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Review article: Soil science

Soils erosion in pineapple (*Ananas comosus* L. Merr) producing areas

Erosión de suelos en áreas productoras de piña (*Ananas comosus* L. Merr)

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ARTICLE DATA

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ABSTRACT

Pineapple is the third most-produced tropical fruit worldwide; however, it is a crop that, due to its management, can lead to the generation and intensification of processes such as soil erosion. This paper presents a bibliographic review about the factors that influence erosion in soils dedicated to pineapple cultivation, addressing papers reported in the international literature, subsequently positioning it in the context of the main producing municipalities presented in the Valle del Cauca region. The available research covers the last four decades, where losses are estimated between 35 and 178t $ha^{-1}year^{-1}$; the topography, the conditions of the access roads, some management practices, and edaphic properties related to erodibility stand out among the most critical factors. Finally, based on the climatic, edaphological, and topographic traits reported in the literature for the main pineapple producing region of Valle del Cauca, and considering current management practices, it is found that this area can present very high erosion values since the soils are susceptible, and the slopes are steep, some of them even higher than 70%. Therefore, it is suggested to carry out more research to determine the erodibility and erosivity of these areas to know the potential degradation index, which will function as a valuable tool for decision-making, the generation of management, and conservation recommendations of these soils.

Keywords: Agricultural practices; slope; soil conservation; soil degradation; USLE.

RESUMEN

La piña es la tercera fruta tropical más producida a nivel mundial, sin embargo, es un cultivo que puede conllevar a la generación e intensificación de procesos como la erosión del suelo, debido a su forma de manejo. El artículo presenta una revisión bibliográfica acerca de los factores que inciden en la erosión en suelos dedicados al cultivo de la piña, abordando artículos reportados en la literatura internacional, posteriormente posicionándolo en el contexto de los principales municipios productores presentes en la región del Valle del Cauca. Las investigaciones disponibles abarcan las últimas cuatro décadas, donde se estimaron pérdidas entre 35 y 178ton. ha^{-1}. $año^{-1}$; la topografía, las condiciones de las vías de acceso, algunas prácticas de manejo, así como propiedades edáficas relacionadas con la erodabilidad se destacan entre los factores más importantes. Finalmente, a partir de las características climáticas, edafológicas y topográficas reportadas en literatura para los principales municipios productores de piña del Valle del Cauca, y considerando las actuales prácticas de manejo, se encuentra que esta zona puede presentar valores muy altos de erosión, ya que los suelos son susceptibles, y las pendientes son pronunciadas, algunas de ellas incluso superiores al 70%. Por lo tanto, se sugiere realizar más investigaciones que permitan determinar la erodabilidad y la erosividad de esas áreas, para conocer el índice de degradación potencial, que funcionará como una valiosa herramienta para la toma de decisiones, la generación de recomendaciones de manejo y conservación de estos suelos.

Palabras clave: Conservación del suelo; degradación del suelo; pendientes; prácticas agrícolas; USLE.

INTRODUCTION

Soil is an essential resource for food and climate security around the world, and its main threat since the beginning of agriculture has been erosion (Amundson *et al*., 2015), which represents the most visible effect of soil degradation (Lugo-Morin & Rey, 2009; Sampietro-Vattuone *et al*., 2019). Erosion consists of the accelerated removal of the upper layer of the same through water influence and wind or farming practices (FAO & ITPS, 2015a). Annually, it represents between 25 to 40 billion kg of the lost soil resource, which in projections towards 2050 will mean losses close to 1.5 million km^2 (FAO, 2015b). Additionally, this phenomenon generates average losses of 0.3% of annual crop yield globally (FAO & ITPS, 2015a).

On the other hand, approximately 48% of soils in Colombia have been degraded (IDEAM & U.D.C.A, 2015). As an illustration, anthropic erosion have been reported in different production systems, such as potato crops in the municipality of Pasto, with losses of 6.12t $ha^{-1}year^{-1}$ (Alvarado *et al.*, 2011); conventional coffee (1.14 t $ha^{-1}year^{-1}$) and blackberry in the region of Huila (0.99t $ha^{-1}year^{-1}$) (Agudelo *et al*., 2015), coffee in municipalities such as Buenavista, Calarca, Cordoba, Genova, and Pijao (26 – 100t $ha^{-1}year^{-1}$) (Castro *et al*., 2017), and coffee (1.4 – 2.4kg/ha) and bean (1.9 – 3.1kg/ha) in Dagua (Alarcon & Reyes, 2013).

However, soil loss varies according to developed agricultural systems, such as crop cover, which reduces soil erosion, especially on steep slopes (Loch, 2000; Huerta *et al*., 2018). Management practices and climatic and edaphic conditions also contribute to this purpose.

The hillside soils of the western region of Valle del Cauca are susceptible to erosion (Tafur, 2006; Alarcón & Reyes, 2013), where processes are favored not only by topographical and climatic conditions but also by the scarce vegetation cover during the first months of pineapple growth, and the incorrect agricultural practices applied.

In this regard, this review aims to address this agricultural culture by showing and analyzing the crucial factors that bring on the erosion of soils in the major pineapple-producing municipalities in the region of Valle del Cauca.

Generalities, importance, and distribution of pineapple (*Ananas comosus* L. Merr). Pineapple, whose scientific name is *Ananas comosus* L. Merr is an essential contribution of pre-Colombian culture to agriculture (Delgado & Arango, 2015), as it is one of the most prominent tropical fruits worldwide (Zhang *et al.*, 2014). It is grown and consumed on all continents, named after the queen of colonial fruits due to its pleasant characteristics of smell, taste, and appearance (Crestani *et al.*, 2010).

