Estimating the Efficiency of Anti - Erosion Agricultural Operation for the Corn Crop on the Slopes

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Abstract. The efficiency of the anti - erosion agricultural operations is one of the main objectives of the designers for machinery and soil working tools on slopes. Mathematical modelling that using a systemic approach of the phenomena and processes and realistic assumptions, allows the optimum constructive-functional parameters for soil working tools, in order to achieve a properly working with low energy consumption. Storage capacity of the sediment profiles achieved by ground shaping is properly estimated according to the geo-climatic conditions of the area.

Previous researches (Cardei, Cota, 2008) led to the establishment of a calculation model in this respect. The method of calculation for choosing the geometry of profiles is the application of the final investigations, in conditions to assure a satisfactory storage capacity of sediments and a minimum energy consumption for the soil working processes.

Keywords: anti - erosion, soil, profile, optimization, efficiency

INTRODUCTION

Anti - erosion agricultural facilities include not only soil and drainage, methods of work along the lines, etc. Another method of soil conservation on cultivated slope, is soil profiling on the slopes so that sediment produced after rain, trigger factor in the soil erosion and maintenance processes, to be held entirely in the channels thus created. Such a process is used in weeding crops, especially maize, situated on the slopes. Equipment designed in order to achieves such profiles were made at INMA Cluj-Napoca - CPU machine equipped with anti-erosion bodies working, OLAC. In (Cardei, Cota, 2008) were given details about the equipment and its performance. We also showed in (Cardei, Cota, 2008) how to make a checklist of minimum storage capacity of the sediment profile created and how the tilt is estimated that storage capacity may become insufficient. In this article we give an alternative account and also check the calculation of (Cardei, Cota, 2008). For comparison we estimated the loss of soil on a smooth surface of the same length with corrugated slope.

1. GEOMETRY AND PROFILE OF SLOPES

The geometry of the profiled slope and of the smooth slope is shown in Fig. 1. Note that, in comparison with (Cardei, Cota, 2008), we simplified the profile, so that geometry has as date only two parameters: distance between two consecutive peaks, \( d \) and the depth profile, \( a \). Distance between two peaks of the profile, \( d \) is fixed by the crop characteristics, for
example, $d = 0.7$ m for the cultivation of grain maize. Parameter remains free is the depth profile, $a$, defined as the distance between minimum and maximum share of the profile measured on the vertical of the smooth hill slope.

To calculate the storage capacity of a profile (channel) is used the formula (1).

$$A_s = \frac{a \cdot d}{2} \cdot \frac{2a - d \cdot \tan \alpha}{2a + d \cdot \tan \alpha}$$

For the storage capacity of the cell profile calculus, is considered a band width of the slope $l_f$ and soil density, $\rho$. Then, the storage capacity on patches slope is given by formula (2).

$$c_i = \rho \cdot l_f \cdot A_s = \frac{a \cdot d \cdot \rho \cdot l_f}{2} \cdot \frac{2a - d \cdot \tan \alpha}{2a + d \cdot \tan \alpha}$$

1.1 ASPECTS OF INTERACTION BETWEEN PROFILE AND ANGLE SLOPES

In this chapter will look better detailed geometry profile in relation with slope angle. A detail on the geometry horizontal profile and rotated profile with the angle of slope, $\alpha$, appears in Fig. 2.
Theoreticaly, the corrugated slope is obtained by the horizontal corrugate plan by a rotation with the slope angle. By rotation, the segment AB becomes segment A'B' and the segment BC becomes B'C', the angle of those keeps the value. We suppose that management ensures the cultivation on the approximate lines of level. Initial angle of the channel walls with the horizontal, AB and AC is \( \beta \) (small angle to the first dial, which is interested for calculating the sediment delivery). After rotation, the slope angle of the wall AB' is \( \alpha + \beta \) and the angle of wall B'C' with the horizontal is \( \beta - \alpha = \gamma \). The formula for the \( \beta \) angle calculus is

\[
\beta = \arctg \left( \frac{2a}{d} \right) \quad (3)
\]

in radians. The length of the profile walls is given by the formula (4).

\[
l = \sqrt{a^2 + \frac{d^2}{4}} \quad (4)
\]

Using these formulas, is calculated the area of the triangle C'B'D, which is the area of the profile, where the sediment is stored, \( A_s \), given by the formula (1).

