca (Colombia). Sci Total Environ. 2016;539:410-9. Doi: 10.1016/j.scitotenv.2015.08.153.

[12] del Pino A, Casanova O, Hernandez J, Takata V, Panissa G. Efecto de la aplicación de vinaza en suelos bajo cultivo de caña de azúcar. Cienc Agronom. 2017;30:30-6.

[13] Nicochelli LM, Nascentes R, Lima EB, Soares FSC. Sorção de potássio em amostras de solo submetidas à aplicação de vinhaça. Rev Bras Engen Agri Amb. 2012;16(7):754-60.

[14] del Pino A, Casanova O, Hernandez J, Takata V, Panissa G. Vinasse for sugarcane crop nutrition: accumulation and efficiency in the use of nutrients. Austr J Crop Sci. 2022;16(9):1107-16. Doi: 10.21475/ajcs.22.16.09.p3617.

[15] Vicente TF, Pedrosa EM, Rolim MM, Oliveira VS, Oliveira AKS, Souza AM. Relações de atributos do solo e estabilidade de agregados em canaviais com e sem vinhaça. Rev Bras Engen Agri Amb. 2012;16(11):1215-22.

[16] da Silva A, Rossetto R, Bombecini J, Piemonte M, Muraoka T. Nitrogen mineralization from sugarcane vinasse. J Plant Nutr. 2014;37:1227-36.

[17] Bremner JM, Mulvaney CS. Nitrogen-Total. In: Page AL, Miller RH, Keeney DR, editors. Methods of soil analyses. Part 2, Chemical and microbiological properties. Madison: SAS; 1982. p. 595-624.

[18] Murphy J, Riley JP. A modified single solution method for determination of phosphate in natural waters. Anal Chem Act. 1962;27:31-6.

[19] Isaac RA, Kerber JD. Atomic Absorption and flame photometry: techniques and uses in soil, plant and water analysis. In: Walsh LM, editor. Instrumental methods for analysis of soil and plant tissues. Madison: SSAS; 1971. p. 17-37.

[20] Durán A, García Préchac F. Suelos del Uruguay. Vol 1, factores ambientales, clasificación y caracterización. Montevideo: Hemisferio Sur; 2009. 74p.

[21] Oliveira EC, Freire FJ, Oliveira RID, Freire MB, Simões Neto DE, Silva SA. Nutrient extraction and export by fully irrigated sugarcane varieties. Rev Bras Cienc Solo. 2010;34(4):1343-52.

[22] Meyer J. Sugarcane nutrition and fertilization. In: Meyer JH, Turner PE, Rein P, Mathias K, editors. Good management practices for the cane industry edition. Berlin: Bartens; 2013. p 133-80.

[23] Kingston G, Anink MC, Clift BM, Beattie RN. Potassium management for sugarcane on base saturated soils in northern New South Wales. Proc Austr Soc Sugar Cane Technol. 2009;31:186-94.

[24] Sanchez AL, Arenas V, Marino EN, Dendooven L, Velazquez JB, Davila G, Rodríguez J, Hernández L, Contreras SM. Vinasse irrigation: effects on soil fertility and arbuscular mycorrhizal fungi population. J Soils Sediments. 2018;18(11):3256-70.

[25] Brito FDL, Rolim MM, Pedrosa EM. Efeito da aplicação de vinhaça nas características químicas de três solos da zona da mata canavieira de Pernambuco. Rev Bras Cienc Agrar. 2015;4(4):456-62.

[26] Weih M, Hamnér K, Pourazari F. Analyzing plant nutrient uptake and utilization efficiencies: comparison between crops and approaches. Plant Soil. 2018;430(1-2):7-21.

[27] Machado CT, Furlani A, Cangiani M, Machado AT. Índices de eficiência de variedades locais e melhoradas de milho ao fósforo. Bragantia. 2001;60(3):225-38.

[28] Digonzelli PA, De Ullivarri JF, Medina M, Tortora L, Romero ER, Quinteros HR. Dynamics of sugarcane harvest residue decomposition in Argentina. Proc Int Soc Sugar Cane Technol. 2013;28:1-12.

