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SOIL EROSION BY HAND TOOLS FOR SMALL-SCALE TILLAGE ON HILLSLOPES ASSESSED THROUGH THE UNIVERSAL SOIL LOSS EQUATION

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ABSTRACT

The objective of this study was to evaluate and compare the erosion rates generated by two types of hand tools for small-scale tillage on a hillslope, using experimental tests and the Universal Soil Loss Equation (USLE). The hand tools evaluated were a conventional hoe and a redesigned furrowing hoe. The experimental work was conducted in a 145 m^2 plot with an average slope of 45% in Colombia. Three treatments were evaluated: a) Zero tillage and no herbicide (control); b) tillage with a conventional hoe plus herbicide; c) tillage with a furrowing hoe plus herbicide. Each treatment was represented by a sedimentation plot, using three repetitions in blocks (lower, middle, and upper parts of each plot), according to the maximum slope gradient. Both hand tillage tools generated high to extremely high erosion rates with differences of up to 8.1 times between them. Both types of tools accelerated soil erosion rates, being higher in furrowing hoe tillage. The USLE method showed no differences in erosion rates between the tillage methods, while differences were found in the experimental tests. This is explained by the lower sensitivity of the USLE to detect small-scale changes in factors such as soil type, cover, and slope.

Keywords: tillage tools, USLE, slope, runoff plot, weed cover, lost soil.

INTRODUCTION

One of the biggest problems in agriculture worldwide is soil erosion, resulting in negative impacts on both the physical and chemical quality of this resource. Reports of leaching or nutrient washing, loss of surface layers and/or soil compaction are becoming more frequent. This is leading to a gradual deterioration of the soil structure and, in general, of the useful properties for the establishment of crops, which finally decreases productivity (Maximillian et al., 2019). Therefore, there is a need for methods to reduce erosion rates in agricultural processes.

Heavy tillage, destruction of vegetation, and steep slopes are considered as the main causes of soil loss in agricultural areas. Tillage erosion occurs by the action of agricultural tools, affecting the properties of cultivated soil. In fact, erosion by tillage depends on soil physical parameters and work variables such as speed, depth, direction and characteristics of soil tillage implements

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(Zhang et al., 2018, 2021; Nasir Ahmad et al., 2020) improper farming practices, rainfall regimes, and topography conditions that taken place in agricultural land lead to the soil erosion problem. Soil erosion is the major constraint to agriculture that affects the yield production and degraded environmental sustainability. Furthermore, soil erosion that occurs in the agricultural area has jeopardized the sustainability of agriculture activities. Asia is one of the major agricultural producers in the world. It is essential to know how to mitigate soil erosion in Asian agricultural land. This systematic review aims to analyze the existing literature on research that has been done on control practices that had been taken in Asia agricultural land towards soil erosion. This article is guided by the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analysis.

At present, mathematical models are being used to predict soil movement from tillage implements in order to develop conservation strategies. The Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith, (1978), predicts the average annual rate of erosion based on a series of parameters such as soil type and management, cultivation system or vegetation, rainfall, and slope. The spatial variation of the soil and climatic conditions make soil loss modeling a complicated process. In this sense, geographic information systems (GIS) can facilitate numerical-spatial problem solving, allowing the identification of the spatial variation of the different USLE parameters (Selmy et al., 2021)spatial-based models of soil erosion are required. The current study proposed a spatial-based model that integrated geographic information systems (GIS. Additionally, erosion can be evaluated experimentally with runoff plots, where collectors are used to estimate the amount of sediment carried over a given period, under certain climatic, soil, slope, and management conditions (Komatsu et al., 2018; Liu et al., 2018; Daponte et al., 2019; Carretta et al., 2021)and in particular no-till systems, generally yield improvements in both soil characteristics (e.g. structure, and water holding capacity.

The misuse of soil and farmers' reluctance to change to more friendly tillage methods have encouraged the redesign of hand tools from engineering to reduce erosion rates, with ergonomic improvements when working with the tool in the field. Therefore, the erosion rates produced by tillage with a furrowing hoe designed by researchers from the Universidad Nacional de Colombia (Medellín, Colombia) were evaluated and compared to those produced by conventional hoe tillage Both the geometry and construction materials were evaluated.

In Colombia, the importance of hand tools in the agricultural sector relies on territorial conditions. At the country level, between 35 and 40% of farmers work on small-scale, and do not have the economic capacity to acquire high-scale machinery (Díaz et al., 2006). This was corroborated in the Third National Census of Agriculture carried out by the National Administrative Department of Statistics (DANE) in 2014, which showed that 71% of farmers do not own machinery other than hand tools. Additionally, due to the country's topography, many of the agricultural areas are on steep slopes, the use of machinery such as tractors is limited. Therefore, the use of hand tools is crucial, and the development of new tools is important for the agricultural sector.

The objective of this work was to evaluate and compare the erosion rates generated by two types of hand tools for small-scale tillage on a hillslope, a conventional hoe and a redesigned furrowing hoe, using experimental tests and the Universal Soil Loss Equation (USLE).

MATERIALS AND METHODS

Description of the Study Area

The research was carried out at the Paysandú Agrarian Station of the Universidad Nacional de Colombia (6°12'37" N and 75°30'11" O), Santa Elena, Colombia (Fig. 1), with an altitude of 2690 m.a.s.l. (De los Rios et al., 2004). The station is mainly used for livestock grazing, milk production, and potato planting. The average temperature is 14.7°C, which corresponds to a Cfb climate according to the Köppen classification. Both temperature and an average annual rainfall of 2500 mm (Pérez et al., 2017) ecologically locates the Agrarian Station in the Lower Montane Moist Forest life zone (TLM-mf) (Jaramillo, 2014).