Now is consider a side length \( L \), N shaped profile of this type, so the relationship is valid: \( \Lambda = N \cdot d \). The hill slope is divided in \( N \) walls, which have the length \( l \) and the slope angle \( \beta + \alpha \), and \( N \) walls, which have the length \( l \) and the slope angle \( \beta - \alpha \).

In geometric and physical terms, must be kept in mind that if \( \beta + \alpha > \pi / 2 \) (90°, or negative slope), then the walls of the high profile of the type AB, may not formally contribute sediment, since no received drops of water, unless rain falls obliquely. Do not consider this material in such a profile. If we note:

\[
S_{s0} = \frac{a \cdot d}{2} \quad (5)
\]

The channel area for the hillslope with the null inclination, then, after (1), is obtained for the area of the storage profil, located by the hill slope with inclination \( \alpha \), the next formula:

\[
S_s(\alpha) = S_0 \frac{\sin(\beta - \alpha)}{\sin(\beta + \alpha)} \quad (6)
\]

2. SEDIMENT PRODUCTION ON THE PROFILED HILL SLOPE AND ON THE SMOOTH HILL SLOPE

Production of the sediment on the corrugated hill slope, or smooth hill slope is given by the same formula of the universal equation of soil erosion (USLE factorial model). General formula for calculation is (after (Van Rompey, et all, 2003) and (wikipedia):

\[
A = R \cdot K \cdot L \cdot S \cdot C \cdot P, \; C = C_1 C_2 \quad (7)
\]
where (partial after (Van Rompey, et all, 2003), or (wikipedia)) the meanings and units of measurement are given in Tab. 1. Details appear in Tab. 1.

**Tab. 1**

Significance of the parameters of the USLE formula, (1), and the measurement units.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Significance</th>
<th>Measurement unit</th>
</tr>
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<tbody>
<tr>
<td>$A$</td>
<td>Sediment delivery</td>
<td>kg m$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>$R$</td>
<td>Rainfall/runoff erosivity</td>
<td>kg m$^{-4}$ s$^{-1}$</td>
</tr>
<tr>
<td>$K$</td>
<td>Soil erodibility</td>
<td>m$^{-3}$ s$^{-1}$</td>
</tr>
<tr>
<td>$L$</td>
<td>Factor of the hill slope length</td>
<td>Adimensional</td>
</tr>
<tr>
<td>$S$</td>
<td>Slope factor</td>
<td>Adimensional</td>
</tr>
<tr>
<td>$C_1$</td>
<td>Cover management factor</td>
<td>Adimensional</td>
</tr>
<tr>
<td>$C_2$</td>
<td>Soil management factor</td>
<td>Adimensional</td>
</tr>
<tr>
<td>$P$</td>
<td>Support practice factor</td>
<td>Adimensional</td>
</tr>
</tbody>
</table>

Physical dimensions of the dimensional terms are $[A]=ML^{-2}T^{-1}$, $[R]=MLT^{-4}$ si $[K]=L^{-3}T^{-3}$. Because we suppose a local homogenous condition for the soil and rain, we consider that the factors $R$, $K$, $C_1$, $C_2$ and $P$ are constant, and $L$ and $S$ are functions by the geometrical characteristics: the length and the inclination angle of the hillslope. For the calculus of the $L$ and $S$, is used the formulas (8), (9), (10), and (11), according with (Jianguo Ma, and all, 2001):

$$L(x,\alpha)=\left(\frac{x}{22.13}\right)^{n(\alpha)}$$

where:

$$n(p)=\begin{cases} 
0.2, & p < 1 \\
0.3, & 1 \leq p < 3 \\
0.4, & 3 \leq p < 5 \\
0.5, & p \geq 5 
\end{cases}$$

where $p$ is the slope of the hill, situated in the next relation with the inclination angle:

$$p = 100 \cdot \operatorname{tg} (\alpha)$$

The function $S$, according with (Jianguo Ma, and all, 2001), depends by the inclination hillslope angle, after:

$$S(\alpha) = 65.41 \sin^2 \alpha + 4.56 \sin \alpha + 0.065$$

Generally, if the hillslope with the total length $L$ and the inclination angle $\alpha$ is corrugated with $N$ profile, then appears $2N$ small hillslope – the channels walls. Be the length of the i wall and $\theta_i$, its inclination angle. Then the sediment delivery of the smooth hillslope is given by the formula (12). This formulation is more generally than the formulation for the symmetric profile, because the channel walls can varied in length and angle.
\[ A_n = R \cdot K \cdot C \cdot P \cdot L(\Lambda, \alpha) \cdot S(\alpha) \]  

