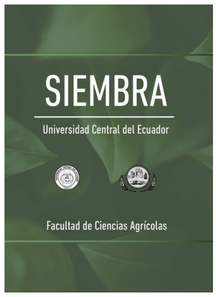
Quantification of soil loss due to runoff under two tillage methodologies in the production of sugarcane for the production of panela



Cuantificación de la pérdida de suelo por escorrentía bajo dos metodologías de labranza en la producción de caña de azúcar para la elaboración de panela

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Abstract

Soil degradation has as a direct consequence the loss of biodiversity, the emission of greenhouse gases and the imbalance of the hydrological water cycle, reducing the productive capacity of the soil and its response to amendments and conservation activities, generating low yields and greater water and nutritional requirements. Since these effects are already defined, it is necessary to know the amount of soil that can be lost in order to size the problem. The objective of the study was to quantify the erosion process in a soil under typical precipitation conditions in the Hoya del Río Suárez (Colombia) for the cultivation of sugar cane. For this purpose, an experiment was carried out evaluating two tillage systems (reduced and conventional) in closed runoff plots, where the amount of soil and water washed away in the rainfall events present in a sugarcane crop cycle for panela production was measured. Statistically significant differences ($p < 0.05$) were observed when the soil was prepared using the proposed system, reducing soil loss by 2.5 times due to runoff compared to traditional tillage, showing to mitigate soil deterioration.

Keywords: soil erosion, slope, precipitation.

Resumen

La degradación del suelo tiene como consecuencia directa la pérdida de la biodiversidad, la emisión de gases efecto invernadero y el desbalance del ciclo hidrológico del agua, reduciendo la capacidad productiva del suelo y la respuesta de este a las enmiendas y actividades de conservación, generando bajos rendimientos y mayores requerimientos hídricos y nutricionales. Dado que estos efectos ya están definidos, se requiere conocer la cantidad de suelo que se puede perder para dimensionar el problema. El objetivo del estudio fue cuantificar el proceso de erosión en un suelo bajo condiciones de precipitación típicas en la Hoya del río Suárez (Colombia) para el cultivo de caña de azúcar. Para esto se estableció un experimento evaluando dos sistemas de labranza (reducido y convencional) en parcelas de escorrentía cerradas, donde se midió la cantidad de suelo y agua arrastrados en los eventos de lluvia presentes en un ciclo del cultivo de caña de azúcar para la producción de panela. Se observó diferencias estadísticamente significativas ($p < 0,05$) cuando se prepara el suelo usando el sistema propuesto, disminuyendo en 2,5 la pérdida del suelo por efecto de la escorrentía comparado con el laboreo tradicional, evidenciando que puede ser una estrategia de mitigación del deterioro del suelo.

Palabras clave: erosión, pendiente, precipitación.

1. Introduction

Soil degradation by erosion refers to "the loss of the surface layer of the earth's crust by the action of water and/or wind, which is measured by humans and brings environmental, social, economic and cultural consequences" (Instituto de Hidrología, Meteorología y Estudios Ambientales [IDEAM], Ministerio de Ambiente y Desarrollo Sostenible [MADS], and Universidad de Ciencias Aplicadas y Ambientales [U.D.C.A.], 2015). Soil loss is mainly caused by water (water erosion) either by runoff and/or infiltration and wind action (wind erosion). Rainfall (frequency and intensity), slope (degree and length), type of vegetation, land use and management are the factors that favor water erosion (Montenegro González and Malagón Castro, 1990). However, when the soil has been disturbed (preparation of land for planting) and has a slope, soil loss due to water erosion can increase by five times compared to a fallow farmland with the same slope (Verhulst et al., 2010).

Soil losses can be estimated by modeling the phenomenon (indirect methods) using equations such as the universal soil loss equation [USLE] (Valdivia-Martínez et al., 2022), and by setting up experimental units in the field (direct methods) such as runoff plots and rainfall simulators (León Peláez, 2001). These methods (direct and indirect) have been compared with each other in different studies, such as experimental plots and the USLE method (Oyarzun Ortega, 1993) in Chile and in Mexico with the use of erosion stakes and the RUSLE methodology [revised USLE] (Pando Moreno et al., 2012), showing that the use of indirect methodologies overestimates water erosion values in the regions studied.

