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Effect of increasing vinasse doses, in association with different harvest times, on sweet sorghum production

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Abstract

The aim of this study was to verify the effect of increasing vinasse doses and different harvest times on the production of sweet sorghum (*Sorghum bicolor*, L. Moench) grown in clayey soil. The experiment was carried out in the experimental area of the Universidade Estadual de Goiás, Brazil. The experimental design used was completely randomized, in a factorial scheme, set up as follows: five doses of vinasse (0, 50, 100, 150, and 200 m^3 ha^{-1}) and two harvest times (69 and 90 days after sowing). There was a 19% increase in forage biomass 90 days after sowing. A vinasse dose effect on forage biomass was observed ($p = 0.008$); thus, as vinasse supply increases, forage production increases as well. For juice yield, there was an interaction between harvest time and vinasse doses ($p = 0.035$); 69 days after sowing, a juice production of 6.97 m^3 ha^{-1} was estimated when 190 m^3 ha^{-1} of vinasse was used. Regardless of harvest time, using vinasse in increasing doses promotes significant increases in the production of sweet sorghum biomass. Although the flowering regulator inhibited panicle production, it did not lead to increases in juice production 90 days after sowing.

Keywords: biomass; fertilization; juice; sucrose; soluble solids.

Practical Application: The study demonstrated that increasing doses of vinasse can significantly boost sweet sorghum juice production. The interaction between vinasse doses and harvest time influenced juice yield. At 69 days post-sowing, 190 m^3 ha^{-1} of vinasse resulted in 6.97 m^3 ha^{-1} of juice. Flowering regulator inhibited panicle production but did not affect juice yield at 90 days. Producers can optimize juice production by adjusting vinasse doses according to harvest time.

1 INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) can be considered a crop of high phenotypic plasticity. When it is grown in regions with acidic soils and consequently low natural bioavailability of nutrients, as is the case of Savannah regions (e.g., Brazilian *Cerrado*), a good development of the aerial parts is observed, making it possible to obtain satisfactory results in primary production (forage mass and grains) (Bezerra et al., 2022; Bhat, 2019; Charlo et al., 2022).

At the same time, some cultivars, such as sweet sorghum, have a high concentration of soluble carbohydrates, which makes them highly energetic. This characteristic allows them to be used as sources for bioenergy production (Regassa & Wortmann, 2014) and can enhance sustainability in agricultural environments.

Because of the pandemic, and in association with war scenarios around the world, the financial viability of the agricultural sector is compromised, as exorbitant increases in the commercial value of agricultural inputs (e.g., chemical fertilizers and fuels) are recorded (Sindhwani et al., 2022). Thus, to reduce fixed costs in agricultural production, there is a need to employ alternative sources of fertilizer. Biofertilizers are a potential source of both macro- and micronutrients (Auler et al., 2020; Oliveira et al., 2022).

A possible organic fertilizer is vinasse (a co-product of the sugar and alcohol industry), with an annual production of up to 360 billion liters (CONAB, 2017); most of the nutrients required by crops of agronomic interest are found in its composition (Carpanez et al., 2022).

Thus, when vinasse is adequately used, it promotes increases in morphological development and in primary production, as seen in sugarcane (*Saccharum officinarum*), lettuce (*Lactuca sativa*), watercress (*Nasturtium officinale*), and chicory (*Cichorium intybus*) (Andrade et al., 2022, Maradiaga-Rodriguez

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et al., 2018). In the corn crop (*Zea mays*), Cabral Filho et al. (2022) verified that the agronomic efficiency of vinasse was 68.5% in relation to the source of potassium, which evidences its potential as a biofertilizer.

In the sugar and alcohol industry, it is extremely important for plants to produce a large amount of juice and sucrose in the stem. In this way, to accelerate the maturation process of the plants and obtain higher concentrations of soluble sugars at the time of harvest, plant regulators are used; when applied in doses at appropriate times, they slow down the flowering process and result in an increase in the concentration of sugars in the stem (Roberto et al., 2015).

Thus, using inhibitors as a strategy to speed up maturation can influence the quality of the harvested product. However, accurate results from studies associating flowering inhibitors with harvest time in sweet sorghum plants have not yet been published.

In light of the foregoing, to elucidate the effects of vinasse and harvest time for sweet sorghum, the following hypotheses were elaborated: using vinasse will promote good plant development, generating significant increases in biomass production and after application of the flowering regulator, the sweet sorghum plants will present a higher production of juice and sucrose 90 days after sowing.

