Application of the MMF model for soil erosion evaluation in the karstic slopes of the agricultural district "Nazareno"

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An application of the MMP conceptual-empirical model is shown to evaluate quantitatively soil erosion in the karstic regions of the north slope of the Bejucal-Madruga-Coliseo Heights destined for grazing and located in Mayabeque province, Cuba. In specialized home literature there is no information available on this type of estimations. The model is based on the dynamics of the erosive processes, soil properties, climatic characteristics, relief conditions and the use of the edaphic cover. Slope values in the basins were indispensable for MMF application. This required the processing of the Digital Model of Elevations (DME) in the environment of a Geographical Information System that will allow obtaining the drainage net and the basins of interest. These latter were generated on considering as closing sectors some of the sampling points in which the soils were characterized. As result the drainage net and the generated basin maps are presented. For the first time the magnitudes of soil losses in slope environments are obtained. These heights are identified as the main source of sediments that sequentially descend to sectors of lower hypsometry. The estimated soil losses affect the productive capacity and soil fertility in cattle establishment.

Key words: *slope karstification, slope erosion, erosion model. Rhodic ferralsol soils, Cuba*

The San José de las Lajas valley in Mayabeque province is characterized by the large development of the karstification processes giving rise to a genetic type of karst, identified as flat karst. In diverse studies on soil erosion (Febles *et al*. 2008a, 2011, Vega 2006, Vega and Febles 2006 and 2008) erosion cartography has been used in the environment of a Geographical Information System (GIS) and it has been applied together with the erosion model to estimate soil losses. These investigations have revealed the specific modalities of erosion of the ferrallitic edaphic cover caused by karstic-erosive processes. However, the erosion processes in slopes have not been evaluated with a carbonated substrate on which karstification processes have been developed. This is the geological-geomorphological situation of the Bejucal-Madrugal-Coliseo Heights, where important cattle establishments (dairy units) of Mayabeque province are located, among them, the agricultural district "Nazareno".

From this background, this study was aimed at the evaluation of the dynamics of the erosion processes at the north slope of Bejucal-Madruga-Coliseo heights by the estimation of soil losses at the slopes with the application of an erosion model.

Materials and Methods

Study region. It belongs to the north slope of the natural region of Bejucal-Madruga-Coliseo Heights (Gutiérrez and Rivero 1999). It is localized at the center of Mayabeque province, where the cattle sub-basin Nazareno (figure 1) is found. Reference is made to a landscape of hills and karstic-denudative heights, formed by sedimentary terrigenous-carbonated and carbonated rocks, covered with pastures and semi-deciduous forests (Gutiérrez and Rivero 1999). Geologically they coincide with the structures type horst-anticlinal (Iturralde-Vincent 2011).

The rocky substratum, of carbonated composition, has given place to the development of karstification processes. According to the typological classification, of genetic or morphological characters, the karst of the region is classified as of hills, mountains or plateaus (Gutiérrez 1997).

The relief is characterized by heights (Portela *et al*. 1989) ranging between 130 – 270 m and descending abruptly by a well-defined scarp to a denudative type plain developed on rock layer (of socle), undulating and slightly dissected (H = 100 – 120 m). The main dividing line of the superficial drainage runs through these heights.

Rainfall of the region ranges between 1 000 and 1 100 mm/year, representing approximately 76-80% of the rainfall occurring in the province (INSMET 2012). This rainfall abundance favors the development of geomorphological processes: karstic-erosive and gravitational. The annual absolute minimum temperatures in the territory present average values of 19.5ºC and annual absolute maximum of 26.33ºC, with an annual mean temperature of 23.47ºC.