In Colombia, sugarcane production for the elaboration of panela is located in areas with mountain topography (Hoya del río Suárez region) and, together with the tillage that is carried out for the establishment of the crop, makes soils prone to erosion (Vargas Diaz et al., 2023). Although, the causes of soil erosion and its control are already well defined, however, it is critical to know the rates of soil loss (Food and Agriculture Organization of the United Nations [FAO], 2019). For this reason, it is important to be able to quantify soil losses due to water erosion in two tillage scenarios and under the precipitation conditions typical of sugarcane production for the production of panela in the Hoya del Río Suárez region.

2. Materials and Methods

The study was located in the department of Santander (municipality of Vélez) at an altitude of 1,518 m above sea level. The area has average rainfall ranges between 1,000 and 2,000 mm per year and average temperatures between 18° and 28 °C (Álvarez Contreras and Camacho Ariza, 2018). The experiment was carried out on a soil with Pachic Humudepts taxonomy, mountain landscape, on the structural slope of a crest in predominantly fine-grained sedimentary rock, the average slope of 12 % and the topographic slope of the experiment site correspond to the same slope. Main soil characteristics are shown in Table 1:

Table 1. Soil characteristics in the test performed in the department of Santander (municipality of Vélez).

Granulometry				**Density**		**WAD****	**Organic Matter**
Fraction %			**Class***	g cm^{-3}			
Sand	**Clay**	**Silt**		**True**	**Apparent**	mm	%
13,44	43,91	42,65	ArL	2,21	1,13	17,35	5,05

* silty clay; ** Weighted average diameter

The experimental design used was a one-factor fixed effects model with two treatments (Montgomery, 2004), where the factor evaluated is the method of preparation, or primary tillage of the soil, and the two treatments correspond to a reduced tillage alternative, where the soil is prepared only with a rigid chisel pass (T1) and the conventional preparation performed by the farmer, consisting of a rigid chisel pass and two passes of a smooth disk plow (T2). Evaluating three replicates for each of the treatments for a total of six closed runoff plots. Each of the plots has a confined area of 75 m^2 using removable artificial boundaries (constructed with galvanized iron sheet), and a water storage capacity of 1,250 liters (tank A: 250 L and tank B: 1,000 L) (Figure 1).