[29] Cherubin MR, Lisboa IP, Silva AG, Varanda LL, Bordonal RO, Carvalho JL, Otto R, Pavinato OS, Soltangheisi A, Cerri CE. Sugarcane straw removal: implications to soil fertility and fertilizer demand in Brazil. Bioenergy Res. 2019;12(4):888-900.

[30] Cerri CC, Galdos MV, Maia SMF, Bernoux M, Feigl BJ, Powlson D, Cerri CEP. Effect of sugarcane harvesting systems on soil carbon stocks in Brazil: an examination of existing data. Eur J Soil Sci. 2011;62(1):23-8.

[31] de Aquino GS, de Conti Medina C, Junior AD, Pasini A, Brito OR, Cunha AC, dos Santos Junior JH, Kussaba DAO, Almeida LF. Impact of harvesting with burning and management of straw on the industrial quality and productivity of sugarcane. Afri J Agric Res. 2016;11:2462-8.

[32] Lisboa IP, Cherubin MR, Lima RP, Cerri CC, Satiro LS, Wienhold BJ, Schmer MR, Jin VL, Cerri CE. Sugarcane straw removal effects on plant growth and stalk yield. Ind Crops Prod. 2018;111:794-806.

Supplementary Material

Table S1. Sugarcane yield (Mg/ha), absorbed nutrients(kg/ha of P, N, Ca, Mg, K, Fe and Mg ; g/ha of Cu and Zn), extraction in product (%) and nutrient use efficiency (kg/Mg)

			Yield	Absorbed nutrients in aerial biomass									Extraction in product										Nutrient use eficiency				
			Mg/ha			kg/ha					g/ha						%						kg/Mg				
			cane	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	MS	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	P	N	Ca	Mg	K
2015	1	V1	95	44	150	98	42	247	4	2	41	181	66	75	49	34	57	64	20	38	49	37	0,5	1,6	1,0	0,4	2,6
2015	2	V2	64	12	88	52	26	162	3	1	65	233	66	56	49	41	63	72	20	42	79	73	0,2	1,4	0,8	0,4	2,5
2015	3	V3	104	22	195	83	53	276	4	3	65	223	66	57	60	39	62	72	21	35	68	35	0,2	1,9	0,8	0,5	2,6
2015	4	V5	88	15	104	87	28	355	2	3	81	303	71	66	56	58	71	74	60	62	94	69	0,2	1,2	1,0	0,3	4,0
2015	5	V10	83	20	111	51	35	214	2	2	110	349	69	71	59	33	60	71	44	64	85	83	0,2	1,3	0,6	0,4	2,6
2015	6	V11	89	31	160	115	51	430	3	4	119	660	66	72	62	58	70	79	56	66	82	83	0,3	1,8	1,3	0,6	4,8
2015	7	V12	79	22	105	93	33	212	4	2	64	219	65	55	32	33	57	56	61	57	75	54	0,3	1,3	1,2	0,4	2,7
2015	8	V14	88	17	148	60	35	184	3	1	58	287	69	62	64	44	63	61	56	52	86	65	0,2	1,7	0,7	0,4	2,1
2015	9	V15	125	30	162	103	52	303	5	2	167	364	70	71	61	50	63	75	53	46	88	70	0,2	1,3	0,8	0,4	2,4
2015	10	V16	66	21	94	67	32	88	2	1	38	185	68	65	55	36	52	47	28	44	62	47	0,3	1,4	1,0	0,5	1,3
2015	11	V17	61	20	142	47	32	129	2	1	91	322	75	67	62	42	66	43	54	49	83	66	0,3	2,3	0,8	0,5	2,1
2015	12	V18	66	17	113	69	50	56	2	1	50	363	67	60	65	45	60	38	68	48	67	52	0,3	1,7	1,0	0,8	0,9
2015	13	BV1	91	22	136	89	46	211	4	2	57	345	66	65	47	43	65	59	78	54	77	61	0,2	1,5	1,0	0,5	2,3
2015	14	BV2	82	25	130	69	48	196	3	3	75	418	67	63	48	40	60	70	40	54	84	63	0,3	1,6	0,8	0,6	2,4
2015	15	BV3	83	20	101	78	39	310	4	3	114	347	63	54	28	31	54	66	41	46	78	62	0,2	1,2	0,9	0,5	3,7
2015	16	BV4	70	22	59	41	19	152	1	2	41	298	71	71	53	36	60	66	56	51	70	72	0,3	0,8	0,6	0,3	2,2
2015	17	BV5	61	19	78	33	20	173	3	2	49	248	74	72	58	42	68	66	44	55	82	75	0,3	1,3	0,5	0,3	2,8
2015	18	BV6	92	28	103	66	34	239	3	3	109	373	65	66	42	31	56	64	53	45	86	78	0,3	1,1	0,7	0,4	2,6
2015	19	C2	63	14	118	63	33	179	3	2	93	222	64	51	53	33	57	61	22	52	77	60	0,2	1,9	1,0	0,5	2,8
2015	20	C3	67	17	72	27	17	206	2	2	26	190	72	70	43	24	39	64	38	43	42	47	0,3	1,1	0,4	0,3	3,1
2015	21	RS2	64	16	109	65	34	80	1	1	32	169	65	60	53	37	59	39	48	60	51	53	0,2	1,7	1,0	0,5	1,2
2016	1	V1	69	27,2	138	40	26	128	1	2	184	257	64	78	56	59	75	77	33	70	64	61	0,4	2,0	0,6	0,4	1,8
2016	2	V2	67	28,8	133	61	30	265	9	2	92	476	64	86	53	39	68	79	68	55	37	71	0,4	2,0	0,9	0,4	3,9
2016	3	V3	50	11,6	146	18	16	174	3	1	53	204	53	51	43	16	53	75	31	30	53	70	0,2	2,9	0,4	0,3	3,5
2016	4	V5	49	21,3	92	35	19	233	4	3	109	365	62	61	34	16	45	62	58	37	52	23	0,4	1,9	0,7	0,4	4,7