The soil study carried out at the Agrarian Station reveals a sloping topography, with slopes between 7 and 50%. Horizon A has a clay-loam texture and ranges from 10-24 cm in thickness. It is the layer of soil where agricultural work is carried out, while most hand implements used in soil preparation reach up to this soil depth (Pérez et al., 2017). However, it is important to note that the depth of work depends on the type of activity, soil properties, and crop to be established (Reynolds and López, 2019). The structure of the horizon found is subangular, fine, moderate, and slightly blocky. Finally, the soil is classified as Acrudoxic Fulvudands, medial, mixed, and isothermal. Table 1 shows the results of the textural composition for each of the plots used in this study.

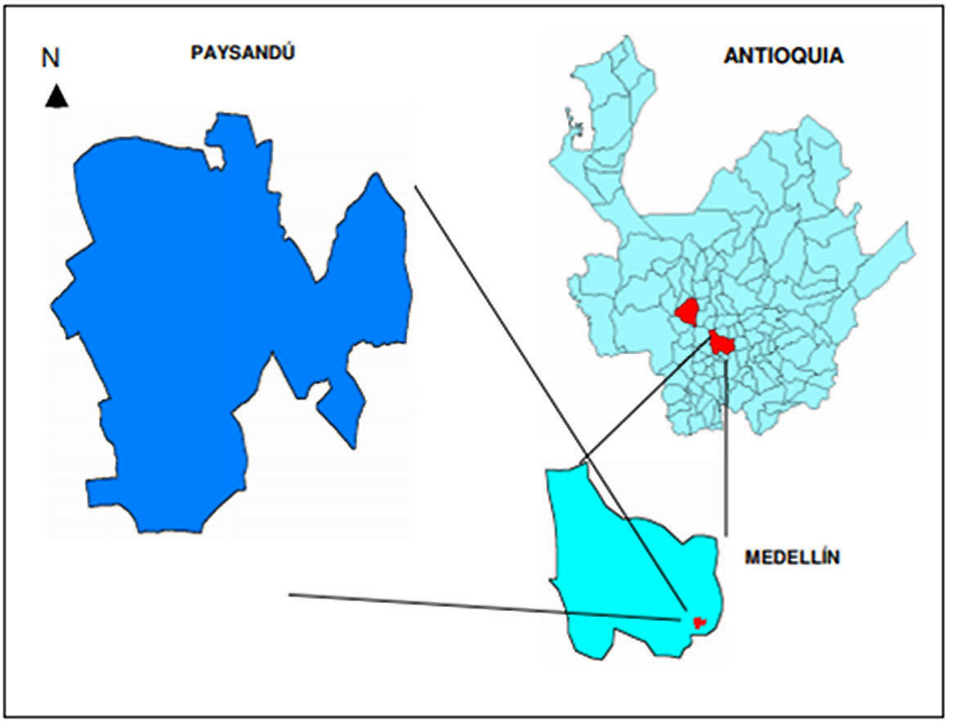

Fig. 1. Location of the Paysandú Agrarian Station, Medellín, Colombia. Source: De Los Rios et al. (2004).

Table 1. Soil texture and organic matter content for each plot according to their location on the slope (block), in the direction of the maximum gradient.

Block	Location Hillshade	Plot	Sand (%)	Clay (%)	Silt (%)	Organic matter (%)	Texture
I	High	a	64	8	28	24.9	FA
		b	86	2	12	24.3	A
		c	84	4	12	27.7	AF
		$\bar{y}^{(1)}$	78	4.67	17.33	25.63	Coarse
II	Medium	a	60	12	28	20.2	FA
		b	28	38	34	10.1	Far
		c	62	8	30	24.4	FA
		$\bar{y}$	50	19.33	30.67	18.23	Coarse
III	Low	a	34	38	28	8.6	FAr
		b	36	30	34	8	FAr
		c	58	20	22	2.1	FArA
		$\bar{y}$	42.67	29.33	28.00	6.23	Medium

(1) Average. Source: The authors.

Tillage tools

Erosion caused by two different tillage hand tools, a conventional hoe and a furrowing hoe, was evaluated. The conventional hoe is a quadrangular tool used to carry out primary tillage (Fig. 2a), while the furrowing hoe, which was designed by researchers of the Universidad Nacional de Colombia, has a tip design that allows to carry out primary and secondary tillage in a single pass (Fig. 2b). Erosion rates were obtained in order to determine if the furrowing hoe reduces soil susceptibility to erosion during the tillage process in hillslopes.

Fig. 2. Hand tools evaluated; a. conventional hoe b. furrowing hoe. Source: a. MundoHuerto (2019) b. The authors.

Experimental design

The experiment was established in a plot of 145 m^2 (average slope of 45%) at the Paysandú Agrarian Station of the Universidad Nacional de Colombia. A randomized complete block design (RCBD) was used, where the blocks control the variation by treatment location in the direction of maximum slope gradient. Blocks I, II, and III were installed for variability control of treatments located in the upper, middle, and lower parts of the slope, respectively (Fig. 3). Soil texture of each block according to the location on the hillside are described in Table 1. In each of the blocks, three runoff plots (2.5 m x 1.25 m) were installed for a total of nine. Each runoff plot was connected in the lower part to a 20 L container for the collection of runoff water with soil in suspension. Three treatments were used: a. Control without tillage and no weed management; b. tillage with a conventional hoe plus herbicide; c. tillage with a furrowing hoe plus herbicide. Herbicide was applied to recreate bare soil conditions. Once the experiment was installed, tillage was carried out with the tools covering the entire area during the study period (October 10 to November 10, 2020).