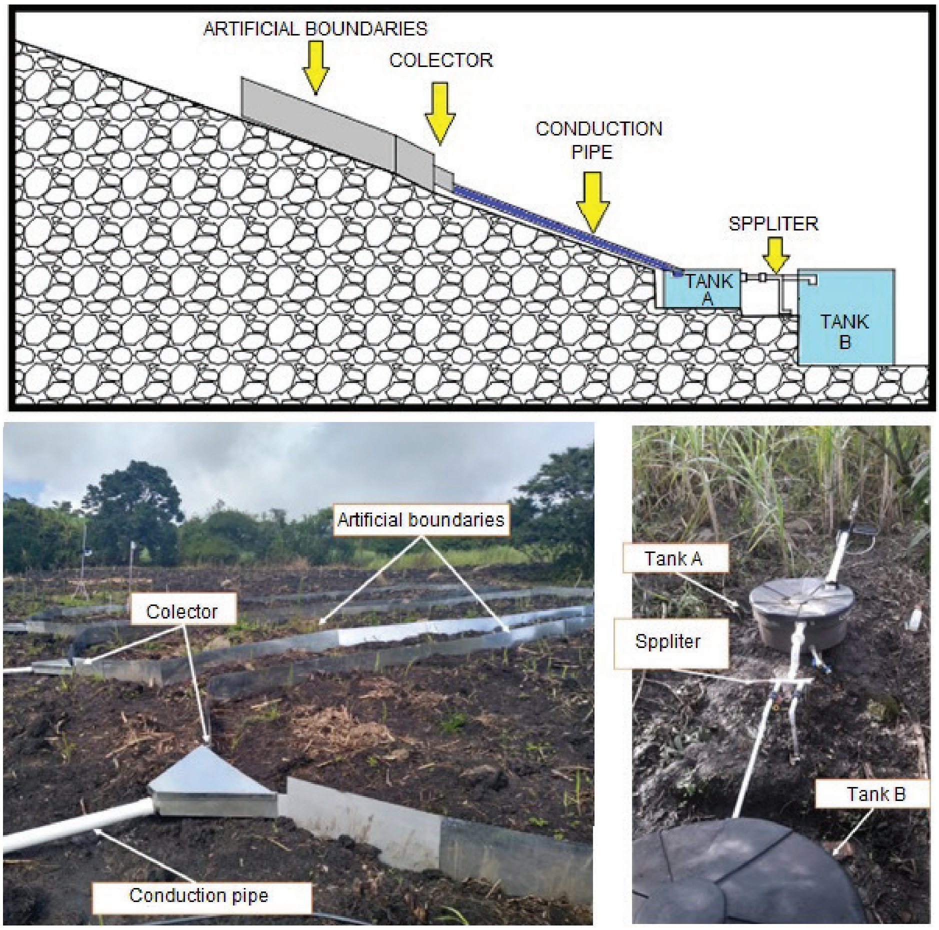

Figure 1. Layout scheme for runoff plots in the department of Santander (municipality of Vélez).

Rainfall characterization was performed by visualizing rainfall sheets and calculating the temporal rate of rainfall, or depth per unit time (mm h^{-1}) (rainfall intensity) (Chow et al., 1994). After one or more rainfall events, runoff water samples from each of the plots were collected together with the aggregates present in the hopper (Figure 2). These samples were taken to the laboratory where they were dried and the dry weight of the sediments and aggregates were estimated.

The study of the information was carried out using analysis of variance [ANOVA], to establish if there were differences in the treatments evaluated at the end of the cycle studied. Normality and equality of variance in the residuals were verified in the ANOVA model. The statistical software R® (R Core Team, 2020) was used for the analyses.

3. Results and discussion

During the evaluation period, we recorded maximum rainfall on March 16, 2021 with a rainfall total of 75.2 mm, followed by December 16th, 2019, with a value of 63.6 mm, and that recorded on October 12th, 2020 and November 4th with 49 mm and 47.4 mm, respectively. Likewise, two continuous rainfall periods were observed (Figure 3), the first one being between the end of April and the beginning of August. The second period was recorded from the end of August to December.

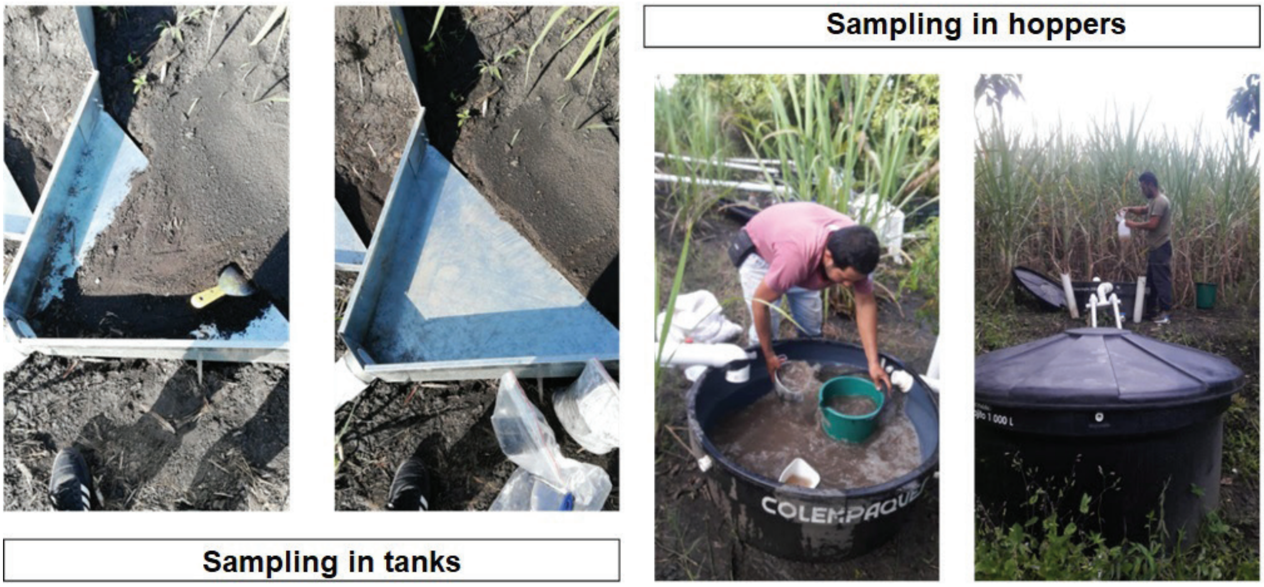

Figure 2. Sampling in the hoppers and tanks of the runoff plots in the department of Santander (municipality of Vélez).