According to the information of the digital soil map (Paneque *et al*. 1991), in the edaphic cover of

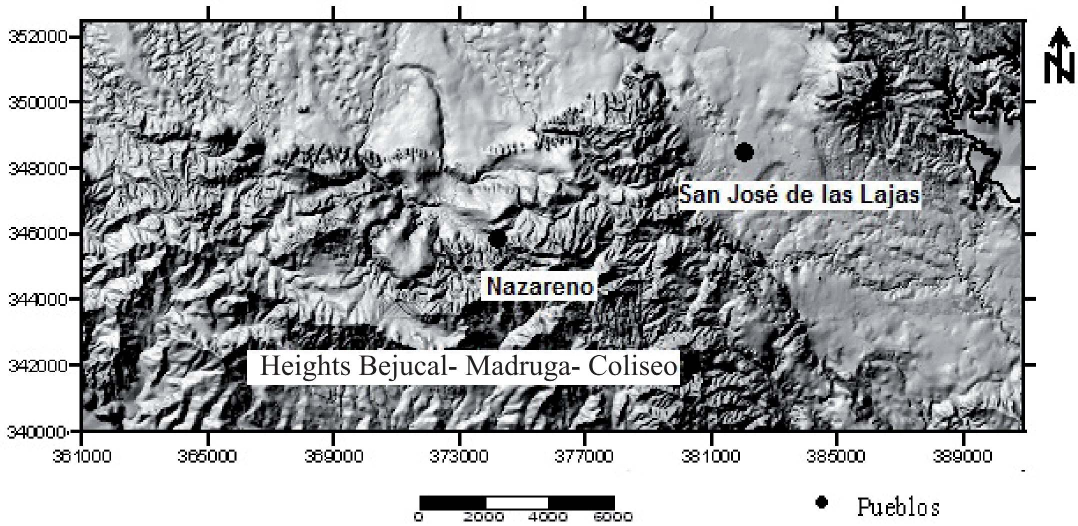

Figure 1. Location of the studied sectors in the Digital Model of Elevations (pixel 25 m)

the region red ferrallitic and brown with carbonate soils prevail. The surface occupied by them is shown in table 1.

There is a spatial differentiation of the vegetation in correspondence with the relief forms. At the tops of flat surfaces are found natural and artificial pastures, with some perennial to caduceus species of stony mounds.

Method to estimate soil losses. Morgan *et al*. (1984) presented a simple empirical model that has been updated by Morgan (2001). This model allows predicting the annual soil loss in slopes. The above mentioned authors used the concepts proposed by Meyer and Wischmeir (1969) for supplying a more solid physical base than the USLE MODEL (Wischmeier and Smith 1960). In this way, besides maintaining the simplicities of an empirical approach, the characteristics of the erosive process was better expressed which they divided in two phases: one hydric and another of sediments. Figure 2 illustrates the diagram of the general flow model.

Hydric phase. Soil erosion in this phase is the result of particle disintegration, due to the wearing away by impact or to the particle transit through the surface flow. Thus, it is necessary to estimate the kinetic energy of the rainfall impact (E) and the surface flow volume (Q).

$E = R\ (11.9 + 8.7\ \log 10I)$, (1)

where:

E = kinetic energy of rainfall (Wischmeier and Smith 1958) (J/m^2)

I = typical value of rainfall intensity for tropical climates (25 mm/h)

$Q = R \exp(- Rc/Ro)$ (2)

$R_c = 000 * MS * BD * RD\ (E_T / E_0)0.5$ (3)

$R_o = R/Rn$ (4)

where:

Q = surface flow volume (mm)

R = annual rainfall (mm)

R_c = critical value of moisture storage

R_o = average rainfall of the rainy days yearly (mm/d)

SM = soil moisture (%)

BD = soil density (kg/m^3)

RD = rooting depth (m)

E_t = current evapotranspiration

E_o = potential evapotranspiration

Sediment phase. The rate of soil dispersed by splash (F) and by the transit capacity of the surface flow (G) was evaluated through the following equations:

$F = 0.001 * K(E * \exp(0.05 * A)$ (5)

where:

F = particles mobilized by splash (kg/m^2)