Variables

Net soil erosion. All runoff water was recovered and placed in collection containers of each plot. The collection frequency depended on the frequency and intensity of rainfall events during the study period. The net soil erosion was determined by the accumulated dry soil contained in each one of the oven-dried samples at 105°C until constant weight, obtained from each plot during the evaluation and expressed as t ha^{-1} $year^{-1}$, considering plot area, sampling time, and average annual rainfall.

Soil loss. The amount of soil being removed from the plots was estimated using the USLE (Equation 1). The equation estimates the average annual loss (A, ton $ha^{-1}year^{-1}$) as a function of the product between erosion factors by rainfall and runoff events (R, MJ mm ha^{-1} h^{-1} $year^{-1}$), soil erodibility (K, ton h MJ^{-1} mm^{-1}), slope length (L, dimensionless), slope steepness (S, dimensionless), coverage, vegetation management (C, dimensionless), and supporting practices (P, dimensionless) (Wischmeier and Smith, 1978; Roy, 2019; Madasamy, Joshua and Rajangam, 2020; Selmy et al., 2021)spatial-based models of soil erosion are required. The current study proposed a spatial-based model that integrated geographic information systems (GIS.

$$A = R * K * L * S * C * P \qquad (1)$$

The R factor indicates the annual average amount of kinetic energy as a consequence of frequency and intensity of rainfall and runoff events to remove and drag soil particles over an extended period (Madasamy, Joshua and Rajangam, 2020)

The R factor was calculated for an extended period of four years using the rainfall records between January 2014 and December 2017 and with a monthly resolution. Data were obtained from the climatic station located in the Santa Elena educational institution at a straight-line distance of 0.96 km from the experimental site, which is part of the Early Warning System of Medellin and the Aburrá Valley (Sistema de Alertas Tempranas de Medellin y el Valle de Aburrá - SIATA) (Fig. 4).

The R factor was estimated by adding the proportions between the accumulated rainfall of the i^{th} month (Ppi, mm), the accumulated rainfall of the corresponding j-th year (Ppj, mm), and divided by the number of years in the series (n_j, years) (Equation 2) (Mhangara, Kakembo and Lim, 2012; Bai and Cui, 2021; Han et al., 2021).

$$R = \frac{\sum_1^{12} 1{,}735 * 10^{\left(1{,}5 * \log_{10}\left(\frac{Pp_i^{\,2}}{Ppj}\right) - 0{,}8188\right)}}{n_j} \qquad (2)$$

The K factor represents soil susceptibility to erosion or capacity to be transported as sediment and depends on soil characteristics.

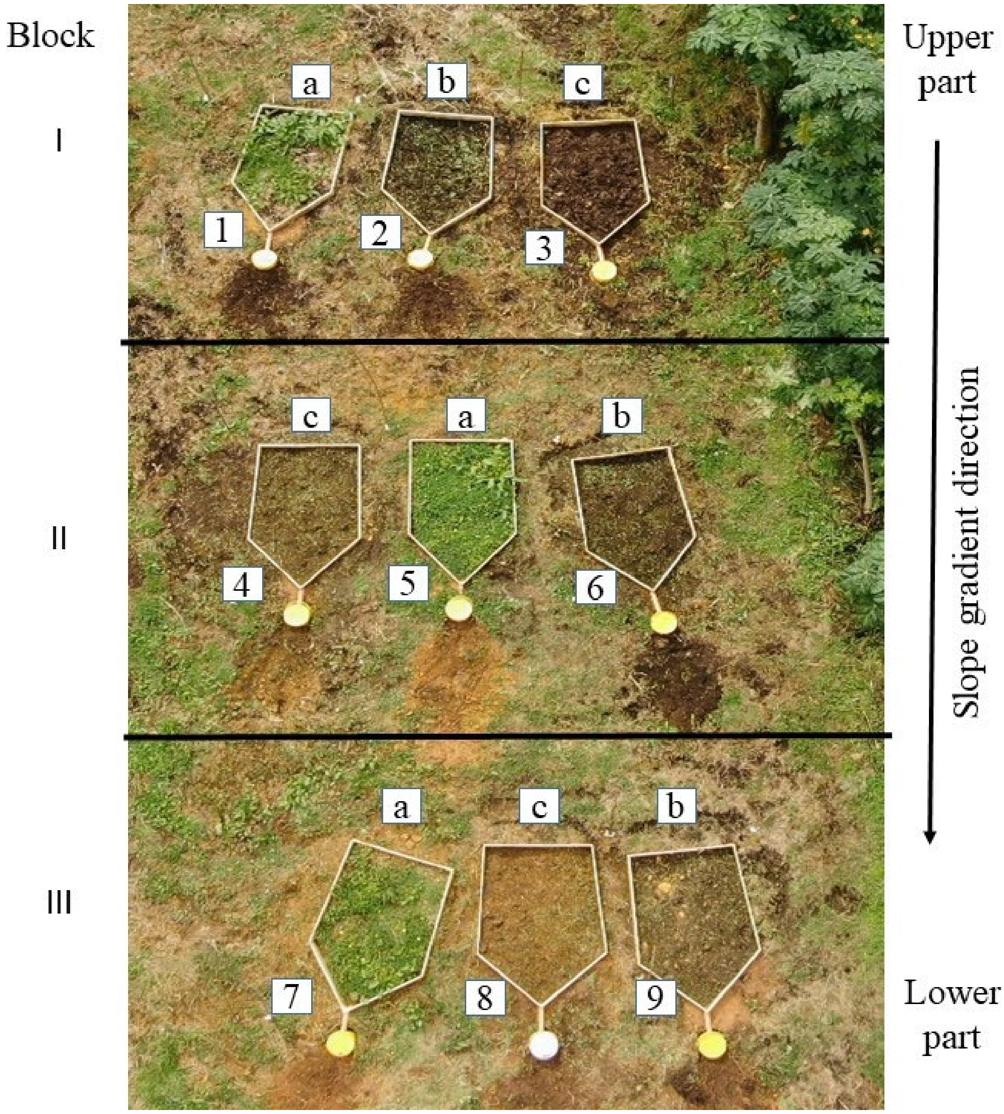

Fig. 3. Perpendicular view of the lot and plots. Blocks I, II, and III delimit the location on the slope according to the direction of the maximum slope gradient. Treatments: a. Control without tillage and no weed management; b. tillage with a furrowing hoe plus herbicide; and c. tillage with a conventional hoe plus herbicide. Source: The authors.

