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WATER RETENTION AND PORE SIZE DISTRIBUTION IN SOILS CULTIVATED WITH SUGARCANE COMPARED TO A PERMANENT PRESERVATION AREA[1]

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1 ABSTRACT

The soil structural condition, cultivated with sugarcane, is related to the type of harvest adopted which influences the soil porosity, an important variable in the circulation of the liquid and gaseous phases of the soil. These phases can be directly affected by soil management and cultivation, where mechanized raw sugarcane harvesting can improve them. Thus, this research aimed to evaluate soil porosity (P) and its pore size distribution (PSD) in classes, as well as the soil water content at field capacity (θfc), cultivated with sugarcane under two harvest methods: raw and burnt sugarcane. Thus, three areas were compared: two under different ways of harvesting sugarcane (with and without burning); and one in a native forest as a reference. P, PSD (macro, meso, and microporosity), and θfc were determined in soil samples collected in volumetric cylinders, by the saturation and tension table methods, respectively. The results point out that the soil under native forest presented the highest values for the evaluated attributes, indicating that sugarcane cultivation, with or without burning, reduces them. Burning promoted negative changes in the soil concerning water conduction and soil aeration, even in a recent cultivation area (five years), promoted by the reduction of θfc (-62.09%), mainly reflecting the decrease in macroporosity (-31.73%) and microporosity (-24.48%).

Keywords: burned sugarcane, raw sugarcane, sandy soil, field capacity, native forest.

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RETENÇÃO DE ÁGUA E DISTRIBUIÇÃO DE TAMANHO DE POROS EM SOLOS CULTIVADOS COM CANA-DE-AÇÚCAR EM COMPARAÇÃO COM ÁREA DE PRESERVAÇÃO PERMANENTE

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2 RESUMO

A condição estrutural do solo, cultivado com cana-de-açúcar, está relacionada com o tipo de colheita adotado, o qual influencia a porosidade do solo, uma importante variável de circulação das fases líquida e gasosa do solo. Estas fases podem ser afetadas diretamente pelo manejo e cultivo do solo, onde a colheita mecanizada da cana-de-açúcar crua pode melhorá-las. Assim, esta pesquisa objetivou avaliar a porosidade do solo (P) e sua distribuição de tamanho de poros (PSD), bem como o conteúdo de água na capacidade de campo (θfc) do solo cultivado com cana-de-açúcar sob dois métodos de colheita: crua e queimada. Desse modo, foram comparadas três áreas: duas sob diferentes formas de colheita de cana (com e sem queima); e uma em mata nativa, como referência. A P, PSD (macro, meso e microporosidade) e θfc foram determinadas nas amostras coletadas em cilindros volumétricos, utilizando-se os métodos da saturação e da mesa de tensão, respectivamente. Os resultados comprovam que o solo sob mata nativa apresentou os maiores valores para os atributos avaliados, comprovando que o cultivo da cana-de-açúcar, com ou sem queima, reduz os valores desses atributos. A queima promoveu mudanças negativas no solo em relação à condução hídrica e aeração do solo, mesmo em área de cultivo recente (cinco anos), promovidas pela redução da θfc (-62,09%), refletindo, principalmente na diminuição da macroporosidade (-31,73%) e microporosidade (-24,48%).

Palavras-chave: cana queimada, cana crua, solo arenoso, capacidade de campo, floresta nativa.

3 INTRODUCTION

The importance of sugarcane (*Saccharum* spp.) cultivation is due Brazil is the world’s largest producer which is the third-largest crop in planted area, with 8.3 million hectares, and the state of Pernambuco has the seventh-largest area under this crop (Cana-de-açúcar, 2023). At the national level, 92.4% of sugarcane is already harvested mechanically; however, manual harvesting predominates in more than 96% of the areas in Pernambuco (Cana-de-açúcar, 2023).