K = erosional index

E = kinetic energy of rainfall (J/m^2)

A = interception factor by rainfall

$G = 0.001 * C * Q^2\ Sen\ (S)$ (6)

where:

G = transit capacity of the surface flow (kg/m^2)

C = vegetation factor

Q = volume of the surface flow (mm)

S = slope (degrees)

The final prediction of soil loss is made by the

Table 1. Surface occupied by the main types of soil

Type (Paneque *et al*. 1991)	Surface occupied (ha)	World Reference Base (2006)
Red ferrallitic	38 106.496	Ferralsol Rhodic
Brown with carbonates	24 658.760	Cambisol Calcic

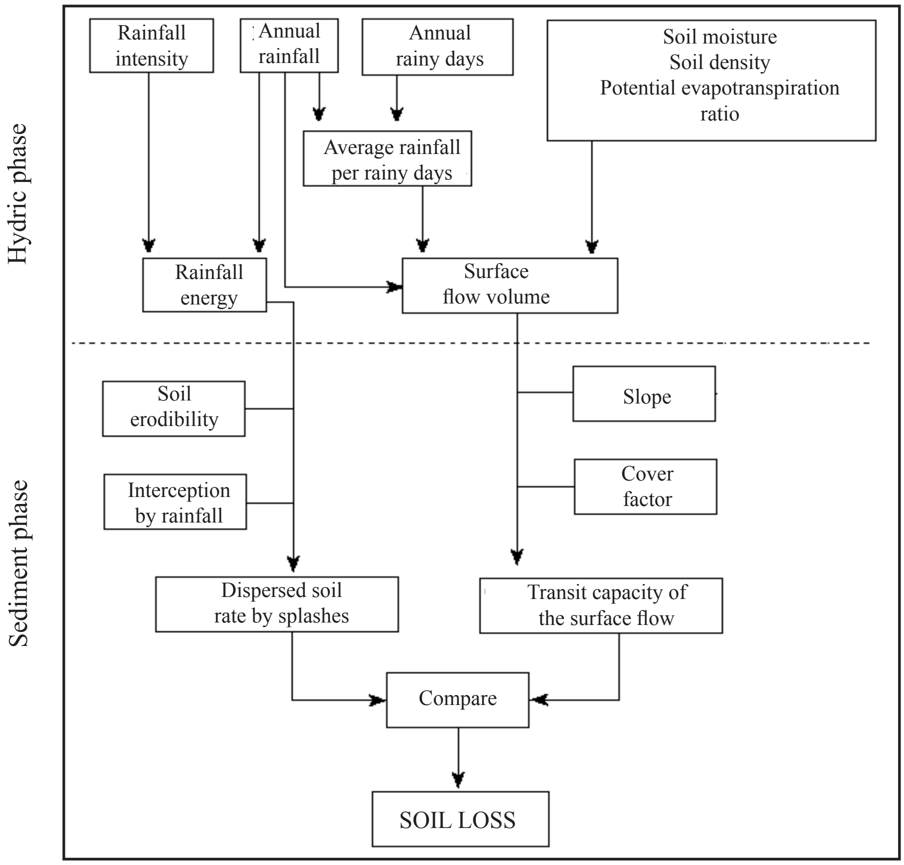

Figure 2. Flow diagram of the MMF model (Morgan *et al*. 1984 and Morgan 2001)

comparison of the values obtained for the transit capacity of the surface flow (G) and for splash removal (F). The lowest of them is taken as annual soil loss rate.

Cartographic base and sampling points. As cartographic base the DME of the studied region (figure 3) was used, together with the location of the points where soil samples were taken for its characterization.