It was calculated using equation 3 (Wischmeier and Smith, 1978; Cassol et al., 2018; Marques et al., 2019; Xu et al., 2019; Efthimiou, Lykoudi and Psomiadis, 2020; Jeanneau, Herrmann and Ostendorf, 2021; Selmy et al., 2021)spatial-based models of soil erosion are required. The current study proposed a spatial-based model that integrated geographic information systems (GIS, where soil erodibility K is a direct function of the organic matter content of the soil (OM, %), structure (s), permeability (p) and the parameter M, which is estimated based on soil particle size using equation (4).

$$K = \left[\frac{2{,}1*10^{-4}(12-OM)*M^{1{,}14}+3{,}25(s-2)+2{,}5(p-3)}{100}\right]*0.1317 \quad (3)$$

$$M = (Silt(\%) + Sand(\%))*(100 - Clay(\%)) \quad (4)$$

OM content was evaluated in soil samples collected in each of the plots following the method of Walkley and Black (1934). The values for the s and p parameters were assigned according to the classification by Wischmeier and Smith (1978); depending on soil structure values are assigned from 1 to 4, where 1 is very fine and 4 is blocky (Table 2).

Similarly, permeability is classified on a scale

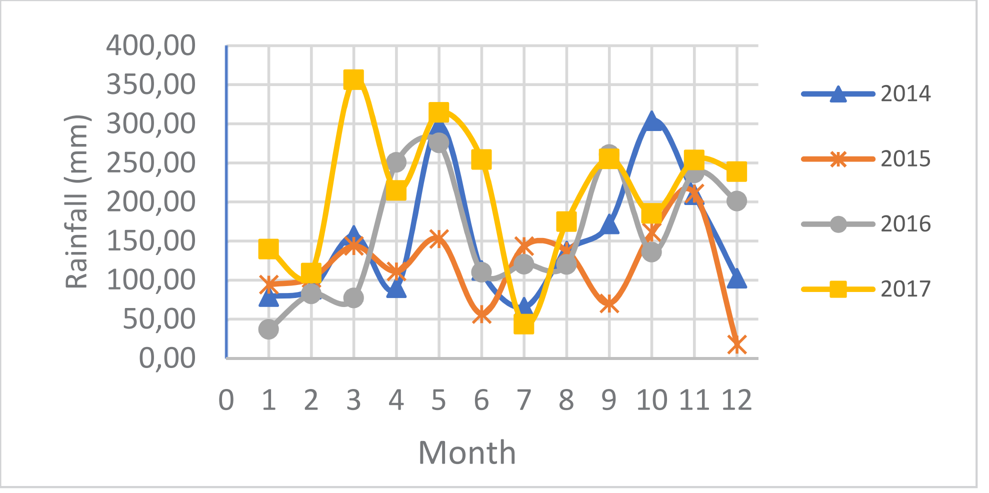

Fig. 4. Monthly rainfall data for the 2014-2017 period, obtained from the Early Warning System of Medellin and the Aburrá Valley (SIATA) and used to estimate the extended period. Source: The authors.

Table 2. Classification of soil structure to calculate the erodibility factor.

Classification Structure	Code
Very fine	1
Fine	2
Moderate granular - coarse	3
Blocky	4

Source: Wischmeier & Smith (1978).

from 1 to 6, where 1 corresponds to fast speed and 6 to very slow speed (Table 3).

The topographic effect of erosion is visualized by the L and S factors since they determine the influence of the slope. The calculation was made based on the equations proposed by Wischmeier and Smith (1978) as illustrated in equations 5, 6, and 7.

$$L = \left(\frac{\lambda}{22.13}\right)^m \quad (5)$$

Where: L: Slope length factor (dimensionless); λ: horizontal length; m: exponent that depends on the slope of the terrain (dimensionless). It is equal to 0.5 when the slope is equal to or greater than 4.5%; it takes the value of 0.4 when the slope is between 3 and 4.5%; 0.3 if the values oscillate between 1 and 3%; and 0.2 in uniform gradients or less than 1%. The S factor was calculated based on equation 6 as described by (Wijesundara, Abeysingha and Dissanayake, 2018)low, moderate, high, very high, and extremely high. The study revealed that majority of extremely vulnerable soil erosion areas (> 60 t ha −1 year −1.

$$S = 10.8\ \sin\theta + 0.03\ , if\ s < 9\% \quad \text{or} \quad S = 16.8\ \sin\theta - 0.05\ , if\ s \geq 9\% \quad (6)$$

Where θ is the angle of the slope in degrees.

Slope values were obtained from a categorized map of terrain slopes, finding the slope area for each of the plots. The slope map was also generated from a digital elevation model obtained through the IDW interpolation process of a mesh of spot height (m) determined within the study area.