Such characteristic components have led to the growth of this fruit in the market, increasing its demand and generating competitive prices (Martínez *et al.*, 2012; Abu Bakar *et al.*, 2013). On the other hand, this growth in recent years has been associated with a customer increase in income and a change in consumer preferences towards a healthy life based on an adequate diet and nutrition (Altendorf, 2017). Therefore, it is expected that the scenario will continue to increase in terms of production in the coming years (PTP *et al.*, 2013).

It has been noted that this crop ranks third place among the most produced tropical fruits worldwide, after bananas and citrus fruits (Hassan & Othman, 2011; El-Ramady *et al.*, 2015; Oculi *et al.*, 2020). In this regard, the major pineapple-producing countries are Costa Rica (3056.45mt), Philippines (2671.71mt), Brazil (2253.90mt), Thailand (2153.18mt), and India (1891.00mt) (FAO, 2022). In terms of representation, Costa Rica contributes 10.62% of total production worldwide, while in second and third place are the Philippines and Brazil with 9.4% and 9.3%, respectively (FAO, 2019).

Production is mainly associated with tropical countries; however, it is widely cultivated in South America and consumed fresh or processed in various food products, as shown in Figure 1.

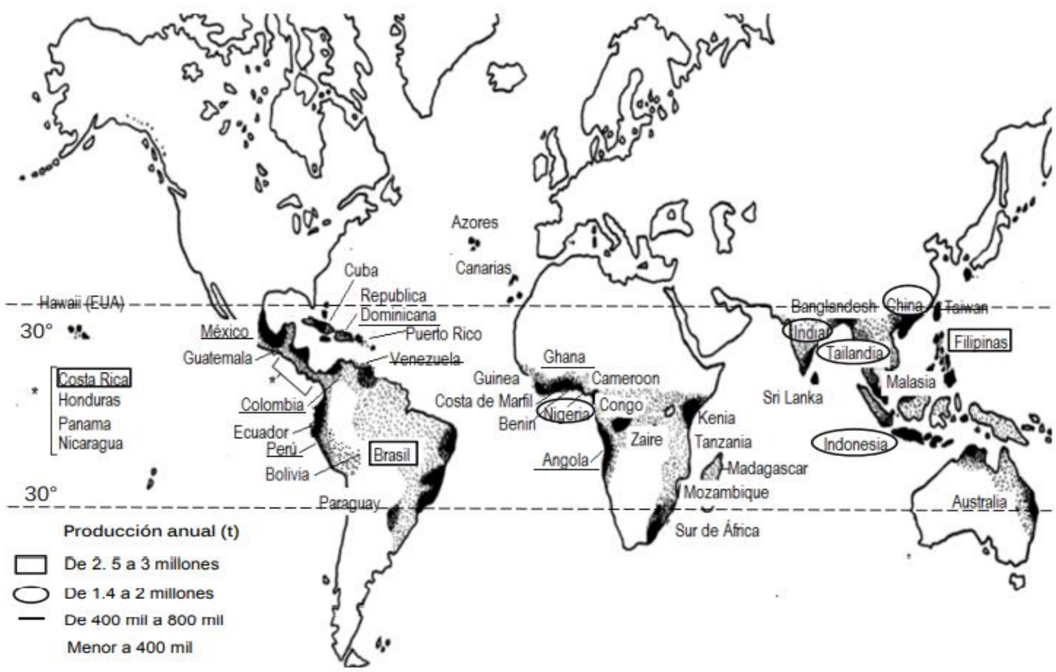

Figure 1. Main pineapple-producing countries. Source: Uriza *et al.* (2018).

However, Belgium, Netherlands, Germany, Japan, the United Kingdom, Italy, Spain, and the United States are reported as the primary consumers of this fruit, which demand about a quarter of the total production (PTP *et al*., 2013), also used in different presentations, such as fresh fruit, canned pineapple or pineapple juice.

In Colombia, during the period 2014 to 2018, production increased at an annual rate of 12%, where Santander, Valle del Cauca, and Meta recorded the highest participation. In this sense, Santander ranked first with a production of 455.701t and Valle second with 145.162t, values representing 43% and 14% participation of each of the two regions, respectively (Asohofrucol, 2018; Figure 2).

At the level of Valle del Cauca, the leading pineapple producer in hillside areas during 2018 was the municipality of Dagua, which yielded 46.680t in 1.270ha. Next, Restrepo with 35.700 t in 650ha, Vijes with 14.400t in 421ha, and La Cumbre with 14.179t in 178ha (AGRONET, 2019).

Factors influencing soil loss in pineapple cultivation. A starting point for addressing the factors that influence soil loss dedicated to pineapple cultivation is to consider the Universal Soil Loss Equation factors, known by its acronym in English as the USLE. This equation was proposed by Wischmeier & Smith (1978) and represents one of the most widely used approaches during an 80-year history of erosion modeling and has been widely accepted and employed in different researches conducted in 109 countries (Alewell *et al*., 2019).

The equation proposes that annual soil losses are influenced by the erosion or aggressiveness of rain (R), soil erodibility or susceptibility to detachment (K), topographic factor (LS), coverage factor (C), and soil conservation practices (P).