Data for estimating erosion rate by impact (F). Values used as entry parameters to the Morgan model were the following:

E = 33 590 J/m^2 calculated for an erosive rainfall intensity in tropical zones of 25 mm/h

K = 0.02 estimated for the clayey texture characterizing ferrallitic and brown soils

A = 0.30 estimated for a soil occupation by pastures

Data for estimating the transit capacity by surface flow (G)

R = 1 600 mm according data of Tapaste weather station for the year 2010

R_n = 143 according to reports from Tapaste weather station for the year 2003

R_o = 11.18 (mm/d)

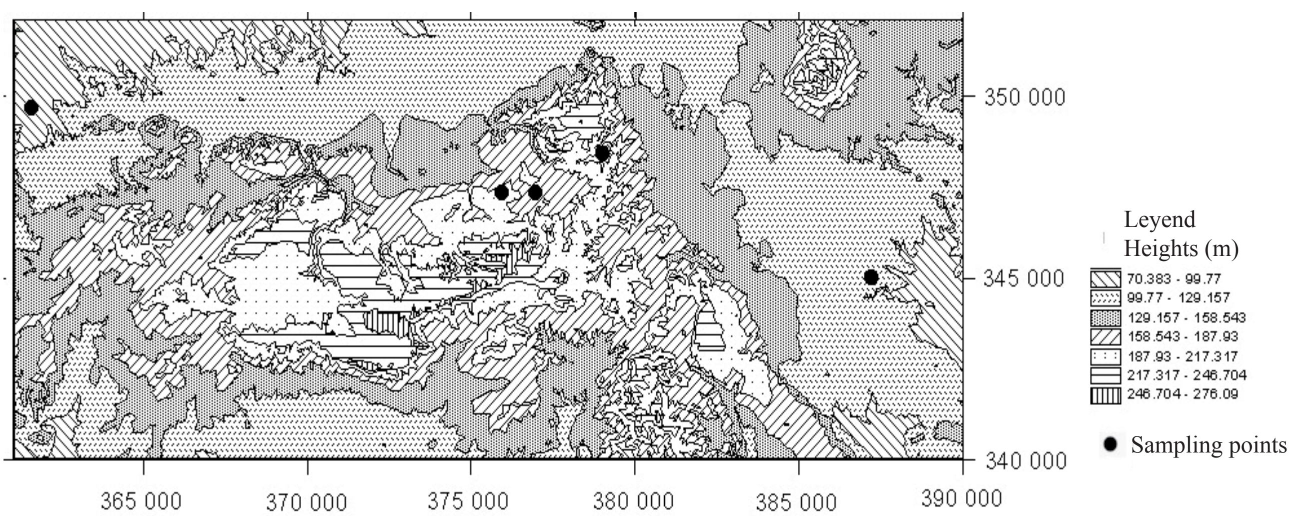

Figure 3. Digital model of elevations with the location of the sampling points

SM = 0.45 estimated for the clayey texture characterizing ferrallitic and brown soils

BD = 1.36 ferrallitics taken from the main soil profiles (Febles 2007)

RD = 0.05 m estimated from the tables proposed by the model

E_r/E_o = 0.85 valued from the tables proposed for the model

C = 0.05 estimated from the tables proposed by the model

Results and Discussion

The Digital Model of Elevations (DME) of the studied region (figure 3) shows that the relief energy values propitiate that the dynamics of the leaching erosion processes be predominant regarding the impact erosion. Topography plays an important role in water distribution and flow in the region, which coincides with Assouline and Ben-Hur (2006) and Blanco and Lal (2008).

The slope is one of the most important relief components regarding soil losses (Morgan 2005). Particularly, in Bejucal-Madruga-Coliseo Heights it determines the sediment transit to sectors of lower hypsometry. For investigating its characteristics the Slope Model was generated from the DME, incorporated to the environment of a GIS. Later, the statistics of the model was calculated, giving as result the predominance of four degrees slopes, although locally these values can reach up to 38 degrees.