Vegetation cover and management factor is crucial for determining erosion, since the existing cover can protect soil from the direct impact of raindrops, resulting in significantly lower erosion rates. Additionally, it allows a higher water infiltration into the soil and improves different chemical and physical properties of the soil. To calculate this factor, it was necessary to capture aerial images of the study area with a DJI Mavic 2 Zoom drone, in order to classify the land cover (Abdo and Salloum, 2017)the soil

Table 3. Classification of permeability values to calculate erodibility using the USLE.

Permeability classification	Code	Value (cm/h)
Fast	1	> 15.24
Moderately fast	2	5.08 - 15.24
Moderate	3	1.52 - 5.08
Moderately slow	4	0.51 - 1.52
Slow	5	0.15 - 0.51
Very slow	6	< 0.15

Source: The United States Department of Agriculture (USDA, 1999); Wischmeier & Smith (1978).

loss model, revised universal soil loss equation (RUSLE. Coverage was calculated using equation 7 developed by Thomas, Joseph and Thrivikramji (2018); Almagro et al. (2019); Amellah and Morabiti (2021); Bai and Cui (2021); Selmy et al. (2021), along with the proposed values of α and β equal to 2 and 1, respectively; the authors also mention that these values are adequate to obtain optimal results. The modified photochemical reflectance index (MPRI) was used as the vegetation index, which uses the red and green bands as illustrated in equation 8. This is suitable for evaluating the variation of vegetation and soil cover (Barbosa et al., 2019; Pacheco and Montilla, 2021).

$$C = e^{\left(-\alpha * \frac{MPRI}{(\beta - MPRI)}\right)} \quad (7)$$

$$MPRI = \frac{Green - Red}{Green + Red} \quad (8)$$

The conservation factor (P) is a parameter that evaluates the practices implemented and the level of conservation of these activities. These can change the pattern of water flow, causing the amount of soil that moves to decrease or increase. At times, vegetation does not prevent runoff, and thus only contour plowing, strips, and terraces are considered for the P factor (Wischmeier and Smith, 1978). According to Kumar and Kushwaha (2013) and Senanayake et al. (2020)such as multi-temporal Landsat images, soil data, rainfall data, land-use land-cover (LULC, P factor values can be estimated for a certain type of land use as illustrated in Table 4.

Statistical analysis

The impact of hand tillage tools on soil erosion determined by experimental tests and using the USLE was evaluated using a model of analysis of variance for randomized complete blocks, and a p-value of 0.05.

$$y = \mu + \tau + \beta + \varepsilon \quad (8)$$

Where: y represents the soil erosion determined experimentally or using the USLE, μ is an overall mean, τ is the effect of the treatments, β is the block effect, and ε is the experimental error.

The treatment grouping was made using the Tukey test with a significance level of 0.05. The analysis was executed in the R language and environment for statistical computing (R Core Team, 2021).

RESULT AND DISCUSSION

The R factor for the area is 256.52 MJ mm ha^{-1} h^{-1} $year^{-1}$, which can be classified as intermediate. Wijesundara, Abeysingha and Dissanayake (2018)low, moderate, high, very high, and extremely high. The study revealed that majority of extremely vulnerable soil erosion areas (> 60 t ha −1 year −1 reported similar values in a study carried out in Sri Lanka, with rainfall values similar to those found in the Paysandú Station**.**

The K factor was variable both within and between plots, with values ranging between 0.022 and 0.071. The highest values were in the upper part of the slope (southern zone), which presented thicker texture but higher contents of organic matter. Conversely, the lowest values were found in the lower part (northern zone). High values were also observed in the plots located in the western part, which decreased towards those located in the eastern part (Fig. 5A). This behavior is mainly explained by the relationship between the factor and parameters such as soil texture and organic matter, which presented a similar spatial behavior (Table 1). In the case of factor C, variations occurred in the control plots (no tillage and no weed management) due to the variability of plants present in each of them. On the contrary, in the plots in which tillage and weed control processes were carried out, this factor takes the value of 1, since the soil was bare (Fig. 5B). Additionally, the presence of weeds, along with organic matter, favors soil structuring

Table 4. P factor according to land use.

Land use	P Factor
Dense forest	1.00
Low-density forest	0.50
Paddy fields	0.50
Urban zone	0.80
Bodies of water	1.00
Cultivated land	0.35
Forest plantation	0.80

Source: Senanayake et al. (2020); Kumar and Kushwaha (2013).

processes, decreasing the speed of runoff flow with an increase in infiltration rates, which finally prevents and reduces erosion (Xu et al., 2019; Zhao et al., 2019). The combination of the L and S factors, obtained by the product of the length and the degree of inclination of the slope derived from the digital elevation model, shows the highest values in the plots located both in the upper and lower parts, while lower values are observed in the plots located in the central part of the slope. Additionally, there is a gradient from high to low values in the west-east direction, very similar to that observed in the K factor. The L and S factors are closely related to the direction, concentration, and speed that surface runoff flows will take, increasing their kinetic energy and, consequently, their capacity to transport soil particles. Once a rainfall event occurs, high slopes increase the speed of surface water runoff, increasing erosion power in the direction of greater slope gradient, which corresponds to the south-north direction and, to a lesser extent, to the east-west direction in the present study. The speed at which water moves does not allow the soil to store the normal amount of water, especially in soils with internal drainage problems. As mentioned by Koirala et al. (2019)causing the loss of topsoil and fertility in agricultural land in mountainous terrain. Estimation of soil erosion in Nepal is essential because of its agriculture-dependent economy (contributing 36% to national GDP, the increase in slope generates an increase in erosion due to the abrasion and displacement of sediments, while most of the water infiltrates into the soil at low slopes. Regarding the P factor, a value of one (1) was considered for the plots with a tillage process (no conservation procedure was carried out); while a value of 0.35 is taken as a no-tillage system (Table 4). In this sense, it is desirable that farmers in the area establish crops that do not require the use of conventional tillage systems or implement systems based on conservation agriculture such as terraces or contour plowing, as suggested by Wischmeier and Smith, (1978) and Jia et al. (2020) further researches are needed to quantify the effectiveness of contour tillage in reducing water erosion and identify the influencing factors in China. We conducted a nationwide meta-analysis based on 229 runoff and 290 sediment paired observations from 47 published papers from national and international literatures. The results showed that compared to traditional tillage, the benefits of contour tillage in China with respect to runoff and sediment reduction were 35.86% and 49.02%, respectively. Sediment yield reduction by contour tillage was greater under simulated rainfall than under natural rainfall. Runoff reduction by contour tillage decreased with the increasing mean annual precipitation and temperature, while sediment yield reduction was not affected by climate factors. Contour tillage in loamy soils and soils with organic carbon content > 1% showed the greatest benefits in reducing sediment yield (64.26% and 52.52%, respectively.