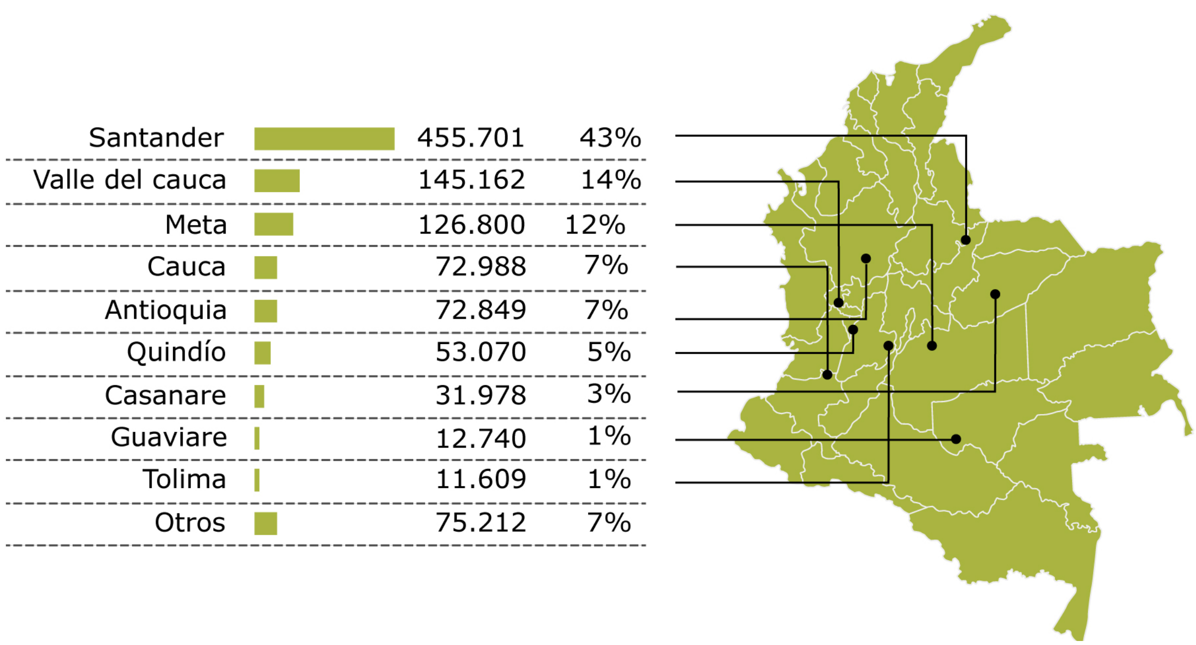

Figure 2. Main pineapple-producing areas in Colombia. Source: (Asohofrucol, 2018).

Although this equation has been applied in a large number of researches in different crops at an international level, the information on erosive processes in pineapple cultivation is still very scarce, especially at the planting level; therefore, the results reported in this regard are diverse for the different regions that have been studied (Afandi & Novpriansyah, 2020).

The following are the primarily reported researches on the erosion of pineapple cultivation, which have been carried out over the past four decades, and are presented chronologically.

Valentin & Roose (1980) developed research on the erosion of the soil cultivated with pineapple in the humid tropical area of Ivory Coast; they pointed out that the value of farming practices (P) was scant (0.002-0.070) in that area. In addition, they concluded that the main conservation problem did not come initially from pineapple fields but the drainage of roads and access roads.

El-Swaify *et al.* (1993), in the study "Problems of erosion and conservation needs in pineapple culture", highlight that the loss of soil in the Hawaiian pineapple lands reached 35t/ha/year and that this value was more significant than that presented in sugarcane fields. Such a problem may respond to the conditions of the access roads to the field since they are unpaved and the soil exposed during the tillage and the early growth stage of the crop.

Ciesiolka *et al*. (1995), in their study "Erosion and hydrology of the slopes under commercial production of pineapple", found that soil erosion of pineapples that are grown on steep slopes (up to 40%) in southeastern Queensland, Australia, was very high, reaching 178t ha^{-1}; however, soil erosion and runoff decreased in the second and third year after planting.

Wan & El-Swaify (1999) analyzed the effects of the plastic mulch on erosion and runoff in a Hawaiian pineapple field. They reported that, for all simulated storms, the plastic plot showed the highest runoff and soil erosion rates, while those values were lower on the plastic plot with pineapple crowns. Therefore, it can also be considered a variable within crop management practices, an issue that should be further evaluated.

Hernández & Florentino (2004) evaluated two types of coverage in pineapple-grown soils (*A. comosus*) in Lara state under simulated rain. They found out that the scarce soil cover and the high slopes are crucial aspects that favor water loss from runoff and soil from erosion, mainly in the early stages of pineapple cultivation. Likewise, the authors also note a beneficial effect of coverage on the decrease in water erosion and runoff on the erosion trays assessed and the increase of water infiltration into the soil.

In this regard, Ingwersen (2012) developed a study called "Costa Rica's Fresh Pineapple Life Cycle Assessment," where, among other aspects, it assessed the impact on soil erosion. The sensitivity analysis results showed that the slope was the factor that most influenced the erosion response and found that an increase in the slope of only 2.5 to 30% caused an increase in erosion in kg/ha/harvest of 2100%. Likewise, it also reported that the sensitivity of the soil texture, about the percentage change in average erosion (58 to 33%), together with the degree of contouring of the rows (44 to 0%), yield (43 to 96%), use of plastic mulch (78%) and the use of double harvest systems (32%) showed significant influences on soil erosion in pineapple-grown farms.