Regarding the sugarcane harvesting system, Galdos, Cerri and Cerri (2009) comment that there is a global trend towards replacing the burned harvest system with mechanized unburned. This replacement provides environmental benefits as the burned sugarcane harvesting system emits CO_2 into the atmosphere while the unburned sugarcane system leaves residue from the sugarcane straw to be incorporated into the soil. On the other hand, according to Moitinho *et al.* (2021), sugarcane field burning before manual harvesting is a common management practice in Brazil and worldwide, aiming at reducing the amount of straw and hence facilitating cutting operations and mechanical loading.

Arcoverde *et al.* (2023) comment that studies intending to propose conservation practices of soil management in different edaphoclimatic environments for sugarcane production are essential for the sustainability of these systems, mainly in environments with soil under physical and/or chemical restrictions and under water deficit in periods of the year. In this context, discussions about the system of sugarcane harvest and their environmental impacts have stimulated research that compares the effects of the burning of the sugarcane field before manual cutting and mechanized cutting, carried out on raw sugarcane (Castioni *et al.*, 2018; Kumar *et al.*, 2020). In fact, when the soil reaches a temperature of 270 °C, water repellency in the pores tends to increase, reaching maximum values at temperatures above 300 °C (Arcenegui; Jiménez-Morillo; Jiménez-Pinilla, 2019).

The opposite is observed concerning the indices that evaluate the structural condition of the soil, where the weighted mean diameter and the stability of aggregates in water, as well as organic matter, decrease with increasing temperature (Badía; Marti, 2019). The multiple benefits of straw incorporated or left on the soil surface include amelioration of soil water retention resulting in improved soil structure (Siedt *et al.*, 2021).

Soil pores are spaces for the circulation of water and air, which are distributed in different diameters, being associated with their origins and functions in the soil. Pores with larger diameters allow water movement, and smaller ones retain (Kutílek, 2004) which are relevant for irrigation efficiency. However, pores are subject to changes due to the type of management (plowing, harrowing, or direct-planting system), which can alter soil structure and pore size distribution, reducing them and, consequently, making difficult water entry and circulation (Lipiec *et al.*, 2006).

The soil available water storage capacity is directly linked to the rearrangement of the pore size distribution. Any change in both soil field capacity and the permanent wilting point of the soil directly affect its available water storage capacity (AWC). Braida *et al.* (2010), studying areas under direct seeding compared to areas under conventional tillage, comment on two contradictory effects of the accumulation of organic matter (OM) on soil compression resistance: the increase in the binding strength between mineral particles; and the change in particle arrangement, i.e. total porosity (P) and bulk density (Bd). According to these authors, when the effects of reducing Bd by increasing P predominate, compressive resistance decreases, making the soil more susceptible to compaction, as also verified by Pereira, Fossez and Richard (2007). On the other hand, when Bd is reduced due to the dilution effect (lighter organic particles homogenized with heavier mineral particles), or due to the effect of increasing soil elasticity, OM will increase the soil compression resistance, and consequently, compaction resistance.