Soil loss

Table 5 shows soil loss for each of the plots per treatment and location on the hillslope (block), estimated using the USLE and experimental tests. Based on the classification described by Mhangara, Kakembo and Lim, (2012), the results with the USLE show Very low (0 - 5 t ha^{-1} year $^{-}$1) to High (25 – 60 t ha^{-1} year $^{-}$1) (Fig 6.A) soil loss, meanwhile the experimental results are classified between Low (5 – 12 t ha^{-1} year $^{-}$1) to Extremely High (> 150 t ha^{-1} year $^{-}$1) soil loss (Fig 6.B). In general, both methods presented considerable differences, particularly in the case of the plots of the lower zone; e.g., the value obtained experimentally for furrowing hoe tillage is 17.7 times higher than that obtained using the USLE, and thus the underestimation of erosion by the USLE becomes evident.

It is important to note that erosion measured experimentally was higher compared to that found by the USLE model, except for the control located in the upper part. Additionally, the control plot located in the lower part of the slope presented a very high and unexpected experimental erosion for this treatment, indicating low protection of this type of cover and a higher incidence of the slope. At the hillside level, the experimental evaluation shows an increase in erosion processes towards the lower part of the slope. When analyzing the factors associated with the equation, the factors that would explain the variability between the USLE equation and the experimental tests are related to soil characteristics, microtopography, and soil coverage; on the contrary, parameters associated with rainfall can be considered constant for all plots. As rainfall events of high

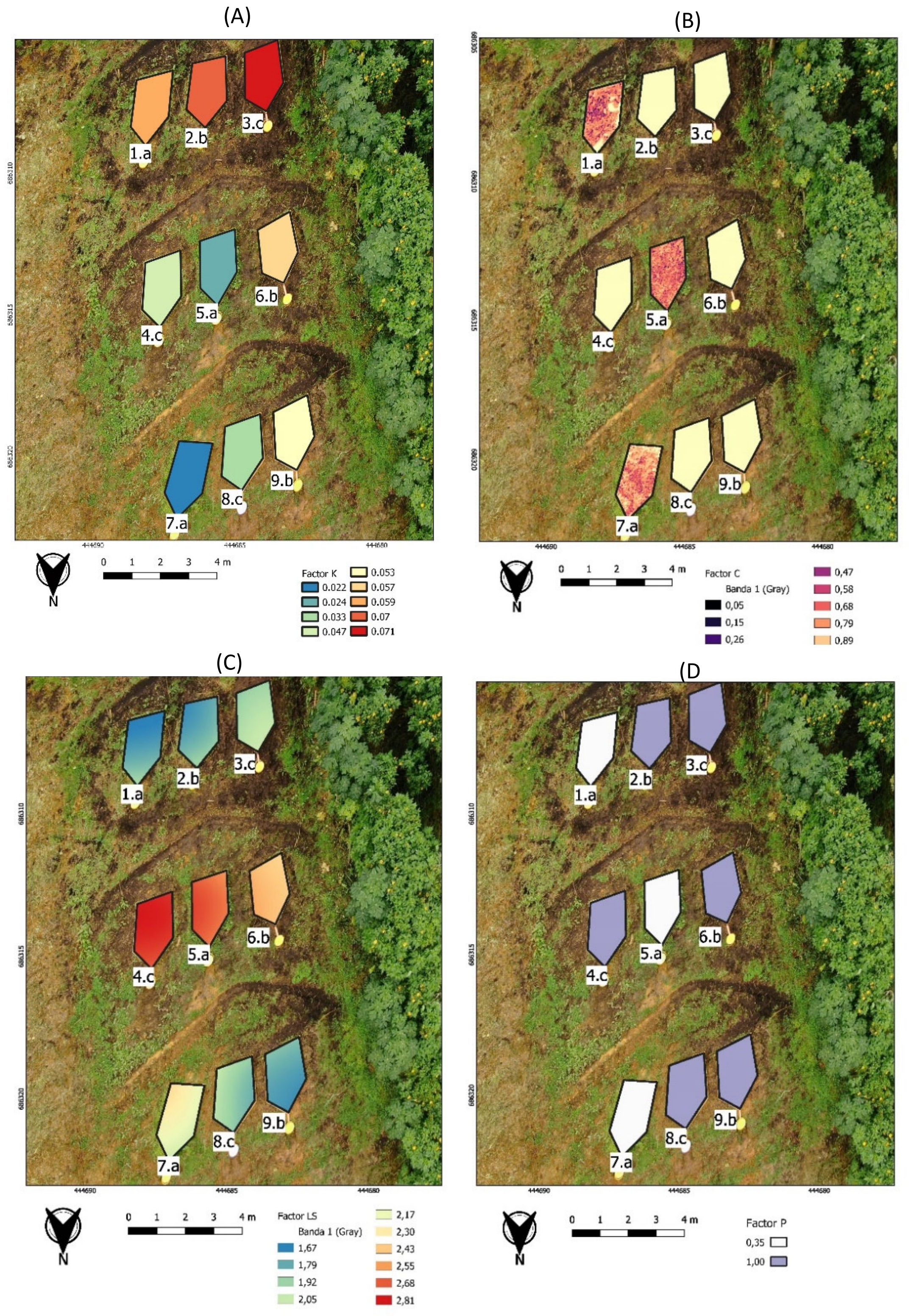

Fig. 5. Behavior of the component factors of the USLE in each of the plots (A. Factor K, B. Factor C, C. Factor LS, D. Factor P.) Source: The authors.