Alvarez & Peña (2013) estimated erosive levels in soils with pineapple cultivation in Sarapiquí, reported values of up to 142t/ha/year, which are framed in the category of severe erosion. They concluded that the levels of erosion recorded could be associated with the parameters of water capacity and apparent density. An inadequate condition of these parameters would affect the soil structure, and the soil system would be more fragile, increasing the erodibility processes and the effects of erosivity. Therefore, these factors must also be analyzed.

Afandi & Novpriansyah (2020) studied soil erosion in pineapple plantations in Indonesia under climate change analysis and used the USLE as an evaluation methodology. They concluded that erosion values at various research sites were low, and although the erosivity value found was high, other erosion factors in the equation were low, so soil erosion tends to be low.

Agroclimatic effects on erosion in pineapple. The hillside area where pineapple is grown in Valle del Cauca has the following location: in flat coordinates (Magna sirgas Colombia west) 1046866.83 (centroid x) and 898276.9324 (centroid y) and in geographic coordinates of the centroid 3-40'34.324"N and 76-39'20.266"W. That zone has an approximate area of 138800.885 ha and a perimeter of 229.587512 km (Figure 3).

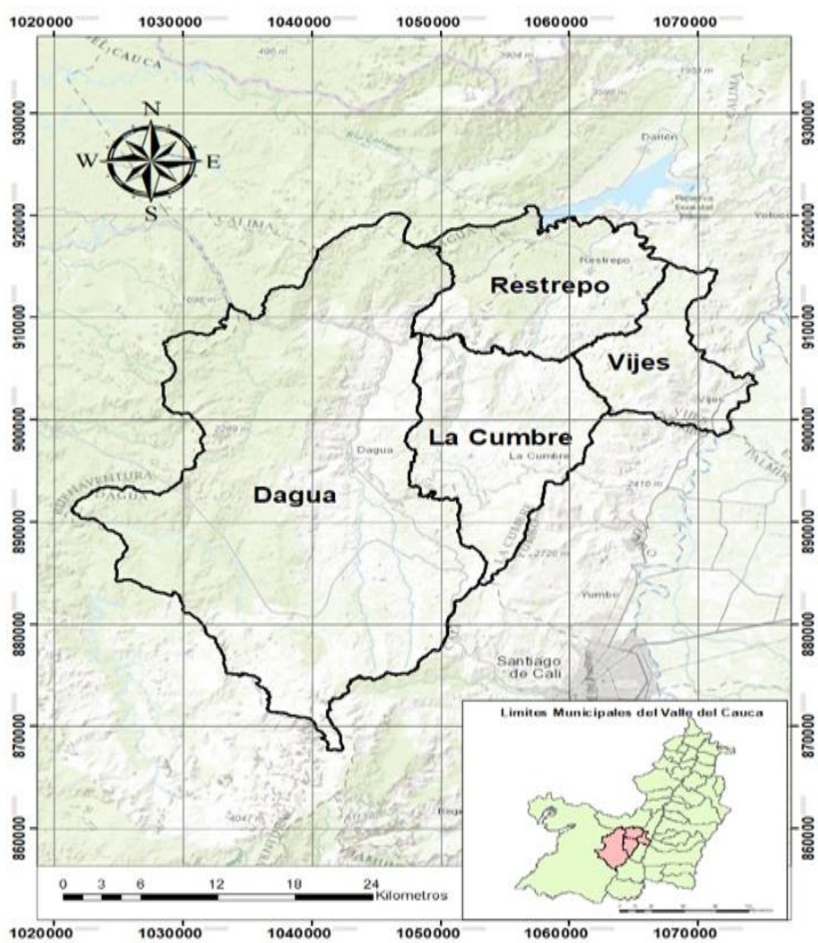

Figure 3. Main pineapple-producing municipalities in the Valle del Cauca region.

Dagua, Restrepo, La Cumbre, and Vijes municipalities are circumscribed to the Dagua River basin, being of great importance to Colombia, for its responsibility in more than half of foreign trade and for communicating the country with the Pacific Basin. Nevertheless, the inappropriate use of productive activities, represented mainly by pineapple farming (Loaiza *et al*., 2012), has caused severe damage to the ecosystem (Daza *et al*., 2012; Cardona *et al*., 2014); soil erosion processes stand out where more than 50% of the area has been degraded (Loaiza *et al*., 2012).

In climate terms, the Dagua River watershed is connected to one of the highest precipitation centers in the world. In this way, in its upper part, it presents precipitation levels in the range of 900 to 1600mm/year, and in its lower part, it ranges from 6000 to 8000mm year^{-1} (Aguirre *et al*., 2017).

On the other hand, studies carried out in areas near this region by Ramírez *et al*. (2009) and Castro *et al*. (2017) indicate values of erosivity that are between the high and very high categories. Likewise, a study developed by Pacheco *et al*. (2019) reports erosivity values framed between 3162.12 and 12683.72MJ.mm.ha^{-1} for an Ecuadorian tropical region, and more recently, Yue *et al*. (2020) report values for the last two decades for South America up to 10273.67MJ.mm.ha^{-1}.

Although information regarding soil erodibility (k factor) is scarce, Alarcón & Reyes (2013) found K values of up to 0.003254t.ha.h/MJ.mm.ha of *typic dystrudepts*, *typic hapludands*, and *andic dystrudepts* by rain simulator in La Centella micro-basin (Dagua, Valle del Cauca), which mean that the susceptibility of these soils to erosion is high.