			Yield	Absorbed nutrients in aerial biomass										Extraction in product										Nutrient use eficiency				
			Mg/ha			kg/ha						g/ha						%						kg/Mg				
			cane	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	MS	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	P	N	Ca	Mg	K
2016	5	V10	44	13,1	82	41	22	123	3	2	107	518	56	58	48	25	46	67	54	30	24	57	0,3	1,9	0,9	0,5	2,8
2016	6	V11	66	16,5	154	56	28	138	8	6	32	268	58	59	59	54	58	47	49	50	6	38	0,2	2,3	0,9	0,4	2,1
2016	7	V12	38	14,8	97	49	20	108	2	2	157	429	51	45	36	28	56	38	18	37	44	53	0,4	2,5	1,3	0,5	2,8
2016	8	V14	69	24,2	87	110	40	121	5	2	106	716	57	55	38	57	48	48	40	36	110	71	0,3	1,2	1,6	0,6	1,7
2016	9	V15	82	24,0	110	67	32	120	5	3	98	815	66	59	43	36	45	52	35	41	49	30	0,3	1,3	0,8	0,4	1,5
2016	10	V16	50	18,0	95	74	19	122	2	2	155	532	59	66	40	65	65	60	84	64	59	40	0,4	1,9	1,5	0,4	2,4
2016	11	V17	59	18,8	123	62	38	136	4	1	114	429	59	41	42	18	39	66	48	37	33	52	0,3	2,1	1,1	0,6	2,3
2016	12	V18	59	24,5	95	63	28	118	5	1	215	691	62	81	40	31	57	53	48	47	55	69	0,4	1,6	1,1	0,5	2,0
2016	13	BV1	54	15,4	214	65	32	146	3	2	102	277	44	45	22	24	39	32	21	21	61	28	0,3	4,0	1,2	0,6	2,7
2016	14	BV2	45	22,1	135	52	22	142	4	2	125	407	46	29	17	5	25	34	51	18	22	20	0,5	3,0	1,1	0,5	3,2
2016	15	BV3	44	16,8	125	23	12	144	2	1	61	228	44	44	15	11	44	54	32	23	44	47	0,4	2,8	0,5	0,3	3,2
2016	16	BV5	37	9,7	59	18	15	96	1	1	54	105	58	51	47	74	46	65	75	26	41	85	0,3	1,6	0,5	0,4	2,6
2016	17	BV6	60	16,6	108	10	12	190	4	2	122	527	64	74	48	37	64	68	52	47	31	35	0,3	1,8	0,2	0,2	3,1
2016	18	C2	39	10,9	121	35	21	118	4	2	52	288	45	40	21	13	33	30	60	21	45	41	0,3	3,1	0,9	0,5	3,0
2016	19	C3	58	15,8	93	54	28	147	5	4	106	182	53	54	34	7	27	68	36	13	36	63	0,3	1,6	0,9	0,5	2,5
2016	20	RS2	34	28,3	134	59	23	142	3	3	137	641	46	36	26	18	37	22	47	16	46	43	0,8	3,9	1,7	0,7	4,1
2016	21	S3	60	17,7	179	29	17	233	2	1	107	283	56	66	39	13	46	84	34	31	72	68	0,3	3,0	0,5	0,3	3,9