Table 5. Soil loss in each of the plots per treatments and location on the slope (block) estimated using the USLE and experimental tests.

			Soil loss (t ha^{-1} year^{-1})	
Block	**Plot**	**Slope**	**USLE**	**Experimental tests**
I	a	Control	6.21	5.64
	b	Furrowing hoe	31.75	69.53
	c	Conventional hoe	36.67	56.26
II	a	Control	3.03	36.76
	b	Furrowing how	35.76	401.99
	c	Conventional hoe	33.68	218.60
III	a	Control	3.18	62.88
	b	Furrowing hoe	23.78	421.75
	c	Conventional hoe	16.23	306.89

Source: The authors.

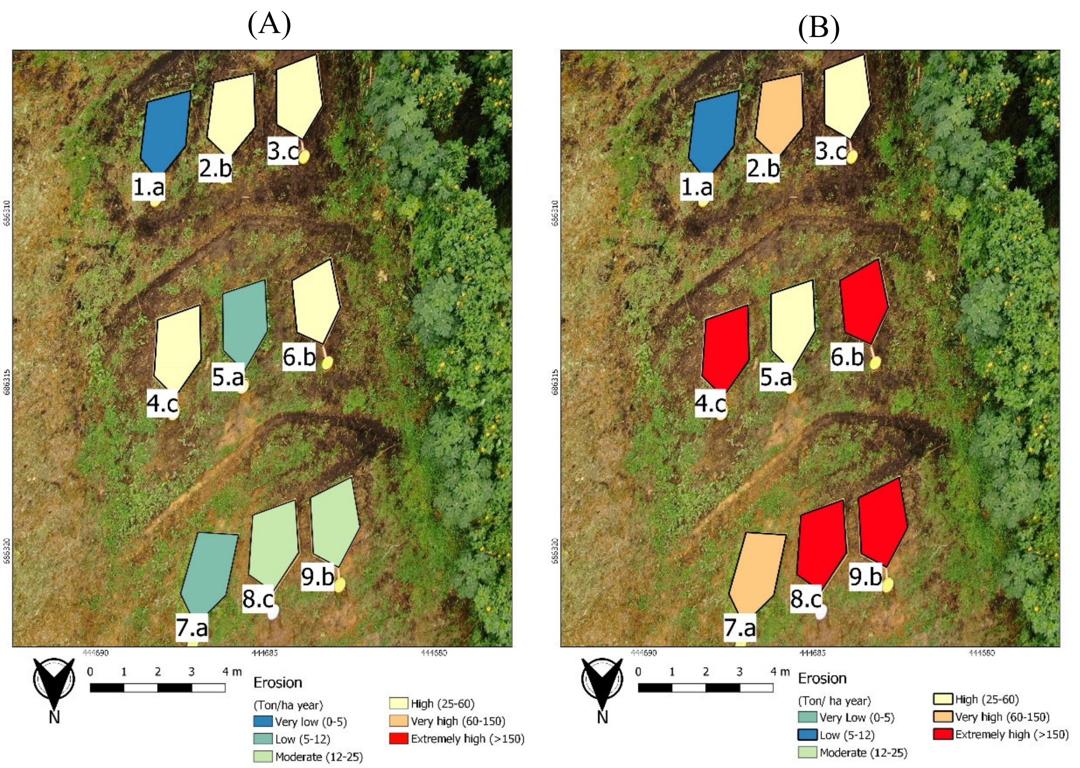

Fig. 6. Erosion in the plots. A. Estimated by the USLE n. B. Evaluated by experimental tests. Source: The authors.

intensity were recorded during the study period, it is also important to consider that the higher the intensity, the less resilient the soil is, and thus erosion tends to increase.

The analysis of variance and Tukey test show significant differences between furrowing hoe tillage and zero tillage (control), but with no differences between this treatment and conventional hoe tillage (Fig.7.A). Based on the USLE, the two tillage treatments show no significant differences, but both differ from the control (Fig 7.B), indicating that there is a significant influence of the hand tillage tool on soil erosion. However, the USLE is less sensitive to small-scale changes derived from factors such as soil type, cover, and slope, which are detected by the experimental method. Furthermore, the USLE does not consider the