According to the basic plan of territorial ordering, the soils of Dagua have adequate drainage, but they show a high tendency to landslides, ranging from superficial to moderately deep (Alcaldía Municipal de Dagua, 2001). On the other hand, the main orders of soil present correspond to Inceptisoles, followed to a lesser extent by Alfisols, Mollisols, Andisols, and Entisols, many of them susceptible to erosion (Tafur, 2006; CVC, 2013; CVC, 2014).

In Dagua, the crops are located in hillside areas from the subxerophytic zone belonging to the canyon of the Dagua River at 1500 meters above sea level, where slopes exceed 20% (Chaparro *et al.,* 2012). The municipality of Restrepo also establishes this crop in hillside areas, and the municipalities of Vijes and La Cumbre are not the exceptions, as they show more significant environmental effects at the regional level.

A recent study developed by Martínez *et al*. (2021) indicates that the highest values of the topographic index in the Dagua River basin extend from the northwest to the southwest, mainly covering the municipality of Dagua. This finding coincides with the upper part of the basin, where the slopes that can reach 81 degrees are located. In this sense, it is essential to consider this factor as one of the most critical factors contributing to soil erosion in pineapple cultivated areas around this region.

Regarding the plant coverage factor (C), in the USLE, this represents the relationship between the soil losses generated in a plot subject to fallow and those that occur for the same plot, under conditions of specific coverage of a given crop (Wischmeier & Smith, 1978).

According to Afandi & Novpriansyah (2020) using USLE to calculate soil erosion cultivated with pineapple plants is complex, mainly to estimate the factor (C) of the crop. Pineapple has a long-life cycle and is harvested between 15 and 18 months after planting; then, it could be continued as a ratoon crop for about 15 months.

Pineapple canopy coverage increases as age increases. Six months after planting, the pineapple canopy would completely cover the soil surface to affect soil erosion significantly. Furthermore, soil erosion would be affected by the number of canopies covering the soil surface. Soil losses in the field cultivated with pineapple will vary during pineapple growth. Thus, values ranging from 0.1 to 1 have been found, depending on the crop's phenological stage (Afandi *et al*., 2020).

Abbasi & Jamal (1999) indicated that soil loss and runoff are more substantial during the first four months of pineapple crop establishment, and then it is gradually reduced due to the development of plan cover. Nevertheless, Sugahara *et al*. (2001) state that pineapple growth is so slow that, for at least one year, the fields do not have sufficient plant cover that could lead to severe erosion problems. In any case, this index must be calculated because it is one of the essential aspects in determining soil erosion.

In the case of the pineapple regions of Valle del Cauca, it must be known that this agricultural culture has to be managed as a clean crop, as it is a very demanding plant in weed control (Gómez *et al*., 2006). Therefore, farmers do not allow the establishment of weeds, which increase the percentage of uncovered area, maximizing the area exposed to the impact of the falling raindrop that causes soil detachment.

Pineapple management and influence on erosion. Regarding the management practices, developed by AGROSAVIA (formerly CORPOICA) in "simple practices for planting pineapple on the hillside," the basic principle for hillside planting is through the slope, being also indispensable to be established in areas with slopes below 30%, using soil conservation practices; However, is possible to find soils without plant cover associated with intensive livestock farming and overgrazing. In addition, no conservation practice is applied, burning is carried out before planting, and activities such as weeding leave the soil entirely uncovered and exposed to favor the processes of erosion (Gómez *et al*., 2006).

Likewise, crops are established in favor of the slope. In many cases, plastic mulch is used, causing effects on soil erosion, and the environmental effects of productive activity in terms of loss of soil quantity are unknown.

Currently, drip irrigation continues to be the most recommended system in terms of conservation of water and soil resources, whose application has intensified in recent years due to greater efficiency and savings (Cubero & Sandí, 2013). This method consists of localized, low flow, low pressure, and high-frequency water application, allowing significant savings in energy consumption (Cruz, 2015).

The factors mentioned above added to aspects such as the inadequate selection of the land to be sown, limited plant coverage, and its management as a clean crop can lead to the loss of soil in a few decades. In this sense, when crops are located in areas of high rainfall, their productive potential can fall in less than twenty years, and if it also has a level of slope, the problem is even more significant, leading to a total loss of soil in a short time (Quijandria *et al.*, 1997).

Relevant Results. Finally, as relevant results, although there is not enough research on erosion in soils dedicated to pineapple cultivation, the available studies indicate losses that range between 35 and 178t/ha/year, values that can be classified in the category of severe erosion.

Regarding pineapple-producing municipalities in Valle del Cauca, erodibility, erosivity, and topographic factors can reach high values, taking into account the predominant soil orders, heavy rains that reach 10273.67 $Mj.mm.ha^{-1}$ (very high erosivities), and considering that in this sector, the slopes are usually higher than 20%. On the other hand, the coverage is almost nil during the first months of the plant's life and lacks conservation practices.

CONCLUSIONS

It was possible to address the agricultural culture of pineapple and present and analyze the leading factors that bring on the erosion of soil in the main pineapple-producing municipalities in the region of Valle del Cauca. According to this study, it is highlighted that one of the most important factors that favor soil erosion is given by the topography, mainly the inclination of the slopes. The conditions of access roads, unpaved roads, practices such as the use of plastic mulch also show an influence; besides, apparent density, texture, structure, and water capacity are correlated with erodibility. Furthermore, concerning pineapple-producing municipalities in Valle del Cauca, erodibility, erosivity, and topographic factors can reach high values, considering the predominant soil orders and heavy rains.