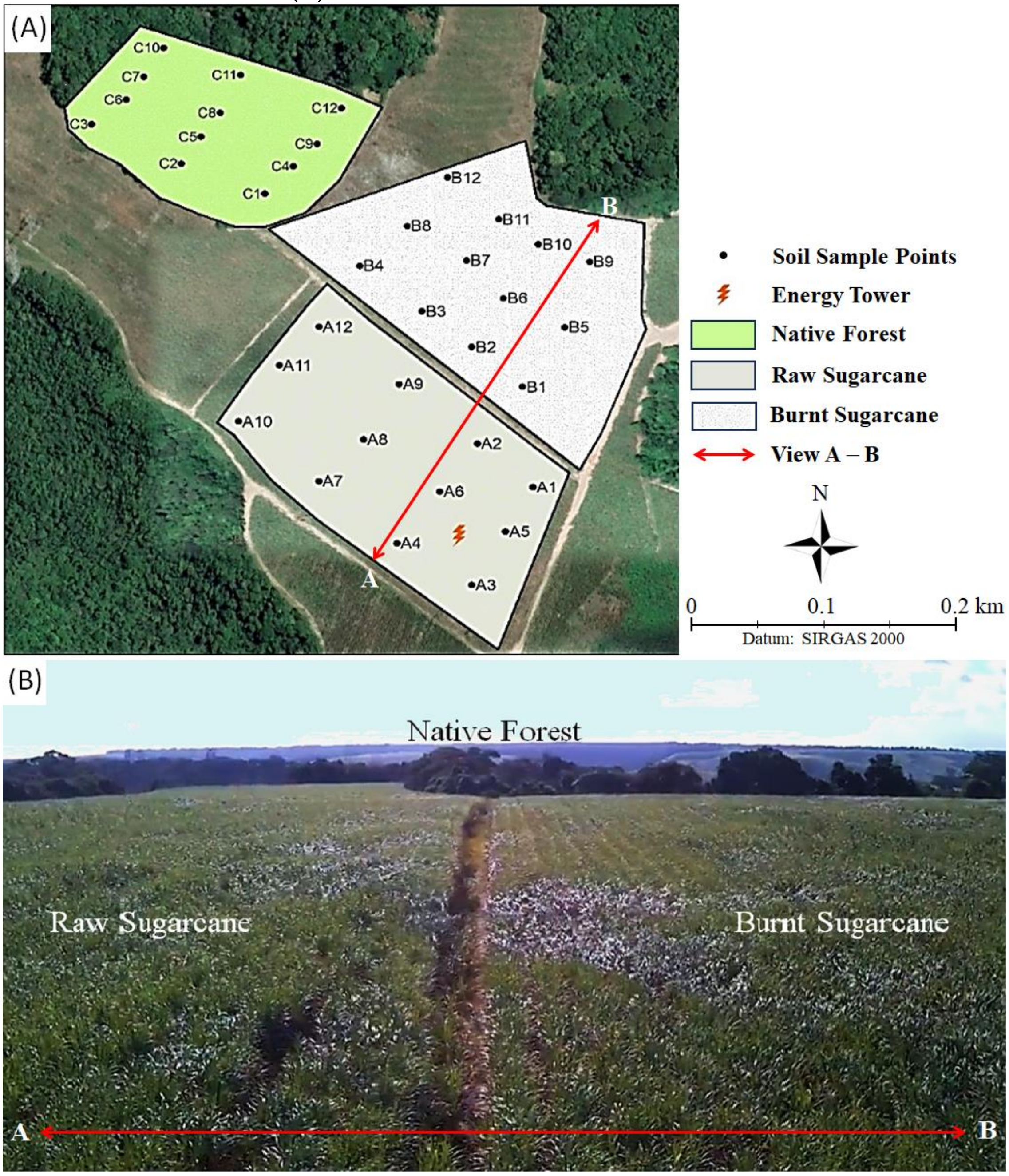
Decision-making on straw management in sugarcane production involves economic, agronomic, environmental, and logistic aspects, and should be guided in each region, based on the culture and soil responses to the removal of straw, according to the local specific characteristics of soil, climate, and culture management (Castioni *et al.*, 2019).

Some types of soil management can lead to structural alterations that reduce the water retention capacity (Centurion *et al.*, 2007; Gonzaga *et al.*, 2019), and negatively affect the soil water availability. As a result, it is necessary to better understand the impacts of harvest methods on the soil's structural condition, seeking bases for more sustainable agriculture. Given to above, this research aimed to evaluate soil porosity and its distribution in pore size classes, as well as soil water content at field capacity, cultivated with sugarcane under two harvest methods: raw and burnt sugarcane.