The objective of this research was to verify the effect of increasing vinasse doses and different harvest times on the production of sweet sorghum grown in clayey soil.

2 MATERIALS AND METHODS

2.1 Experimental area characterization

The study was carried out in the experimental area of the Universidade Estadual de Goiás—Santa Helena de Goiás Campus, located in the southwest of the state of Goiás, Brazil (17° 49' 34.3" S, 50° 36' 24.4" W, and 570 m of altitude), being implemented in May 2016 and conducted until August 2016.

According to the Köppen classification, the climate in the region is of the Aw type, with an average temperature of 23.5°C, ranging from 20.7°C (June) to 25.0°C (December). The average annual rainfall is 1,785 mm, of which 87% is concentrated between the months of October and March. The region has an average rainfall deficit period of 4 months (Alvares et al., 2013).

2.2 Experimental design

The experimental design used was completely randomized, in a factorial scheme, with three replications, five vinasse doses (0, 50, 100, 150, and 200 m^3 ha^{-1}) and two harvest times (69 and 90 days after sowing), totaling 30 experimental plots.

The experimental plots consisted of five rows—2 m long and 2.80 m wide—with a spacing of 14 cm in between plants and 70 cm in between rows. The central lines were considered useful for data collection and observations.

2.3 Soil preparation, fertilization, and liming

Before the implementation of the experiment, a chemical and physical characterization of the soil was carried out in the 0–20 cm layer, with 20 simple samples being collected at equidistant points. Subsequently, a composite sample was taken and sent to the laboratory for analysis, in accordance with the method described by Donagema et al. (2011).

The soil was classified as a dystrophic Red Latosol type (Santos et al., 2018), with a clayey texture (510, 90, and 400 g kg^{-1} of sand, silt, and clay, respectively). Regarding its chemical parameters, the following results were found: active acidity (pH, in $CaCl_2$) of 5.0; 1.7, 0.7, 4.2 $cmol_c$ dm^{-3}, respectively, of calcium (Ca), magnesium (Mg), potential acidity (H+Al); 45.0 and 7.7 mg dm^{-3} of potassium (K) and phosphorus (P) (Mehlich I); cation exchange capacity of 6.72; 24.0 g dm^{-3} of organic matter (OM); and base saturation of 37.50%.

Through soil analysis in the experimental area, the soil was corrected using 1.89 t ha^{-1} of limestone, raising the base saturation to 60%. A period of 30 days was allowed for incorporation and ration of limestone and, after this process, the soil was prepared in a conventional way, being plowed twice and harrowed twice.

2.4 Sowing management

A commercial cultivar of sweet sorghum (*S. bicolor*, L. Moench), NS 106, with indeterminate growth, was used. Sowing was carried out in May 2016 at a density of 21 seeds per linear meter and a depth of 3 cm. After emergence, thinning was performed to leave seven plants per meter.

For calculating the amount of fertilizer used at sowing, the chemical characteristics of the soil and expected productivity were taken into account, with 90 kg ha^{-1} of nitrogen (N), divided into 20 kg for sowing and 70 kg for top dressing (stage V5: five expanded leaves), and 50 kg ha^{-1} of P being applied to the soil.

2.5 Vinasse application

The applied vinasse was obtained through a partnership with private companies located in the city of Santa Helena, Goiás. To verify the chemical composition of the vinasse, an analysis was carried out in accordance with Miyazawa et al. (1999), and the following values were found: pH: 5.87 $CaCl_2$; OM: 12.00 g L^{-1}; N: 0.52 g L^{-1}; P: 0.09 g L^{-1}; K: 2.84 g L^{-1}; Ca: 0.23 g L^{-1}; Mg: 0.16 g L^{-1}; Na: 0.02 g L^{-1}; sulfur (S): 0.23 g L^{-1}; sodium (Na): 0.02 g L^{-1}; and carbon (C): 6.67 g L^{-1}.

Vinasse was manually applied from sowing to 42 days, with the aid of a watering can over the sown area. From the emergence of seedlings, it began to be applied in the spacing between rows so that it covered the entire total area of the experimental plot. The applications took place in the morning.

2.6 Crop treatment and irrigation management

The sweet sorghum seeds were treated with a pre-planting insecticide based on bifenthrin + imidacloprid at a dose of 1.25

L/100 kg of seeds, providing systemic and contact action and thus protecting the root and aerial parts of the seedling against early pests.

The control of insect pests was carried out twice, using insecticides based on thiamethoxam + lambda-cyhalothrin, with the addition of an adjuvant—Aureo—and another insecticide based on deltramethrin. Disease control was not necessary, and other crop treatments, such as weed removal, were carried out manually.