Although Pineapple (*A. comosus*) is a fruit of great importance; inadequate soil management may contribute to the loss of natural capital in a few decades. It is recommended to carry out future studies in which the erodibility and erosivity of these areas are determined to know the potential degradation rate. This aspect is essential and will function as a valuable tool for identifying vulnerable areas, decision-making, generating management, and conservation practices on these soils.

Conflict of interests: The authors declare that there are no conflicts of interest.

BIBLIOGRAPHIC REFERENCES

Abbasi, M. A.; Jamal, T. (1999). Soil Loss and Runoff Measurement From Banana-Pineapple intercropping System. *Pakistan Journal of Biological Sciences*. 2(3): 689-692. doi: 10.3923/pjbs.1999.689.692

Abu Bakar, B. H.; Ishak, A. J.; Shamsuddin, R.; Wan Hassan, W. Z. (2013). Ripeness level classification for pineapple using RGB and HSI colour maps. *Journal of Theoretical and Applied Information Technology*. 57(3): 587–593.

Afandi, D. W.; Novpriansyah, H. (2020). Soil erosion at pineapple plantations in Indonesia under the climate change issue. Recovered from https://iopscience.iop.org/article/10.1088/1755-1315/423/1/012013

Aguirre, A.; López, L. I.; Bolaños, F. V.; González, D. F.; Buitrago, O. (2017). Perception of landscape, water and ecosystems in the watershed of the Dagua river, Valle del Cauca, Colombia. *Geographic perspective*. 22(1): 109-126. doi: 10.19053/01233769.5402

Agudelo, C. A.; Torrente, A.; Vargas, A. (2015). Comparative evaluation of soil loss in the biological corridor between the Purace National park and the guacharos cave in Huila. *Revista Colombiana de Investigaciones Agroindustriale*s. 2(1): 41-52. doi: https://doi.org/10.23850/24220582.168

AGRONET - Red de información y comunicación del sector agropecuario colombiano. (2019). Statistics at home. Area, Production, Performance and Municipal Participation on the Department's website by Cultivation. Recovered from https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=4

Alcaldía municipal de Dagua. (2001). Plan de Ordenamiento Territorial Dagua Valle del Cauca 2001-2009: POT Dagua Valle del Cauca 2001-2009. Recovered from https://repositoriocdim.esap.edu.co/handle/123456789/11214

Alarcón, S.; Reyes, A. (2013). Erodibility Assessment for Typic Dystrudepts, Typic Hapludands, and Andic dystrudepts by using a rain simulator in the watershed La Centella (Dagua- Valle del Cauca). *Natural Resources and Environmental Engineering*. 12:49-57.

Alewell, C.; Borrelli, P.; Meusburger, K.; Panagos, P. (2019). Using the USLE: Chances, challenges, and limitations of soil erosion modeling. I*nternational Soil and Water Conservation Research.* 7(3): 203-225. doi: https://doi.org/10.1016/j.iswcr.2019.05.004

Altendorf, S. (2017). Perspectivas mundiales de las principales frutas tropicales. Perspectivas, retos y oportunidades a corto plazo en un mercado global pujante. Recovered from http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Tropical_Fruits/Documents/Tropical_Fruits_Spanish2017.pdf

Alvarez, M.; Peña, W. (2013). Estimation of erosive levels in soils with pineapple cultivation in Sarapiqui. *Scientific repertoire*. 16(1): 3-11. doi: https://doi.org/https://doi.org/10.22458/rc.v16i1.59

Alvarado, K.; López, V.; Castillo, J. (2011). Pérdida de suelo por erosión hídrica en diferentes sistemas de producción con papa *Solanum tuberosum* L. *Revista de Ciencias Agrícolas*. 28(1): 64-72.

Amundson, R.; Berhe, A. A.; Hopmans, J. W.; Olson, C.; Sztein, A. E.; Sparks, D. L. (2015). Soil and human security in the 21st century. *Science*. 348(6235): 1261071. doi: 10.1126/science.1261071

ASOHOFRUCOL - Colombia Horticultural Association. (2018). Pineapple production in Colombia would reach 1.18 million tons at the end of the year. Recovered from https://www.agronegocios.co/agricultura/la-produccion-de-pina-en-colombia-llegaria-a-118-millones-de-toneladas-al-finalizar-el-ano-2895397

Cardona, F.; Ávila, A. J.; Carvajal. Y.; Jiménez, H. (2014). "Trends into rainfall time series of two andes basins of Valle del Cauca (Colombia)". *TecnoLógicas.* 17(32): 85-95.

Castro, A. F.; Lince, L. A.; Riaño, O. (2017). Determination of the risk to the potential erosion by water in the coffee zone of Quindio, Colombia. *Agricultural and Environmental Research Magazine*. 8(1):17-26. doi: https://doi.org/10.22490/21456453.1828.

Chaparro, O.; Herrera, O.; Otocar, J. (2012). Effect of a mechanized system of sowing to pineapple in the efficiency of operation in areas of the hillside of Dagua (Valle del Cauca). *Agronomic Act*. 61(5): 87-88.