4 MATERIAL AND METHODS

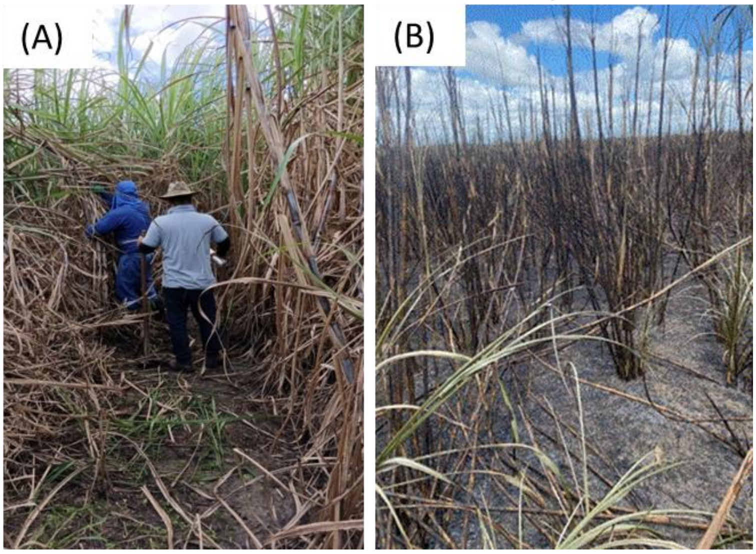
The experimental area belongs to São José Agroindustrial Company, located in the municipality of Igarassu, in the metropolitan region of Recife, Pernambuco. The experimental area was divided into three sub-areas (≈10 ha) represented by: two sub-areas under sugarcane cultivation with distinct harvesting methods (burnt and raw); and a third area under preserved forest, as a reference (Figure 1).

Figure 1. Upper view of the experimental area with soil sample points (A) and perspective view of the three areas (B).



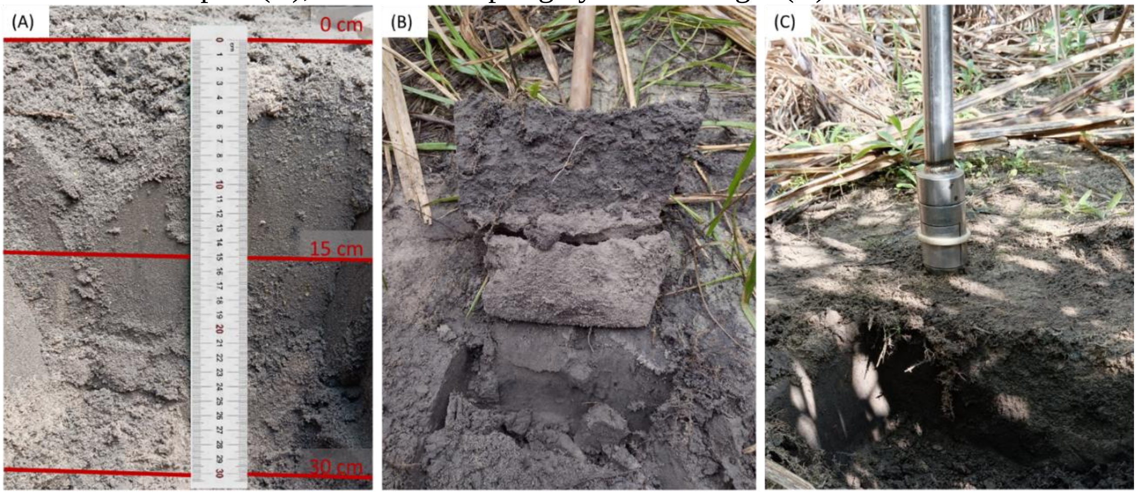
The sugarcane cultivation areas (with and without burning) have been in use for about five years in Argissolo Vermelho-Amarelo distrófico (Santos *et al.*, 2018), but with a sandy loam texture on the surface. During sugarcane harvesting, it was noticeable that in the area without burning (Figure 2A) the amount of residual straw was higher than in the area under burning (Figure 2B). The average productivity in the studied area is 99 t ha^{-1}.

Figure 2. Sugarcane field at harvest time: A) without burning; B) with burning.



Soil samples were collected at depths of 0.0 – 0.15 m and 0.15 – 0.30 m (Figure 3A) and divided into disturbed (Figure 3B) and undisturbed (Figure 3C). The granulometric analysis and clay dispersed in water were performed in disturbed soil samples using the densimeter method with modifications (Almeida, 2008; Gee; Or, 2002). To evaluate the total soil porosity and pore size distribution, undisturbed soil samples were collected at 0-20 cm depth by steel cores (≈ 100 cm^3), with 6 repetitions per point, totaling 72 cores sample per treatment. The total porosity tests were carried out by the saturation method, and pore size distribution was evaluated using the tension table method to assess macro, meso, and microporosity.