(12)

For the corrugated hill slope, the sediment delivery is given by formula (13).

\[ A_p = R \cdot K \cdot C \cdot P \cdot \sum_{i=1}^{2k} L(\lambda_i, \theta_i) \cdot S(\theta_i) \]  

(13)

The soil loss for the entire smooth slope will be equal with the sediment delivery:

\[ P_n = A_n \]  

(14)

and for the corrugated slope:

\[ P_p = \begin{cases} 
0, & \text{daca } A_p \leq C_{sp} \\
A_p - C_{sp}, & \text{daca } A_p > C_{sp}
\end{cases} \]  

(15)

where \( C_{sp} \) is the total storage capacity of the corrugated slope:

\[ C_{sp} = N \cdot c_s \]  

(16)

and \( c_s \) is the storage capacity for one profil, given in (2).

Since the profiled hill slope length is greater than the length of the smooth hill slope, and angles of inclination of the profile walls are greater than the angle of inclination of the smooth hill slope, we expect that the production of sediment on the profiled hill slope to be higher than the production of sediment on the smooth hill slope:

\[ A_p > A_n \]  

(17)

However, due to sediment storage capacity, on the profiled hill slope, the sediment doesn’t leave the hill slope until a time. Thus, until the limit time, the loss of soil for the entire profiled hill slope is null, making abstraction by the loss to the edge plots. For this reason, the function of the soil loss, for the profiled hill slope, has the expression given in (15). After the limit time is exceeded, which in terms of designer profile, do not recommend, the soil loss on the profiled hill slope grows quickly and can overcome the loss of soil on the smooth hill slope.

3. EFFECTIVENESS OF PROFILING

A profiling system can be considered effective for a geographic and climacteric situation, if the condition (18) is valid.

\[ P_p = 0 \]  

(18)

Condition (18) can be considered a condition of effectiveness "hard", in contrast with another condition of efficiency, which we call "weak", given by the formula (19).
The “weak” efficiency condition expresses requirement that the loss of soil on the profiled hill slope to be less than the loss of soil on the flat. Both criteria of efficiency (18) and (19) lead to the choice of construction parameters, possibly adjustable, so that efficiency criteria to be satisfied. For example, these criteria can be used for deducing the minimum tread depth at which the criteria of efficiency are satisfied, for a hill slope with a given inclination angle.

To obtain an optimal design formula, add the criterion of efficiency of energy consumption at minimum soil profiling (minimizing the depth and width of work). If the “hard” criterion is considered together with the energetic criterion of efficiency, that will take the depth profiling, depth minima which satisfying (18). If is consider the “weak” criterion of efficiency, (19) and the energy efficiency criteria, may choose less depth than in the first case.

4. CUSTOMIZE THE PROFILE SYMMETRICALLY CONSIDERED

Taking into account the geometry of the profile and the considerations of Chapter 2, formula (13) becomes:

\[
P_p \leq P_n \quad \text{(19)}
\]

The channel with symmetrical profile, considered - isosceles triangle with base length \(d\) and height relative to the base, \(a\) - is characterized by only two parameters. Another parameter of the problem is the inclination angle of the hill slope, \(\alpha\). Geographic and climatic parameters are \(R\), and \(K\) (see Table 1). Another physical parameter of the soil is the soil bulk density in the soil superficial layer, \(\rho\). The past parameters of the model are the management parameters \(C_1\), \(C_2\), and \(P\) (see table 1). Seconary parameters are the hillslope length, \(L\), and the width parcel, \(l_f\). In this parametric space we can study various issues:

1) For an agricultural crop and geo-climatic fixed data, for an established management, and for a certain parcel width, it may be to calculate the necessary depth profile, \(a\), so that the production of sediment to be equal to the maximum storage capacity profile. In this case, the inequality which must be solved is the following:

\[
L(l, \beta + \alpha) \cdot S(\beta + \alpha) + L(l, \beta - \alpha) \cdot S(\beta - \alpha) \leq \frac{\rho \cdot l_f}{R \cdot K \cdot C \cdot P} \cdot S_s(\alpha) \quad \text{(21)}
\]

This inequality and their attached equation can be solved only numerically, because the \(L\) si \(S\) functions are non-linear in arguments \(a\) (which is included in the expression of the angle \(\beta\), formula (3)) and \(\alpha\).