Ciesiolka, C. A.; Coughlan, K. J.; Rose, C. W.; Smith, G. D. (1995). Erosion and hydrology of steep lands under commercial pineapple production. *Soil Technology*. 8(3):243-258. doi: https://doi.org/10.1016/0933-3630(95)00023-2

Crestani, M.; Barbieri, R.; Hawerroth, F.; Carvalho, F.; De Oliveira, A. (2010). Das Américas para o Mundo - origem, domesticação e dispersão do abacaxizeiro. *Ciência Rural, Santa Maria*. 40(6):1473-1483. doi: https://doi.org/10.1590/S0103-84782010000600040.

Cruz, J. R. (2015). *Efficient irrigation management in sugarcane cultivation in the geographical valley of the Cauca River*. Cali, Colombia: *Cenicaña*. 192p.

Cubero, D.; Sandi, V. (2013). Técnicas agroambientales para el manejo del cultivo de piña. Instituto Nacional de innovación y transferencia en tecnología agropecuaria. San José, Costa Rica. Recovered from: http://www.mag.go.cr/bibliotecavirtual/F01-10537.PDF

CVC - Corporación Autónoma Regional del Valle del Cauca. (2013). Internet Site for Data on geography. Recovered from https://www.geo.cvc.gov.co/visor_avanzado/

CVC - Corporación Autónoma Regional del Valle del Cauca. (2014). Levantamiento semidetallado de suelos escala 1:25.000 de las cuencas priorizadas por la Corporación Autónoma Regional del Valle del Cauca - CVC - Convenio interadministrativo 4888 IGAC-087 CVC de 2014. Recovered from https://ecopedia.cvc.gov.co/suelo/caracteristicas-del-suelo/levantamiento-semidetallado-de-suelos-escala-125000-de-las-cuencas

Daza, M. C.; Reyes, A.; Loaiza, W.; Fajardo, M. P. (2012). Index of sustainability of the water resource for the definition of technological sustainable and competitive strategies in the Microbasin la Centella. *Gestión y Ambiente*. 15(2): 47-58.

Delgado, H.; Arango, L. (2015). Morphoagronomic characterization of pineapple (*Ananas spp.*) genotypes in high-terrace soil near Villavicencio. *Orinoquia*. 19(2): 153. doi: https://doi.org/10.22579/20112629.315

El-Ramady, H. R.; Domokos-Szabolcsy, É.; Abdalla, N. A.; Taha, H. S.; Fári, M. (2015). Postharvest management of fruits and vegetable storage. In: Lichtfouse, E. *Sustainable agriculture reviews.* pp. 65-152. 15. Cham: Springer. 401p.

El-Swaify, S. A.; Zhang, J.; Ciesiolka, C. A.; Palis, R.; Rose, C. W. (1993). Erosion problems and conservation needs of pineapple culture. *Acta Horticulturae*. 334(23): 227-240. doi: 10.17660/ActaHortic.1993.334.23

FAO - Food and Agriculture Organization of the United Nations; ITPS - Intergovernmental Technical Panel on Soils. (2015a). *Status of the world's soil resources*. Technical Summary. Rome, Italy: Food and Agriculture Organization of the United Nations and Intergovernmental Soil Technical Group. 92p.

FAO - Food and Agriculture Organization of the United Nations. (2015b). Soil is a non-renewable resource. Recovered from http://www.fao.org/3/i4373e/i4373e.pdf

FAO - Food and Agriculture Organization of the United Nations. (2019). FAOSTAT. Data crops. Recovered from http://www.fao.org/faostat/es/#data/QC

FAO - Food and Agriculture Organization of the United Nations. (2022). Cultivos y productos de ganaderia. Cantidades de producción de Piña tropical por país 2017. Recovered from https://www.fao.org/faostat/es/#data/QCL/visualize

Gómez, J.; Saavedra, R.; Dávila, G.; Gómez, C. O. (2006). Simple practices for planting pineapple on the hillside. Recovered from https://repository.agrosavia.co/bitstream/handle/20.500.12324/2207/44194_56407.pdf?sequence=1&isAllowed=y

Hassan, A.; Othman, Z. (2011). Pineapple (*Ananas comosus* L. *Merr.*). In:, Yahia, E. *Postharvest Biology and Technology of Tropical and Subtropical Fruits*. 4: 194-218e. UK: Woodhead Publishing Ltd.

Hernández, C.; Florentino, A. (2004). Evaluation of two types of mulch on soils cropped with pineapple under simulated rain in greenhouse conditions. *Revista de la Facultad de Agronomía* (serbiluz). 21(1): 228-236.

Huerta, J. D.; Oropeza, J. L.; Guevara, R. D.; Ríos, J. D.; Martínez, M. R.; Barreto, O. A.; Olguín, J. L.; Mancilla, O. R. (2018). Efecto de la cobertura vegetal de cuatro cultivos sobre la erosión del suelo. *Idesia* (*Arica*). 36(2): 153-162. doi: https://dx.doi.org/10.4067/S0718-34292018005000701

IDEAM - Instituto de Hidrología, Meteorología y Estudios Ambientales.; U.D.C.A - Universidad de Ciencias aplicadas y ambientales. (2015). Protocol to identify and asses soil degradation by erosion in Colombia. Recovered from http://documentacion.ideam.gov.co/openbiblio/bvirtual/023647/Protocolo-erosion.pdf

Ingwersen, W. W. (2012). Life cycle assessment of fresh pineapple from Costa Rica. *Journal of Cleaner Production*. 35: 152-163.