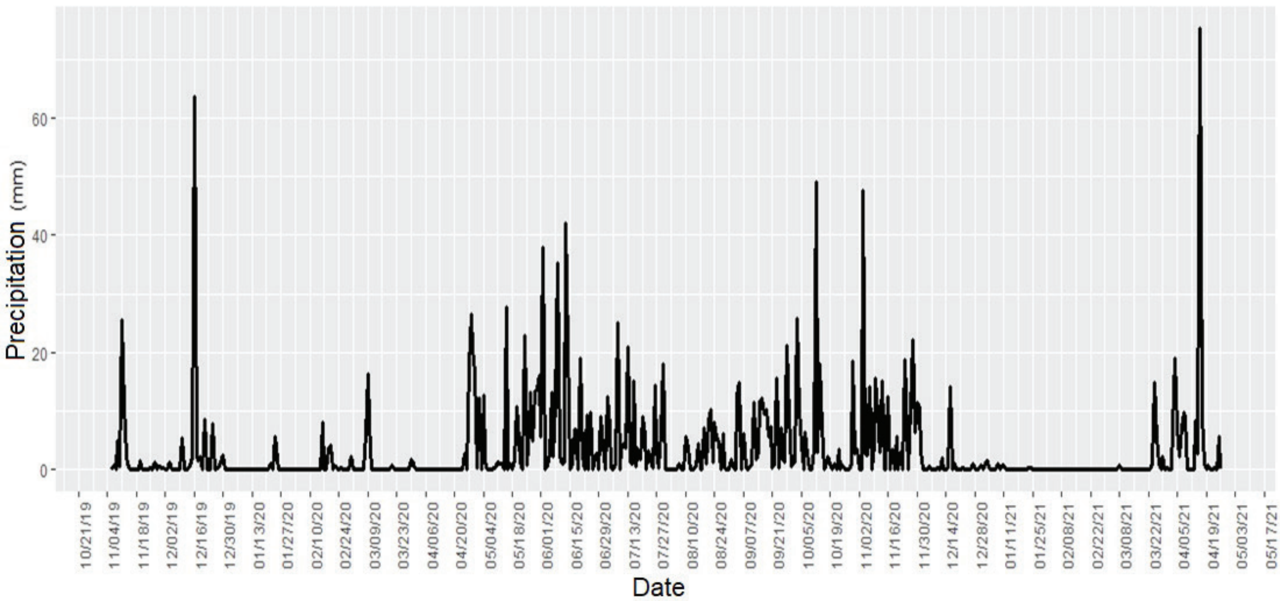

Figure 3. A Daily precipitation in mm from October 2019 to March 2021 in the department of Santander (municipality of Vélez).

We selected daily rainfall events greater than 12.5 mm (36 rainfall events). From the selected storms, a set of intensity-duration curves was obtained for the area (Figure 4A). We observed (Figure 4B) that the highest average intensities ranged between 20 and 40 mm h^{-1} when rainfall durations were less than 30 min.

The soil loss measurement cycle corresponded to 539 days (77 weeks) from October 7th, 2019 to March 29th, 2021. During this period, 45 monitoring activities were carried out in which runoff water samples were taken (Table 2).

Figure 5 shows that the total sediment loss [TSL] measured in the runoff plots showed a high correlation (> 0.8) with runoff water loss [RWL] in the evaluated treatments, indicating that the higher the RWL, the higher the TSL values increase. We observed a similar behaviour in the total accumulated sheet [TAS], where the positive correlation values within the two treatments showed that the more the water produced by precipitation, the higher the TSL and RWL values tend to increase.