Equally, from the DME the drainage net was created (figure 4). It must be highlighted that the drainage represented in the model does not agree with permanent water courses. The model responds to the relative variations of the relief that favor the existence of streams or watersheds along which, when rainfall occurs, the water is channeled and move all sediments generated by its geological action. This dynamics exposed by Tarbuck and Lutgens (2004) gives place to the erosion through the grooves created by the relief, as stated by De Pedraza (1996).

The localization of the sampling points in the drainage model (figure 5) identifies sites to which eroded soil arrives from higher hypsometry levels due to its special link with the streams.

According to what was represented in the map from figure 5, points 2 and 4, in view of their location in the context of the drainage pattern, is essentially produced by impact, when there is a rainfall event that will later generate a flow which is channeled. At the scale of this study, it is not possible to associate any stream. For this reason, only points 1, 3 and 5 were considered to create their respective basins (figure 6). In the same GIS environment the statistics of this map was obtained and table 2 was prepared. This refers the slope parameter of each basin. This result made possible to apply the MMF model.

Table 3 shows the results of the application of the MMF model from the available data and the processing carried out.

Since all values of the transit capacity of the estimated surface flow are lower than those of splash removal F, G values are taken as the annual soil loss in each basin.

Basin C contributes small values of soil losses, which can be explained by its localization in the relief. Figure 7 illustrates its location at the lowest hypsometry level of the region studied, justifying its lower contribution to soil losses.

Those values allow inferring that soil losses in the slopes of Bejucal-Madruga-Coliseo Heights are not tolerable. This statement is based on that according to the information contributed by the drainage net model (figure 5), there is the possibility of delimiting approximately 15 basins more that by their location in the relief will give place to soil losses comparable to basins A and B. As result, total losses at the north slope of the heights will be above 12.5 t ha^{-1} $year^{-1}$, figure that according to Soil Survey Staff (1984) represents the tolerance limit for soil losses.

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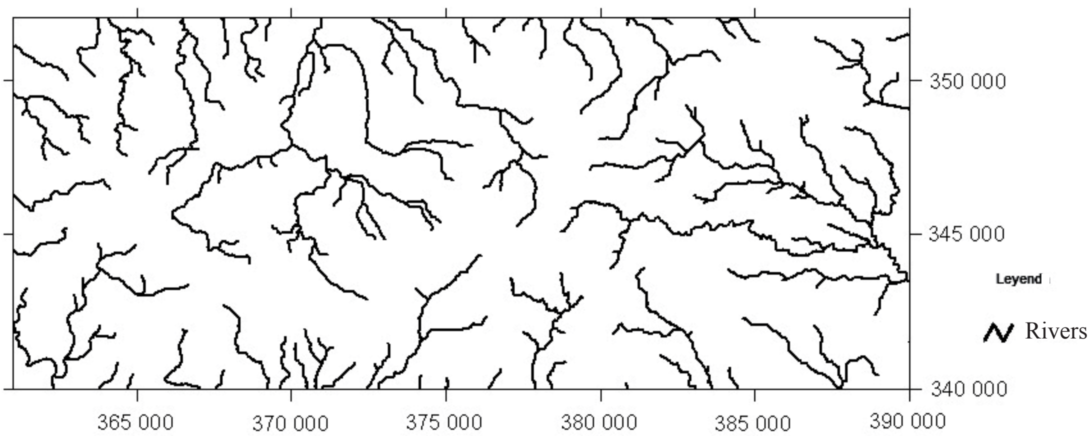