In Fig. 3 is shown the variation curves of sediment delivery for the smooth and profiled hill slope, depending on the angle of inclination of the hill slope. Sediment delivery for the smooth hill slope increase continuously after a nonlinear curve, but not very far from a linear. Sediment delivery for the profiled hill slope is void until the angle of inclination of hill slope is less or equal with the value which involves the equality between the sediment delivery and the storage capacity, and after, and grows very fast, non-linear but very close to a linear. There is an angle of inclination at which the sediments delivery of the two types of hill slope versions are equal, and the value of this angle is slightly greater than that in which sediment delivery shaped slopes becomes void. The curves which are shown in the Fig. 3 are
calculated for the following values of parameters considered constant: \( R = 600 \text{ kgm/s}^4 \), \( K = 0.03 \text{ s}^3/\text{m}^3 \), \( C = 0.186 \), \( P = 0.5 \), \( \rho = 990 \text{ kg/m}^3 \), \( a = 0.15 \text{ m} \), \( d = 0.7 \text{ m} \), \( l_f = 1 \text{ m} \).

![Graph showing the variation of sediment production on the smooth and profiled hill slope, depending on the angle of inclination.](image1)

![Graph showing the dependence curve profile depth vs angle of inclination of hill slope.](image2)

At the same parametric space can be allowed to determine an area of choice for the depth of the profile, \( a \), depending on the angle of inclination of the hill slope, \( \alpha \), using the condition of "hard" efficiency. All the points located on the curve which are shown in Fig. 4 are the points whose coordinates involve equal storage capacity with the sediment delivery for the profiled hill slope. All points above the curve in Fig. 4 correspond to the case in which storage capacity is greater than the sediment delivery of the profiled hill slope. Designer profile, or one that regulates the working of the machine, choose, for an angle of inclination of hill slope, gave a value of depth corresponding to a point located above the curve are equal, given a policyholder reserves, eventually.

A similar situation will find if we use the "weak" efficiency criterion, the curve, in this case, is located under the curve shown in Fig. 4, but at insignificant distance, as shown Fig. 3 (distance between the two roots is very small).

2) In the same sense that the problem 1) can calculate the minimum tread depth, considering the variable and the rainfall erosivity, \( R \). In this case would result expression of depth, \( a \), depending on the angle of inclination of the slopes, \( \alpha \) and the rain erosivity, \( R \). A typical result for this problem is shown in the Fig. 5. In Fig. 5 is shown the changes produced in the value distribution of the “hard” efficiency as a function of two parameters (\( a \), \( \alpha \)), when the rainfall erosivity \( R \) is changing. The designer must choose a point above the 0 line with hill slope angle knowing, received such amount necessary depth profile.
It is recommended that the depth is not chosen yet the curves for annulment of efficiency, but in the positive, in order to provide a useful reserve in case of unforeseen events.

![Fig. 5 The variation of the “hard” efficiency, depending on the angle slopes and profile depth when the change of the rainfall/runoff erosivity.](image)

**CONCLUSIONS**

The study on the possibilities of quantifying of the effect of the hill slope corrugation as anti-erosion measure, in the field of mechanization technologies of weeding crops located on hill slope land, shows not only that these technologies are provided effectively, but demonstrates that there is an algorithm based on which the designer or user and moulding machines for land, can obtain the desired efficiency, depending on the geographic and climatic factors, considering also the minimize energy consumption required for the work performance.

The mathematical model described in this paper, the resulting mathematical relationships, enabling an efficient design of the parameters, since the design phase of the machine tool for the soil corrugation, which is adjustable, allowing the user a correct use, in the sense of satisfying the criterion of efficiency ("hard" or "weak") considering the minimization of energy needed to make the work of forming soil.

**REFERENCES**