Table 3 shows the total soil loss for each plot in each treatment, where T1 corresponds to the conservation tillage treatment (vertical tillage with one rigid chisel pass) and T2 corresponds to conventional tillage carried out by the farmer (one rigid chisel pass and two-disc plow passes). The average soil loss for a sugarcane

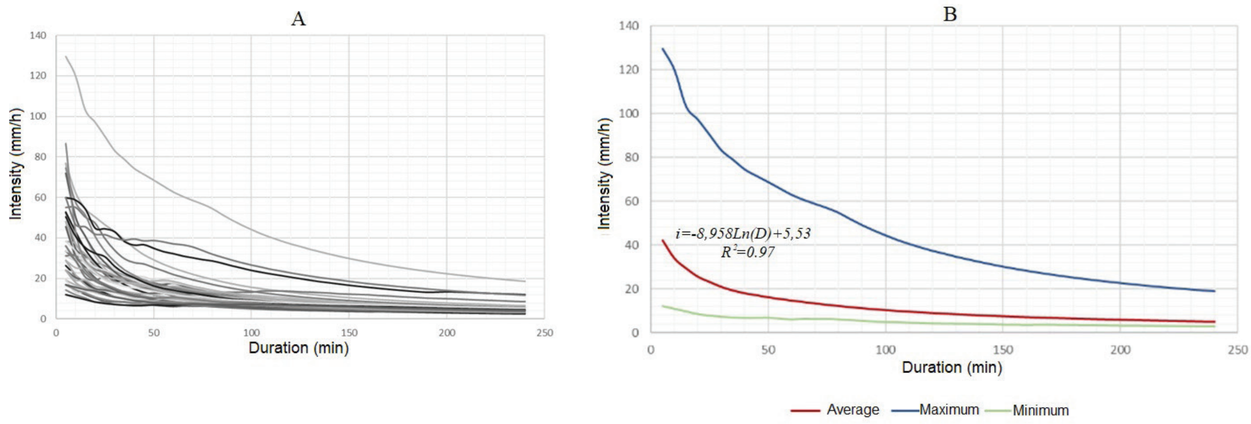

Figure 4. Intensity-duration curves for the 36 storms (A) and intensity-duration curve maximum, average and minimum (B).

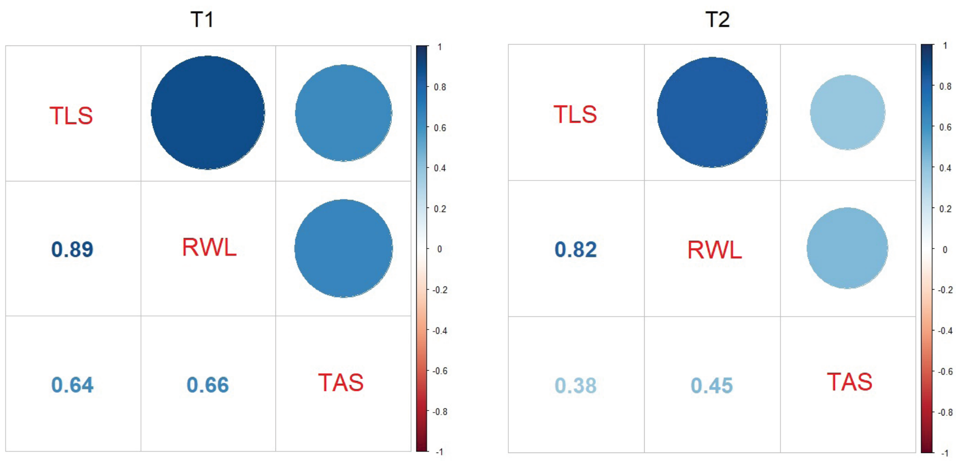

Figure 5. Pearson correlation for the variables: TSL (total soil loss), RWL (loss of runoff water) and TAS (total accumulated sheet).

Table 2. Number of sampling events carried out in the plots under evaluation.

Treatment	Plot	Nº sampling hoppers*	Nº sampling tanks**
	1	12	44
1	2	11	44
	3	17	44
	4	15	45
2	5	17	45
	6	24	43

* The number of samples corresponds to the events where material was found in the hoppers.
** The difference in the number of samples is due to failures in the piping system from the plots to the tanks, being 45 the total number of samples taken.

production cycle (18 months) under the traditional tillage treatment (T2) was 2.63±1.31 t ha^{-1} $cycle^{-1}$. On the other hand, for the conservation tillage treatment (T1), the average soil loss corresponded to 0.4±0.3 t ha^{-1} $cycle^{-1}$. The analysis of variance showed statistically significant differences ($p < 0.05$) among the evaluated treatments, indicating that the average soil loss can be reduced (by 2.5 times) using conservation tillage when sugarcane crops are established compared to conventional tillage.