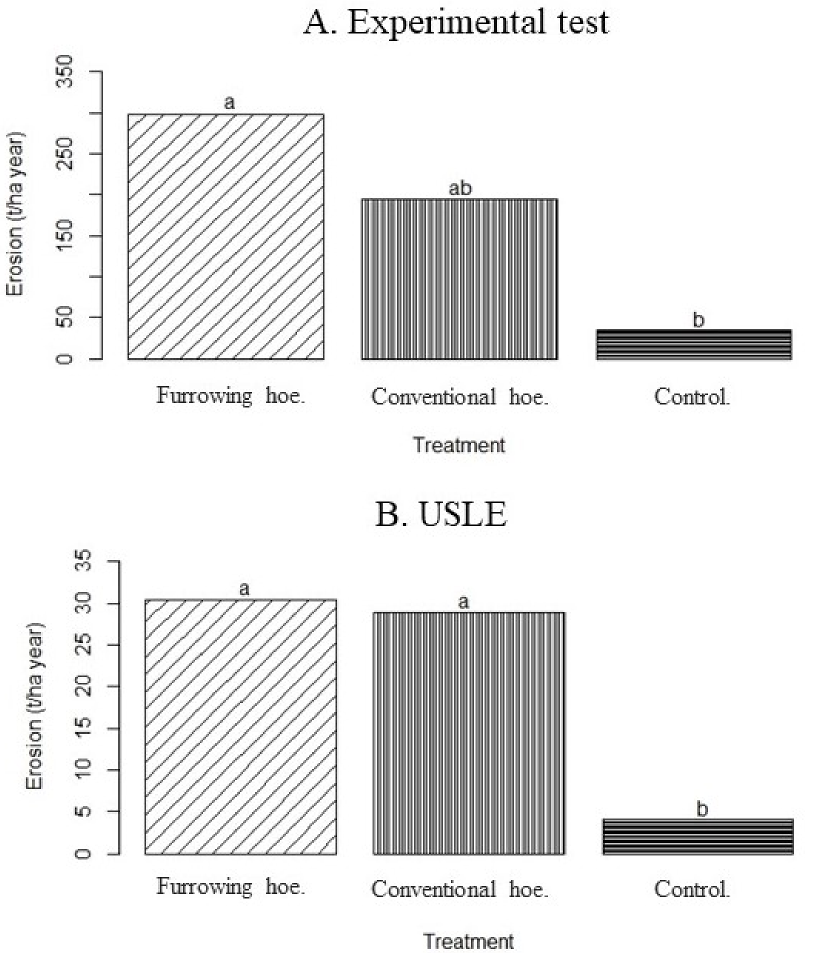

Fig. 7. Soil erosion per treatment (hand tillage tools and control), A. Experimental tests, B. USLE. Different letters indicate differences between the treatments p-value≤0.05 (Tukey HSD).

type of tool used in the tillage process.

Water flow concentration and accumulation was not considered for the plots located in the lower part due to the greater flow accumulation. This favored erosion processes because the area of each plot was isolated (Fig. 3). In the Eastern Antioquia, it is common to find soils with andic properties, characterized by high contents of aluminosilicate minerals and organic matter, with dark colors, and thick texture as observed in all the plots of the upper part (Fig. 3). Depending on intensity and duration, erosion processes remove the surface layer, exposing the horizons formed in situ with lighter colors, with finer texture and with a lower content of organic matter (as observed in the middle part), and with greater intensity in the lower part of the slope. Undoubtedly, factors such as coverage and zero tillage tend to considerably reduce soil loss.

Both hand tillage tools accelerate soil erosion rates; however, based on experimental data or real erosion, furrowing hoe tillage generates higher erosion rates compared to conventional hoe tillage, especially in areas in which transportation of soil particles by dragging and soil loss are more likely to occur, such as those in the middle and lower parts of the hillside. This is because furrowing hoe tillage generates smaller aggregate size. Therefore, the soil is more susceptible to erosion when furrowing hoe tillage is used. In conventional hoe tillage, however, larger aggregates somewhat hinder runoff and improve infiltration, but with less favorable conditions for sowing.

According to the findings of Olivares and Lobo (2010), Olivares et al. (2011), and Olivares, Lobo and Verbist (2015)Metropolitan Region of Chile. Values of erosivity (R, it is possible that the experimentally-measured erosion was higher compared to that found by the USLE model because the USLE may not have considered all of the relevant factors that contribute to erosion, such as weather conditions, land use, and soil properties. Additionally, the USLE model is based on data and assumptions that may not be accurate for a specific location or period. Conversely, the experimentally-measured erosion may have been lower than that predicted by the USLE because field conditions may have been different from the assumptions, and this is why the model should be used as a trend and estimated data.

Despite the differences observed between the erosion rates determined experimentally and those obtained through the USLE, the use of the latter allows explaining the factors responsible for erosion to propose mitigation strategies. It is recommended to adjust the values taken by the USLE parameters according to the conditions of the evaluation site, particularly the types of cover and types of soils − highly variable under the conditions of the tropics − as well as in the reparameterization of these factors to obtain greater sensitivity in the USLE model and approximation to the values obtained experimentally.

By evaluating the potential erosion caused by small-scale manual soil preparation (e.g., the use of plow or hoe), farmers and land managers can make informed decisions about how to minimize erosion and maintain the long-term productivity of their land. Additionally, understanding and mitigating the small-scale erosion caused by manual soil preparation can help improve the overall health of soil (Olivares and López, 2019; Nasir Ahmad et al., 2020; Owens, 2020; Kibii, Kipkorir and Kosgei, 2021) and soil fertility (Lobo, Lozano and Delgado, 2005; De Bie, 2017; Olivares, López and Lobo, 2019), which in turn can benefit crop yield and improve the overall sustainability of farming practices (Olivares and Hernández, 2020; Vanacker et al., 2022).

CONCLUSIONS

Erosion rates obtained by the USLE had significant differences compared to the values obtained experimentally. However, The USLE model provided valuable information about the factors with the highest incidence in soil erosion, revealing that the hand tillage tools evaluated (furrowing hoe and conventional hoe) generated high to extremely high erosion rates. However, the experimental tests revealed that furrowing hoe tillage presented a higher average annual rate of erosion. In addition to rainfall, which was assumed constant for all treatments, the textural characteristics of the soil, organic matter content, and slope were the most favorable factors for erosion.

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