Figure 3. Trench for soil collection (0-0.15 m and 0.15-0.30 m) (A); collection of undisturbed soil samples (B); soil core sampling by Uhland auger (C).



The determination of these pore classes followed the methodology of Almeida et al. (2017a), using the universal capillarity equation (Equation 1). Thus, it was possible to define the retention energy (total water potential in the soil - Ψ) between 0 and 10 cwc for macroporosity, between 10 and 60 cwc for mesoporosity, and from 60 cwc to oven-dried soil (105 ºC) for microporosity. The soil water content retained at field capacity (θfc) was defined under equilibrium at 100 cwc, since the soils used (0-20 cm) have a sandy loam texture.

$$\Psi_{(cwm)} = \frac{1.5 \times 10^{-5}}{\text{Pore radius (m)}} \quad (1)$$

The soil bulk density (Bd, g cm^{-3}) was determined by the volumetric cylinder method (Almeida et al., 2017b), which is based on the relationship between the mass of oven-dried soil (g) contained in the volumetric cylinder and the soil volume (cm^3), represented by the volume of the cylinder ($\pi \times r^2 \times h$), according to equation (2).

$$Bd = \frac{\text{Mass of oven-dried soil}}{\text{Volume of soil}} \quad (2)$$

Data normalization, homoscedasticity, and heteroscedasticity were performed to conduct mean evaluation tests by the software XLSTAT, version 2022.5.1 (LUMIVERO, 2023). Once the normality of the data was confirmed, a Tukey test ($p>0.05$) was carried out to indicate the significance between soil physical attributes.

5 RESULTS AND DISCUSSION

The soil physical characterization showed that the sand fraction was dominant (Table 1). The soil texture was classified as sandy loam in both areas (burning and raw sugarcane). In the native forest area, the soil textural class is sandy clay loam, with greater clay activity, which is consistent with better total porosity conditions.

Table 1. Soil physical characterization in the three areas studied.

Area	Sand	Silt	Clay	WDC	DF	Bd
	g kg^{-1}				%	g cm^{-3}
Unburned	860.13A	15.85B	124.02B	107.40B	13.68B	1.67A
Burned	932.44A	27.35B	40.21C	20.20C	49.77A	1.70A
Native Forest	680.20B	66.73A	253.07A	198.44A	21.22B	1.39B

WDC = water dispersible clay; DF = degree of flocculation; Bd = soil bulk density. Means followed by the same letter in the column do not differ from each other by the Tukey test ($p \leq 5\%$).

The soil bulk density (Bd) values are within normal parameters for this soil category, as described by Brady and Weil (2017). In sandy soils under different types of management, Bd typically ranges from 1.20 to 1.80 g cm^{-3}. In the soil under native forest, the mean value Bd is lower (1.39 g cm^{-3}) than in the areas cultivated with sugarcane. On the other hand, when comparing the two cultivated areas each other, no statistical differences are observed, with the soil under burned sugarcane having a slightly higher absolute value (1.70 g cm^{-3}) compared to the unburned sugarcane area (1.67 g cm^{-3}). This absence of difference indicates that the burning practice before the harvest does not interfere significantly with the bulk density, especially in a short period of use, as is the case in this area (five years).

The soil under native forest showed the highest values for the physical-hydraulic soil attributes evaluated, confirming that sugarcane cultivation, with or without burning, reduces these attributes, with the worst structural condition observed in the area where the sugarcane harvesting method involves prior burning (Table 2). Thus, considering the native forest as a reference and comparing the areas under sugarcane, the area harvested after burning showed the lowest values for P and PSD, as well as the soil water content at field capacity (θ_{fc}), except for mesoporosity (9.50%), where harvesting of unburned sugarcane promoted a decrease in this pore class (8.63%).

Table 2. Physical-hydraulic soil attributes under native forest and different sugarcane harvest conditions, and their respective reductions compared to a permanent preservation area.