2017	1	V1	70	16	150	57	28	154	3	2	159	488	62	36	57	15	45	73	50	30	52	63	0,2	2,1	0,8	0,4	2,2
2017	2	V2	77	17	181	40	17	238	1	1	126	248	59	64	54	33	53	84	41	41	88	62	0,2	2,4	0,5	0,2	3,1
2017	3	V3	50	9	133	29	13	180	2	2	34	236	53	59	50	41	47	78	29	15	88	38	0,2	2,6	0,6	0,2	3,6
2017	4	V5	90	13	200	34	15	244	3	1	13	325	60	71	62	45	66	87	71	42	60	84	0,1	2,2	0,4	0,2	2,7
2017	5	V14	55	10	99	34	12	111	2	1	59	381	56	66	56	29	56	73	72	36	56	83	0,2	1,8	0,6	0,2	2,0
2017	6	V15	82	16	193	51	13	160	2	1	22	423	63	60	67	58	56	72	63	42	34	70	0,2	2,4	0,6	0,2	2,0
2017	7	V16	69	11	104	48	20	126	4	1	52	538	52	68	52	29	52	70	75	30	69	43	0,2	1,5	0,7	0,3	1,8
2017	8	V17	67	10	137	38	33	100	2	1	56	371	52	47	36	21	58	74	62	37	69	57	0,2	2,1	0,6	0,5	1,5
2017	9	V18	72	23	176	106	47	122	5	3	242	753	56	57	75	25	39	59	56	22	56	72	0,3	2,5	1,5	0,6	1,7
2017	10	BV1	43	11	128	30	14	100	2	1	109	115	40	37	50	42	45	69	74	37	47	67	0,3	3,0	0,7	0,3	2,3
2017	11	BV2	43	10	155	31	14	115	2	1	44	300	40	37	36	16	35	71	56	33	57	50	0,2	3,6	0,7	0,3	2,7
2017	12	BV3	53	20	202	64	28	183	2	2	99	401	37	63	23	17	33	65	25	19	47	54	0,4	3,8	1,2	0,5	3,5
2017	13	BV5	45	11	120	29	20	118	3	2	68	628	45	40	48	22	52	57	52	22	76	18	0,2	2,7	0,6	0,4	2,6

			Yield	Absorbed nutrients in aerial biomass									Extraction in product										Nutrient use eficiency				
			Mg/ha			kg/ha					g/ha						%						kg/Mg				
			cane	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	MS	P	N	Ca	Mg	K	Fe	Mn	Cu	Zn	P	N	Ca	Mg	K
2017	14	BV6	44	12	103	20	12	158	1	1	7	163	59	68	57	36	59	80	33	36	59	70	0,3	2,4	0,5	0,3	3,6
2017	15	C2	49	10	190	29	19	185	1	1	104	325	38	38	31	32	48	55	55	35	29	47	0,2	3,9	0,6	0,4	3,8
2017	16	C3	53	14	152	37	19	159	3	3	75	346	47	49	60	19	37	75	31	26	92	60	0,3	2,9	0,7	0,4	3,0
2017	17	RS2	51	19	174	58	19	214	3	2	80	293	42	73	48	19	42	78	28	17	20	49	0,4	3,4	1,1	0,4	4,2
2017	18	S3	60	16	60	38	17	107	3	2	35	249	53	41	43	32	53	60	58	21	88	62	0,3	1,0	0,6	0,3	1,8