Loaiza, W.; Reyes, A.; Carvajal, Y. (2012). Application of a Sustainability Index of Water Resources in Agriculture (ISRHA) to define sustainable technological strategies in the Centella watershed. *Scientific Journal Engineering and Development*. 30(2): 160-181.

Loch, R. J. (2000). Effects of Vegetation Cover on Runoff and Erosion under Simulated Rain and Overland Flow on a Rehabilitated Site on the Meandu Mine, Tarong, Queensland. *Australian Journal of Soil Research*. 38: 299-312. doi: 10.1071/SR99030

Lugo, D. R.; Rey, J. C. (2009). Evaluation of the vulnerability to agro-environmental degradation through the use of the MicroLEIS system in soils of the central plains of Venezuela. *Revista Internacional de Contaminación Ambiental*. 25(1): 43-60.

Martínez, R.; Torres, P.; Meneses, M. A.; Figueroa, J. G.; Pérez, J. A.; Viuda, M. (2012). Chemical, technological and in vitro antioxidant properties of mango, guava, pineapple and passion fruit dietary fibre concentrate. *Food Chemistry*. 135(3): 1520-1526. https://doi.org/10.1016/j.foodchem.2012.05.057

Martínez, C.; Rivera, A. O.; Menjivar, J. C. (2021). Susceptibility to erosion risks in soils dedicated to pineapple cultivation in the department of Valle del Cauca, Colombia. *Earth Sciences Research Journal*. 25(2): 201-206.

Oculi, J.; Bua, B.; Ocwa, A. (2020). Reactions of pineapple cultivars to pineapple heart rot disease in central Uganda. *Crop Protection*. 135: 105213. doi. https://doi.org/10.1016/j.cropro.2020.105213

Pacheco, H. A.; Méndez, W.; Moro, A. (2019). Soil erosion risk zoning in the Ecuadorian coastal region using geo-technological tools. *Earth Sciences Research Journal*. 23(4): 293-302. doi: https://doi. org/10.15446/esrj.v23n4.71706

PTP - Programa de transformación productiva.; ASOHOFRUCOL - Colombia Horticultural Association.; FNFH - Fondo Nacional de fomento hortofrutícola. (2013). Plan de Negocios de Piña. Bogotá. Recovered from https://www.colombiaproductiva.com/CMSPages/GetFile.aspx?guid=f5a9fee6-5fa5-4518-8dc0-4d7289ca4aa7

Quijandria, G.; Berrocal, J.; Pratt, L. (1997). *La Industria de la Piña en Costa Rica Análisis de Sostenibilidad*. Costa Rica: Centro Latinoamericano para la Sostenibilidad y el Desarrollo Sostenible. 24p.

Ramírez, F.; Hincapie, E.; Sadeghian, S. (2009). Erodability of soils of the Central Coffee Zone of the Department of Caldas. *Cenicafe*. 60(1): 58-71.

Sampietro-Vattuone, M. M.; Peña-Monné, J. L.; Roldán, J.; Dip, A. B.; Maldonado, M. G.; Lefebvre, M. G.; Vattuone, M. A. (2019). Land management and soil degradation evidence during the Late Holocene in Northwest Argentina (La Costa 2 - Tafí valley). *Catena*. 182: 104-115. doi: https://doi.org/10.1016/j.catena.2019.104115

Sugahara, K.; Ohwaki, Y.; Banzai, K. (2001). Erosion control in pineapple fields on the island of ishigaky. *Japan Agricultural Research Quarterly*. 35(2): 91-96. doi: https://doi.org/10.6090/jarq.35.91

Tafur, R.; Toro, J.; Reyes, C.; García, R.; Muñoz, C. (2006). National Fruit Plan. Valle del Cauca, land of fruits. Recovered from http://www.asohofrucol.com.co/archivos/biblioteca/biblioteca_117_PFNValledelCauca.pdf

Uriza, D.; Torres Ávila, A.; Aguilar Ávila, J.; Santoyo Cortés, V.; Zetina Lezama, R.; Rebolledo Martínez, A. (2018). *La piña mexicana frente al reto de la innovación. Avances y retos en la gestión de la innovación*. 1 ed. Chapingo, Estado de México. México: UACh. 479p.

Valentin, C.; Roose, E.J. (1980). Soil and water conservation problems in pineapple plantations of south Ivory Coast. In: Morgan, R.P.C. ed. *Soil Conservation: Problems and Prospects.* pp. 239-246. Chinchester: Wiley. 7p.

Wan, Y.; El-Swaify, S. A. (1999). Runoff and soil erosion as affected by plastic mulch in a Hawaiian pineapple field. *Soil and Tillage Reserach*. 52: 29-35. doi: https://doi.org/10.1016/S0167-1987(99)00055-0.

Wischmeier, W. H.; Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. United States: Department of Agriculture, Science, and Education Administration. 67p.

Yue, L.; Zhao, W.; Liu, X.; Pereira, P. (2020). Global rainfall erosivity changes between 1980 and 2017 based on an erosivity model using daily precipitation data. *Catena*. 194: 1-12. doi: https://doi.org/10.1016/j.catena.2020.104768

Zhang, J.; Liu, J.; Ming, R. (2014). Genomic analyses of the CAM plant pineapple. *Journal of Experimental Botany*. 65(13): 3395–3404. doi: https://doi.org/10.1093/jxb/eru101