Attributes	**Native forest**	**Harvest**		**Reduction in comparison to the native forest**	
		Burnt	**Raw**	**Burnt**	**Raw**
	%				
P	45.66 A	36.56 C	38.16 B	19.93	16.43
Macroporosity	5.20 A	3.55 C	4.74 B	31.73	8.85
Mesoporosity	9.82 A	9.50 B	8.63 C	3.26	12.12
Microporosity	30.64 A	23.14 C	24.79 B	24.48	19.09
θ_{fc}	26.75 A	10.14 C	17.77 B	62.09	33.57

P = Total porosity; θ_{fc} = soil water content at field capacity. Means followed by the same letter in the row do not differ significantly according to Tukey's test at a 5% level.

Considering the pore size classification used in this research and that, in soils with sandy loam texture the water retention at field capacity occurs in micropores, we can verify that the value of θ_{fc} for the soil under native forest (26.75%) was extremely reduced due to cultivation, with a negative highlight for the area under burnt sugarcane, with 10.14% (a decrease of 62.09%), followed by the area under raw sugarcane, with 17.77% (a decrease of 33.57%). The water retention capacity is affected due to changes in field capacity, thus, in areas cultivated with sugarcane, where harvesting is done without burning, the straw left on the soil surface contributed to mitigating the impact of deforestation (Galdos; Cerri; Cerri, 2009). Therefore, the reduction in the micropore class of the sugarcane-cultivated areas (24.48% and 19.09%, burnt and raw, respectively), combined with the second-highest percentage loss in the macropore class (31.73% for burning), may have contributed to the lower values of θ_{fc} in these areas.

Therefore, the decrease in macroporosity provides structural changes in the soil and, consequently, decreases the aeration and the water retention capacity. Regarding mesoporosity, compared to the native forest, it was the only pore class where harvesting of raw sugarcane had a greater reduction (12.12%) than burnt sugarcane (3.26%). This fact was also observed by Cavalcanti *et al.* (2020), who found a 9% increase in mesoporosity in the raw sugarcane area and a 2% increase in the burnet sugarcane area compared to the native forest.

Similarly, the studies by Cherubin *et al.* (2016) and Canisares *et al.* (2019) support the results of this research (Table 2), demonstrating that the conversion of native vegetation areas into sugarcane fields, with and without burning, modifies the soil pore size distribution, reducing macroporosity and increasing the proportion of microporosity comparing to native forest, reaching almost 10% in both studies.

The effects of this redistribution among the pore classes may lead to a reduction in soil water conductivity and aeration, attributed to surface compaction, mainly at 0-20 cm depth, caused by mechanization and the reduction of larger pores, promoted by the increase in temperature during burning, which may have a significant impact on soil quality. In addition, the vegetation cover left after mechanized harvesting resulted in improved productivity levels, provided by organic matter left on the soil (Galdos; Cerri; Cerri, 2009; Moitinho *et al.*, 2021; Testa *et al.*, 2023). The soil compaction process can be avoided in sugarcane crops by adjusting machine loads and the soil preparation procedures, aiming to mitigate the reduction of soil pores size and maintaining high water conductivity (Guimarães Júnnyor *et al.*, 2019). The association of these good agricultural practices needs to be evaluated in terms of benefits for productivity and conservation of soil physical quality.

6 CONCLUSIONS

The total porosity of the soil can reach high values in areas under forest due to the organic and litter material, naturally present in this ecosystem. However, the cultivation of sugarcane provided to reduction in the total soil porosity, with changes in the pores size distribution. This reduction was most evident for soil field capacity (θ_{fc}), with a reduction of the original value (forest = 26.75%) to 10.14% and 17.77% in the areas under burned and unburned harvest, respectively, representing a reduction of 62.09% in the area under burning and 33.57% in the area with raw harvested sugarcane.

The reduction in the macropores and micropores classes of the soils under sugarcane may have contributed to the low θ_{fc} values, which can be attributed to the process of burning sugarcane for harvest, which altered the soil structural capacity and, consequently, the water availability in the area under burning.

This study shows that cultivating sugarcane harvested without burning has the potential to reduce the negative impact on water retention and circulation in deforested soil, due to several factors, such as local temperature and the presence of straw on the soil.

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