For irrigation management purposes, a Class A tank was used, which was installed in the experimental area of the Universidade Estadual de Goiás—Santa Helena de Goiás Campus. Daily evaporation readings were taken; irrigation management with a fixed watering shift was adopted, with the application of the depth corresponding to the crop's evapotranspiration (ETc). To determine the reference evapotranspiration (ETo), the amount evaporated in the Class A tank (CAE) was taken into account, multiplied by the tank correction factor (Kp), in accordance with the Equation 1:

$$ETo = CAE*Kp \tag{1}$$

Where:

ETo: reference evapotranspiration (mm day^{-1});

CAE: Class A tank evaporation (mm day^{-1});

Kp: tank coefficient (0.85).

The depth to be applied was obtained through the reference evapotranspiration (ETo), multiplied by the sorghum crop coefficient, in accordance with the crop development phase (Doorenbos & Pruitt, 1977), through the Equation 2:

$$ETc = ETo*Kc \tag{2}$$

Where:

ETc: crop evapotranspiration (mm day^{-1});

ETo: reference evapotranspiration (mm day^{-1});

Kc: crop coefficient (dimensionless).

The same amount of water was applied to all plots, seeking hydric uniformity, with only the amount of vinasse varying.

2.7 Harvest

To prevent panicles from developing, a maturation inhibitor based on ethephon (2-chloroethylphosphonic acid) was applied at a dose of 100 mL of the active principle diluted in 400 mL of water. The first harvest occurred 69 days after sowing, 1 day before the inhibitor was applied. The second harvest took place after 21 days (90 days after sowing) for the detection of whether the plants continued to grow with the application of the maturation inhibitor.

2.8 Evaluated characteristics

The morphological characteristics evaluated were as follows: plant height (m): determined with the aid of a graduated measuring tape by measuring the stems from their base, close to the ground, to the point of insertion of the inflorescence; and stem diameter (mm): obtained with the aid of a digital caliper at the median height of the stem.

To measure the biomass productivity of the sweet sorghum, the following characteristics were evaluated: forage biomass (t ha^{-1}): the sorghum plants were harvested in the useful area of the experimental plot, and, subsequently, the samples were sent to a forced circulation oven at 65°C until reaching constant weight; and fresh stem biomass (t ha^{-1}): determined using the method by Gheller et al. (1999), which consists of weighing all the cut material and discarding the leaves in the useful area of the plots.

Regarding the juice characteristics of the sweet sorghum, the following parameters were evaluated: juice yield (m^3 ha^{-1}): all the stems of each useful area of the plots were processed, and the volume of the juice was quantified using a beaker; total soluble solids (%, Brix): a refractometer was used to obtain the Brix of the juice extracted from the plants in the useful area of the plots; apparent sucrose content (%) and juice purity (%): determined in accordance with methodology described by Caldas (1998); and fiber content (%): determined by the CRSPCTS/PB methodology (Instituto do Açúcar e do Álcool, 1997).

2.9 Statistical analysis

Data related to vinasse doses and harvest time were analyzed following a factorial model ($yijk = \mu + Ei + Vj + Ei*Vj + \varepsilon ij$), yij: observed value; μ = general constant; Ej: harvest time effect (j = 69 and 90 days after sowing); Vi: vinasse dose effect (i = 0, 50, 100, 150, and 200 m^3 ha^{-1} of vinasse); $Ei*Vj$: interaction between vinasse doses and harvest time; and εij: random error, associated with each observed i and j value.

Vinasse doses were subjected to first-degree regression analysis ($yij = \beta 0 + \beta 1*x + \varepsilon ij$) and second-degree regression analysis ($yij = \beta 0 + \beta 1*x + \beta 2*x^2 + \varepsilon ij$); yij: observed value; $\beta 0$, $\beta 1$, and $\beta 2$: equation parameters; x: vinasse doses; εij: random error, associated with each observed i and j value. As a selection criterion among the equations, the model that exhibited a significant effect ($p < 0.050$) and the highest coefficient of determination ($R^2 \geq 0.700$) was chosen.

For the analysis of variance and regression to be performed, the ExpDes package (Ferreira et al., 2015) was used. All statistical procedures were conducted using the R software, version 4.2.1.

3 RESULTS

There was no interaction between harvest time and vinasse rates for plant height ($p = 0.998$) and stem diameter ($p = 0.935$). No differences were observed among harvest times in plant height ($p = 0.318$) and stem diameter ($p = 0.076$). Mean values of 1.01 m and 16.79 mm were estimated, respectively (Table 1). The vinasse doses showed no effect on plant height ($p = 0.227$) and stem diameter ($p = 0.333$), with mean values of 1.00 m and 16.79 mm, respectively (Table 1).