In order to compare this soil loss rate with other studies, it is necessary to convert it to an annual rate. Given that the productive cycle corresponds to 18 months, the annual rate was estimated as 66.66% of the total measured in each plot. Therefore, an annual loss rate of 1.76 t ha^{-1} $year^{-1}$ was found for traditional tillage and 0.27 t ha^{-1} year-1 for conservation tillage. Comparing the soil loss rates obtained in the present study, with the

Table 3. Loss of soil and volume of runoff water by treatment. SD: standard deviation; annual soil loss corresponds to 66.66 % of the soil loss in the cycle. t: ton, ha: hectare, L: liters.

Treatment	Nº Plot	Soil loss cycle*		Annual soil loss	Runoff*	
		kg $ha^{-1}cycle^{-1}$	t $ha^{-1}cycle^{-1}$	t ha^{-1} yr^{-1}	L $ha^{-11}cycle^{-1}$	m^3 $ha^{-1}cycle^{-1}$
1	1	116,68	0,12	0,08	69.599,6	69,6
	2	377,79	0,38	0,25	374.362,0	374,4
	3	712,08	0,71	0,47	1.267.662,0	1.267,7
	Media	402,20 **a**	0,40	0,27	570.541,2	570,5 **a**
	SD	298,40	0,30	0,20	622.658,1	622,7
2	4	1.775,80	1,78	1,18	4.709.850,0	4709,9
	5	1.986,60	1,99	1,32	5.667.691,2	5.667,7
	6	4.139,51	4,14	2,76	2.344.316,5	2.344,3
	Media	2.633,9 **b**	2,63	1,76	4.240.619,2	4.240,6 **b**
	SD	1.308,1	1,31	0,87	1.710.654,3	1.710,7

* Average values with different letter are statistically different ($p < 0,05$).

tolerable soil loss rates that have been established in FAO (2019) according to the average soil formation rate, those found here are below these threshold values (2 t ha^{-1} yr^{-1}).

Comparing these soil loss rates with other studies in Colombia, such as the one conducted on sugarcane cultivation for panela in Cundinamarca, the values obtained in this work are lower than those recorded through the implementation of a rainfall simulator, which in crops with even-cutting and a topographic slope of 35 %, the annual soil loss estimated through the application of the USLE model was 27 t ha^{-1} yr^{-1} (Tauta Muñoz et al., 2018). Soil loss during the first year of development of a sugarcane crop on a soil with 9 % slope was 2.58 t ha^{-1} yr^{-1} (Youlton et al., 2016), values similar to those found in the present study.

Figure 6 shows the accumulated soil loss during the time of vegetative development of the crop, as well as the monthly precipitation during the same period. We can see from the graph that, during the entire productive cycle, the accumulated soil loss was greater for the treatment with traditional tillage (T2), reaching up to 2.5 times greater than the accumulated loss for the treatment with conservation tillage (T1).

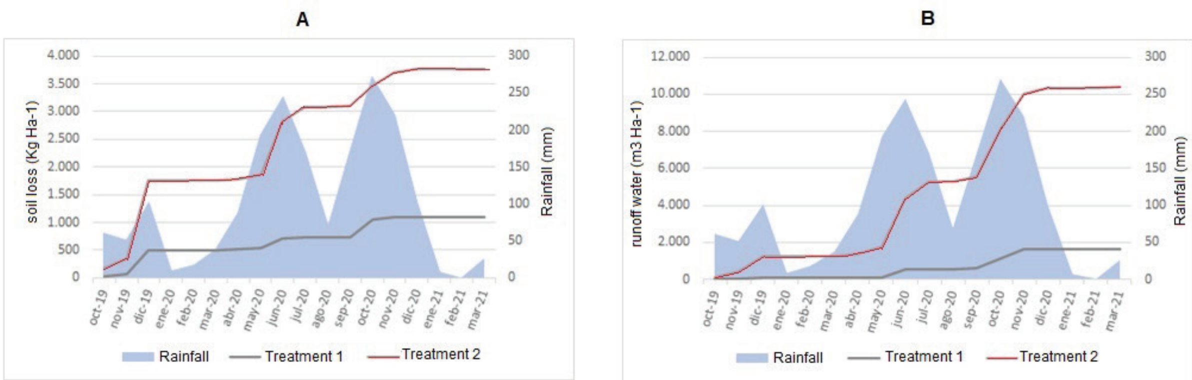

Figure 6. *Accumulated soil loss (A) and accumulated runoff water volume (B) during one canesugar crop cycle for panela production in the department of Santander (municipality of Vélez).*