Figure 4. Digital model for the drainage net

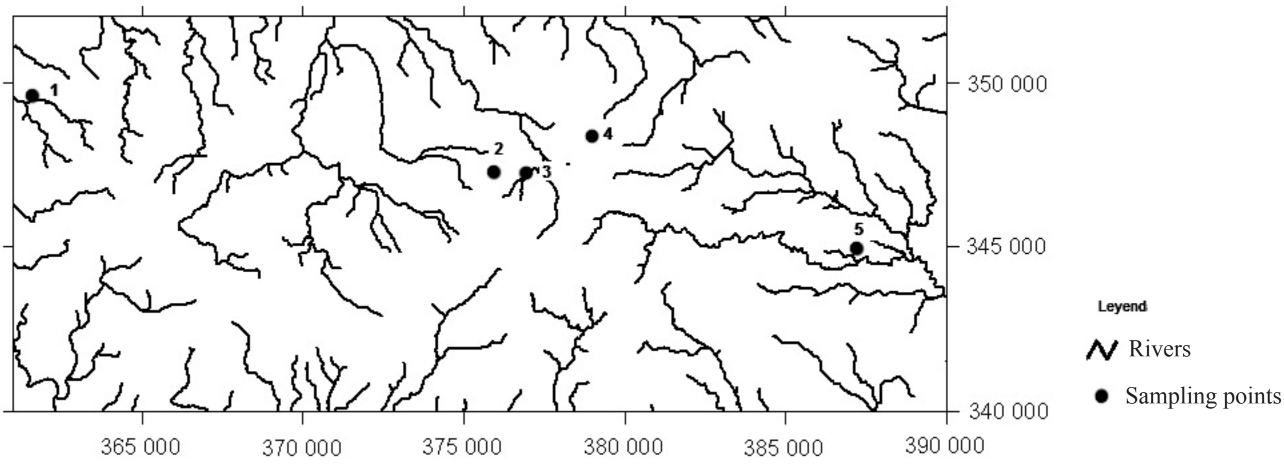

Figure 5. Location of the sampling points in the drainage net

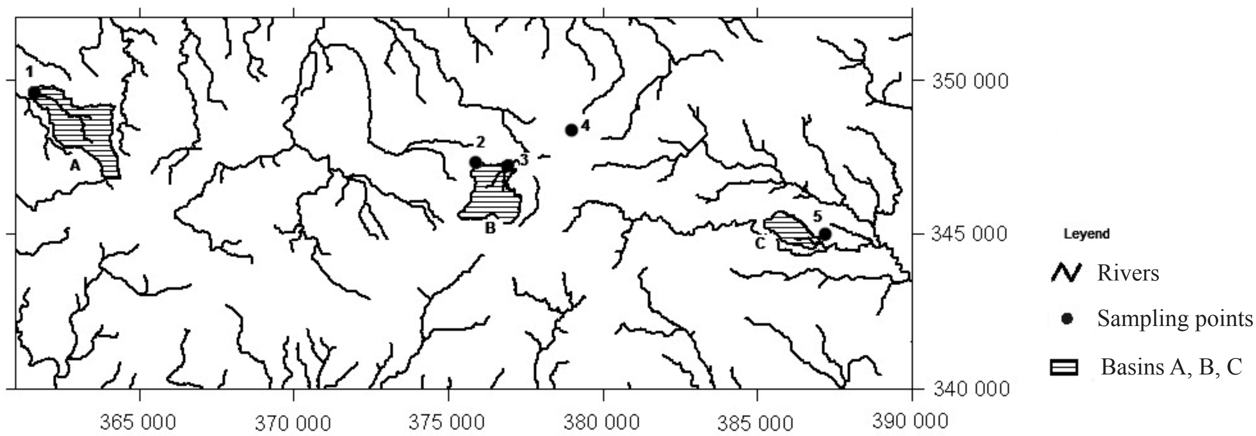

Figure 6. Generated basins

Table 2. Slope statistics of the basins

Basin	Mean slope (S)	Standard deviation	Minimum	Maximum
A	2.67	2.05	0.02	15.11
B	4.85	2.14	0.17	10.57
C	1.14	0.78	0.01	4.39