There was no interaction between harvest time and vinasse doses for fresh stem biomass ($p = 0.953$). Harvest time also did not promote oscillations ($p = 0.075$); 69 and 90 days after sowing, a mean value of 25.33 t ha^{-1} of fresh stem biomass was obtained. On the contrary, a difference was detected among vinasse doses ($p = 0.043$), with a better adjustment to the quadratic equation being noted. Consequently, when using 148 m^3 ha^{-1} of vinasse, it is possible to obtain 29.60 t ha^{-1} of sweet sorghum stem (Table 1).

Regarding forage biomass, no interaction was observed between harvest time and vinasse doses ($p = 0.625$). There was a harvest time effect ($p = 0.034$), in which a 19% increase in sweet sorghum forage biomass was obtained 90 days after emergence. A vinasse dose effect was observed ($p = 0.008$), generating a first-degree equation. Therefore, based on the slope of the equation parameters, as the supply of vinasse doses increases, forage biomass increases as well (Table 1).

For juice yield, an interaction was observed between harvest time and vinasse doses ($p = 0.035$), as 69 days after sowing, the vinasse doses showed different mean values ($p = 0.006$); at the same time, a second-degree equation was generated, which made it possible to estimate a juice production of 6.97 m^3 ha^{-1} when using 190 m^3 ha^{-1} of vinasse. On the contrary, 90 days after sowing, there were no oscillations in juice yield considering vinasse doses ($p = 0.952$) (Table 2).

There was no interaction between harvest time and vinasse doses for fiber content ($p = 0.247$), juice purity ($p = 0.477$), soluble solids content ($p = 0.326$), and apparent sucrose content ($p = 0.262$). Regarding harvest times, an effect was verified on fiber content ($p < 0.001$), juice purity ($p < 0.001$), soluble solids content ($p < 0.001$), and apparent sucrose content ($p < 0.001$), with greater estimates being quantified 90 days after sowing. For vinasse doses, no oscillations were observed in fiber content ($p = 0.407$), purity ($p = 0.397$), soluble solids content ($p = 0.160$), and apparent sucrose content ($p = 0.217$), with mean values of 12.99%, 10.34%, 12.41 (%, Brix), and 1.75%, respectively, being obtained (Table 3).

4 DISCUSSION

An adequate supply of essential nutrients positively influences the morphological development of plants. Santos et al. (2020) found that, for grain sorghum plants, 60 and 90 days after emergence, the impact of abiotic factors becomes more evident in plant height and stem diameter. In the research with sweet sorghum, there was no restriction of nutrients, and the rainfall scarcity during the experimental period was corrected

Table 1. Morphology and productive parameters of sweet sorghum at different harvest times, in association with increasing vinasse doses.

Item	Harvest time (DAS)		Vinasse doses (m^3 ha^{-1})					SEM	Equation	R^2		p-value	
	69	90	0	50	100	150	200			L	Q	L	Q
Plant height (m)	0.970	1.04	0.893	0.963	1.13	1.07	0.963	0.033	$y = 0.955$	-	-	0.299	0.058
Stem diameter (mm)	16.37	17.20	16.54	16.33	16.41	16.98	17.67	0.224	$y = 16.20$	-	-	0.066	0.086
Fresh stem biomass (t ha^{-1})	23.33	27.34	19.26	23.21	29.30	28.57	26.33	1.19	$y = 18.69 + 0.148x - 0.0005x^2$	-	0.938	0.006	0.018
Forage biomass (t ha^{-1})	3.76	4.65	2.99	3.79	4.86	3.99	5.39	0.246	$y = 3.20 + 0.010x$	0.707	0.718	0.001	0.642

DAS: days after sowing; R^2: coefficient of determination; L: linear equation; Q: quadratic equation; p-value: probability of significant effect; SEM: standard error of the mean; y: dependent variable; x: increasing doses of vinasse (0, 50, 100, 150, and 200 m^3 ha^{-1}).

Table 2. Juice yield (m^3 ha^{-1}) of sweet sorghum at different harvest times, in association with increasing doses of vinasse.