Although the evaluated soil presented favorable conditions such as a very stable soil (WAD > 5 mm) (Gómez Giraldo, 2016) (Table 1), with high organic matter content (González Aguilar et al., 2021), and without limitations for the root development of crops due to compaction (bulk density < 1.5) (Roncallo et al., 2012), it is important to note that the months with the greatest soil loss were directly related to the periods of precipitation, with the greatest increase in accumulated soil loss (greater slope of each graph) during the first three months of crop development where the soil was without vegetative cover, just after planting the sugarcane. This behavior in the rate of soil loss reflects the influence of the cover (due to the closing of crop alleys and the fall of dry leaves) (Silva et al., 2012), indicating that, with the increase in vegetation cover, there is an exponential decrease in soil loss.

In the case of runoff (Figure 6), the same behavior described for soil loss was observed. The highest volumes of runoff water during the entire vegetative development period were recorded in the plots with the traditional tillage treatment (T2). In addition, the graph shows that the significant increases in accumulated runoff volume are directly related to the periods of precipitation during crop development. Finally, it is important to note that during the first 6 months of crop development, the accumulated runoff in the conservation tillage treatment (T1) is low (asymptotic behavior on the x-axis), which is expected given that tillage only with chisel forms small "ditches" in the soil that serve as "trenches" or "traps" for both runoff water and suspended sediments (Ortiz Cañavate, 2012).

4. Conclusions

Soil loss and water runoff volume can be reduced in the establishment of sugarcane crops for panela production in hillside areas, using reduced tillage techniques, and thus mitigating the impact of soil deterioration.

The period of greatest susceptibility to soil loss is after the soil preparation work, since it is exposed to the environmental conditions, therefore it is important to establish at this moment in time conservation measures and practices to reduce the effect of erosion.

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Contributor Roles

- Ruy Edeymar Vargas Diaz: investigation, data curation, formal analysis, visualization, writing – original draft, writing – review & editing.
- Viviana Marcela Varón Ramírez: conceptualization, investigation, methodology, validation, writing – review & editing.
- Jhon Mauricio Estupiñan Casallas: writing – review & editing.
- Juan Carlos Lesmes Suárez: data curation, writing – review & editing.
- Ayda Fernanda Barona Rodríguez: writing – review & editing.
- Clara Viviana Franco Florez: writing – review & editing.

Ethical Issues

Ethics approval Not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

Álvarez Contreras, D. L., & Camacho Ariza, E. J. (2018). *Evaluación de las condiciones ambientales por el cambio en la dinámica de los cultivos de Guayaba en la provincia sur de Vélez, Santander.* Universidad Francisco José de Caldas. http://hdl.handle.net/11349/15396

Chow, V. T., Maidment, D. R., & Mays, L. W. (1994). *Hidrología aplicada*. Bogotá: McGraw Hill.

Food and Agriculture Organization of the United Nations [FAO]. (2019). *Soil erosion: The greatest challenge for sustainable soil management*. FAO. https://www.fao.org/documents/card/en?details=CA4395EN

Gómez Giraldo, J. C. (2016). *Manual de prácticas de campo y del laboratorio de suelos*. Servicio Nacional de Aprendizaje. https://repositorio.sena.edu.co/handle/11404/2785

González Aguilar, D., Colás Sánchez, A., Rodríguez López, O., Álvarez Vásquez, D., Gattorno Muñoz, S., & Chacón Iznaga, A. (2021). Variabilidad espacial de la materia orgánica de suelos cultivados con *Ipomea batatas* (l.) Lam. *Centro Agrícola*, *48*(2), 5-13. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0253-57852021000200005