Table 3. Evaluated parameters to apply the MMF model

Evaluated parameters	Ecuation	Result
F: Dispersed soil rate by splash	5	16.9 t/ha
R_c: Critical value of moisture storage	3	28.2L
Q: Surface flow volume	2	112.0 mm
G: Transit capacity of the surface flow	6	Basin A 1.63 t/ha
		Basin B 1.14 t/ha
		Basin C 0.47 t/ha

certain extent, the Special Period or of economic crisis in Cuba throughout the nineties. In this context, cattle establishments (dairy units) were left progressively disabled and natural regeneration of the tree component (natural vegetation) started with "cicatrizing" species, e.g. marabou, aroma and palms. These species have acted as an induced fallow bringing about certain resiliency (Astier-Calderón *et al*. 2002) or morphoedaphological stability in the processes (Febles 2007), favoring the edaphic recuperation with certain independence from

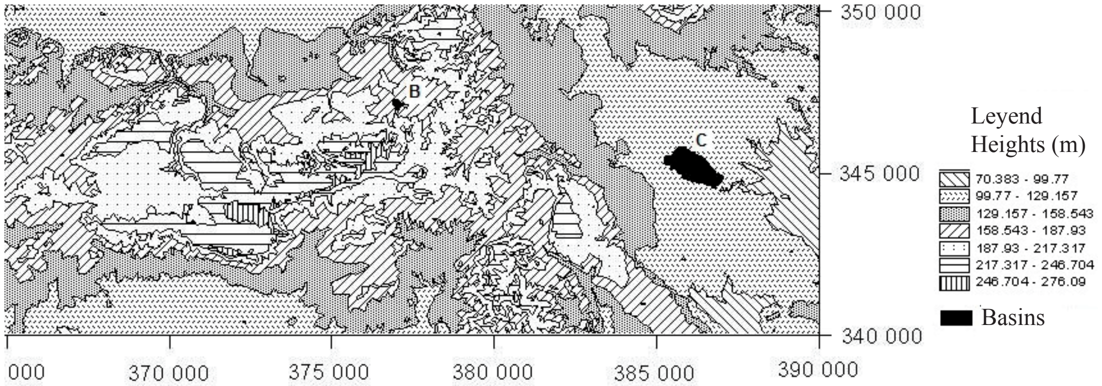

Figure 7. Location of the basins in the relief

the energy value of the relief.

Soil losses, obtained as result of this study, have a negative effect in the agricultural district "Nazareno". They affect the productivity of pasture culture for the cattle, due to the fact that the erosion reduces the productivity by soil loss and changes the physical, chemical and biological properties of the soil (Lobo *et al*. 2005). Particularly in slope areas, similar to those of the agricultural district "Nazareno", soil degradation is an intensive process (Fattet *et al* 2011).

Bejucal-Madruga-Coliseo Heights are the main source of sediments descending sequentially to relief sectors of lower hypsometry where the competition of water courses is progressively lower. This provokes the consequent abandon of sediments which objectively affect the cattle facilities located "downwaters", description agreeing with the results of Jaimez *et al*. (2003).

By the position that the region occupies in the province context, as well as by the morphostructural traits and different processes verified, Bejucal-Madruga-Coliseo Heights are classified as a slithering spacer surface, according to the classification of slope elements proposed by Beasley *et al*. (1986) and Monroe *et al*. (2007).

A more detailed generation of the basins, together with the application of the MMF model, will allow obtaining a total estimation of soil losses for all the north slope of the studied region.

The MMF model supplied the necessary information for estimating for the first time the magnitude of soil losses by karst erosion of heights, for the cattle facilities of the agricultural district "Nazareno".

The north slope of Bejucal-Madruga-Coliseo Heights is the main source of sediments that sequentially descend to plain sectors located at its north.

At the north slope of Bejucal-Madruga-Coliseo Heights can be identified up to 15 basins similar to those studied, where soil losses surpassing the threshold values of tolerance proposed by USLE and the rates of soil formation derived from limestone rocks in Cuba can be predicted.

Soil losses, obtained as result of this paper, have a negative effect in the agricultural district "Nazareno", since they affect the productivity of pasture culture for cattle.

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