Harvest time (DAS)	Vinasse doses (m^3 ha^{-1})					Equation	R^2		p-value	
	0	50	100	150	200		L	Q	L	Q
69	3.12	5.48	5.63	5.68	5.63	$y = 3.36 + 0.038x - 0.0001x^2$	0.550	0.897	< 0.001	0.004
90	4.09	4.16	4.31	4.45	4.45	$y = 4.09$	-	-	0.048	0.150
SEM						0.184				

DAS: days after sowing; R^2: coefficient of determination; L: linear equation; Q: quadratic equation; p-value: probability of significant effect; SEM: standard error of the mean; y: dependent variable; x: increasing doses of vinasse (0, 50, 100, 150, and 200 m^3 ha^{-1}).

Table 3. Sweet sorghum juice quality at different harvest times, in association with increasing doses of vinasse.

Item	Harvest time (DAS)		Vinasse doses (m^3 ha^{-1})					SEM	Equation	R^2		p-value	
	69	90	0	50	100	150	200			L	Q	L	Q
Fiber content (%)	9.96	16.02	12.84	13.33	13.10	12.73	12.95	0.572	$y = 13.07$	-	-	0.925	0.986
Juice purity (%)	3.12	17.56	11.59	10.74	11.10	9.96	8.32	1.43	$y = 11.80$	-	-	0.481	0.760
Soluble solids content (%, Brix)	6.15	18.66	13.13	12.28	12.98	12.11	11.53	1.18	$y = 13.08$	-	-	0.694	0.922
Apparent sucrose content (%)	0.194	3.30	1.96	1.79	2.07	1.64	1.27	0.311	$y = 2.05$	-	-	0.496	0.729

DAS: days after sowing; R^2: coefficient of determination; L: linear equation; Q: quadratic equation; p-value: probability of significant effect; SEM: standard error of the mean; y: dependent variable; x: increasing doses of vinasse (0, 50, 100, 150, and 200 m^3 ha^{-1}).

via irrigation; therefore, these factors explain the standardized morphological development among the tillers at the end of the production cycle (69 and 90 days after sowing).

The use of the plant regulator slowed down the reproductive process, as panicle emission was not observed; however, despite the product used influencing the maturation process, no effect was observed as to forage biomass reduction when the sweet sorghum was harvested belatedly (90 days after sowing). Thus, it is possible to infer that the organ expansion process was not influenced by the plant regulator. In this way, older sweet sorghum plants, even when presenting a standardized morphological development in relation to young plants, develop tillers with a higher specific weight.

Supplying nutrients by increasing doses of vinasse promotes significant increases in forage biomass, that is, the application of this biofertilizer in moderate doses can boost the primary production of grasses grown in regions with soils devoid of natural nutrient reserves. In other grasses used as an alternative source of bioenergy, such as sugarcane, using vinasse as a nutritional source of N-P-K, in association with irrigation in times of low rainfall, potentiates stem production (Barbosa et al., 2012; Barbosa et al., 2013).

In other crops of agronomic and commercial interest, vinasse also positively increases primary production; the use of this biofertilizer in a cooking banana (*Musa acuminata* × *Musa balbisiana* hybrid) crop increased production by up to 17% (Berilli et al., 2022).

The plant regulator did not favor increases in juice production 90 days after sowing; this event may be related to the natural tissue flow process, leading to a greater accumulation of fibrous material and lignin polymers in the aerial part of the sorghum plant at a more advanced stage of maturation, thus reducing the moisture fraction of the fresh biomass (Oliveira et al., 2020; Souza et al., 2019).

When sweet sorghum plants were harvested 69 days after sowing, a fiber content close to the recommended level (10%) was generated, which may favor greater sucrose extraction (Barbosa et al., 2012).

The values obtained for the soluble solids content of sweet sorghum using increasing vinasse doses are within the expected range (13%; Regassa & Wortmann, 2014). The other quality parameters for sweet sorghum juice (purity and apparent sucrose content) present inadequate values for the industry, as they are lower when compared to sugarcane cultivars (Masson et al., 2015).

Although using vinasse does not promote juice production with the quality required by the industry, its use in sweet sorghum crops cannot be disregarded because increasing doses of this biofertilizer favor satisfactory biomass production, as observed by Lucena et al. (2018). For the *Cerrado* region, it is necessary to verify the effect of vinasse on other sweet sorghum cultivars during the rainy season, when there is a greater supply of natural hydric resources and an adequate temperature for the maximum development potential of C4 plants.

5 CONCLUSION

Regardless of harvest time, using vinasse in increasing doses promotes expressive increases in the production of sweet sorghum biomass. On the contrary, no positive effects on juice quality have been verified.

Although the flowering regulator inhibited panicle production, it did not lead to increases in juice production 90 days after sowing.

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