Instituto de Hidrología, Meteorología y Estudios Ambientales [IDEAM], Ministerio de Ambiente y Desarrollo Sostenible [MADS], & Universidad de Ciencias Aplicadas y Ambientales [U.D.C.A.]. (2015). *Estudio nacional de la degradación de suelos por erosión en Colombia - 2015*. IDEAM. https://observatorio.epacartagena.gov.co/ftp-uploads/pub-estudio-nacional-degradacion-de-suelos-por-erosion.pdf

León Peláez, J. D. (2001). *Estudio y control de la erosión hídrica*. Universidad Nacional de Colombia. https://repositorio.unal.edu.co/handle/unal/20071

Montenegro González, H., & Malagón Castro, D. (1990). *Propiedades físicas de los suelos*. Instituto Geográfico Agustín Codazzi [IGAC].

Montgomery, D. C. (2004). *Diseño y análisis de experimentos*. Limusa Wiley.

Ortiz Cañavate, J. (2012). *Las máquinas agrícolas y su aplicación* (2ª ed.). Mundi-Prensa Libros.

Oyarzun Ortega, C. E. (1993). Evaluación del modelo USLE para predecir pérdidas de suelo en áreas forestadas de la cuenca del río Bío-Bío. *Bosque*, *14*(1). https://doi.org/10.4206/bosque.1993.v14n1-06

Pando Moreno, M., Gutiérrez Gutiérrez, M., Maldonado Hernández, A., Palacio Prieto, J. L., & Estrada Castillón, A. E. (2012). Comparación de métodos en la estimación de erosión hídrica. *Investigaciones Geográficas*, (51), 23-36. https://doi.org/10.14350/rig.30412

R Core Team. (2020). R: *A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Roncallo, B., Murillo, J., Bonilla, R., & Barros, J. (2012). Evolución de las propiedades del suelo en un arreglo agrosilvopastoril basado en Ceiba roja (*Pachira quinata* (Jacq.) W.S Alverson). *Ciencia y Tecnología Agropecuaria*, *13*(2),167-178. https://doi.org/10.21930/rcta.vol13_num2_art:252

Silva, G. R. V. da, Souza, Z. M. de, Martins Filho, M. V., Barbosa, R. S., & Souza, G. S. de. (2012). Soil, water and nutrient losses by interrill erosion from green cane cultivation. *Revista Brasileira de Ciência Do Solo*, *36*(3), 963-970. https://doi.org/10.1590/s0100-06832012000300026

Tauta Muñoz, J. L., Camacho-Tamayo, J. H., & Rodríguez Borray, G. A. (2018). Estimación de erosión potencial bajo dos sistemas de corte de caña panelera utilizando la ecuación universal de pérdida de suelos. *Revista U.D.C.A Actualidad & Divulgación Científica*, *21*(2), 405-413. https://doi.org/10.31910/rudca.v21.n2.2018.1074

Valdivia-Martínez, O., Peña-Uribe, G. de J., Rufino-Rodríguez, F., Torres-González, J. A., Meraz-Jiménez, A. de J., & López-Santos, A. (2022). Ajuste de la ecuación universal de pérdida de suelo en parcelas de escurrimiento ubicadas en una región del centro de México. *Terra Latinoamericana*, *40*, e990. https://doi.org/10.28940/terra.v40i0.990

Vargas Diaz, R. E., Galindo Pacheco, J. R., Giraldo Henao, R., Varón Ramírez, V. M., Wilches Ortiz, W. A., & Franco Florez, C. V. (2023). Metodologías de interpolación y predicción espacial para el análisis de las propiedades físicas del suelo en la hoya del río Suárez (Colombia). *Siembra*, *10*(1), e4118. https://doi.org/10.29166/siembra.v10i1.4118

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P. C., Chocobar, A., Deckers, J., & Sayre, K. D. (2010). Conservation agriculture, improving soil quality for sustainable production systems? In R. Lal, & B. A.Stewart (eds.). *Food Security and Soil Quality* (1st ed.). CRC Press. https://doi.org/10.1201/EBK1439800577

Youlton, C., Bragion, A. P., & Wendland, E. (2016). Experimental evaluation of sediment yield in the first year after replacement of pastures by sugarcane. *Ciencia e Investigación Agraria*, *43*(3), 374-383. https://doi.org/10.4067/s0718-16202016000300004