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A THEORETICAL METHOD OF DETERMINING THE OPTIMUM FOR PREVENTING WATER EROSION

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ABSTRACT:
Research works of many years and in many counties have indicated that the field relief and more specifically the gradient and the length of the slope as its basic elements have determinative effect on water erosion intensity. It has been determined that the higher the slope's gradient and length are, the higher the quality of water runoff resulting from erosion rainfalls and snowmelts and the quantity of washed out and eroded soil are. Therefore, to bring this process under control, it is necessary to divide the length of the slope into separate parts through forming water runoff stemming earth works. They are intended for taking in the surface water runoff and are set up transversely to the slope or along the horizontal lines. These earth works are as follows: water runoff stemming furrows, cuts with subsoil dead-furrows at the bottom, parallel cuts with subsoil dead-furrows at the bottom or a combination of furrows, cuts and subsoil dead-furrows.
The present report goes into the manners of determining the optimum distance between these earth works with the purpose of maximum diminishing the surface water runoff and the quantity of eroded soil.
KEY WORDS:
soil water erosion, water runoff stemming earth works interspacing, optimum distance

1. INTRODUCTION

The research work carried out by Kostyakov A.N. (1951), Kocherga F.K. (1965), Wischmeier W.H. D.D. Smith (1965), Daskalov J.T.(1972), Stanev J.S. (1979), Onchev N.G. (1983), Zakov D. (2001) etc. indicate that the terrain relief and more particularly the gradient and the length of the slope as its basic elements have determinative influence on water erosion intensity. It has been determined that the higher the slope's gradient and length are, the higher the quality of water runoff resulting from erosion rainfalls and melting snow as well as the quantity of washed out and eroded soil are.

Therefore, to bring this process under control it is necessary to divide the length of the slope into separate parts through forming water runoff stemming earth works, which are intended for taking the surface water runoff. They are set up transversely to the slope or along the horizontal lines and are as follows: water runoff stemming furrows, cuts with dead-furrows at the bottom, parallel cuts with dead-furrows at the bottom or a combination of furrows, cuts and dead-furrows.

It has been proved that the smaller interspacing of these works results in reduced quantity of surface water runoff and hence in the quantity of eroded soil. Having taken that into consideration, Kostyakov A.N. (1951) assumes that the interspacing on the slope surface should be calculated so that the speed of water runoff caused by heavy rainfalls between two erosion control works (cuts) should not exceed the top speed of soil crossing and introduces the formula:

$$l = \frac{V_{max}^2}{m^2 c.i\sigma} \quad (1)$$

Where:

- l - the interspacing between two water runoff stemming works, m;
- V – maximum speed of the surface water runoff at which soil starts being washed out, m/s;
- m – the water runoff speed factor along the slope;
- c – the factor resulting from the slope gradient and the soil surface roughness;
- i – rainfall intensity, m/s;
- σ – water runoff factor.

This approach has also been applied by other authors [5], [7] and [3], but we believe that applying it creates some difficulties and inaccuracies at calculating the interspacing between the water runoff stemming earth works formed at different soil types as they all use only one and the same value for V_{max} for soil (for soft and poor soil $V_{max} = 0{,}15$ m/s) at applying formula (1).

Taking that into consideration there is yet another approach for determining the optimum (the most suitable one from erosion control point of view) interspacing between the water runoff stemming earth works.

2. EXPOSITION

The gist of the suggested new approach lies in determining the interspacing (l_{on}) between the separate water runoff stemming earth works under the circumstances for reducing the surface water runoff, which according to Kostyakov A.N (1951) reaches its highest value at the end of the slope at rainfall discontinuance (provided the rainfall duration equals the runoff duration).

The volume of this maximum surface water runoff with different soil types can be determined accurately enough through utilizing water runoff stemming works and immediate observations as well as through imperative formulas. Stanev J.S. (1979) believes that it can be determined according to the formula

$$W_{max} = h.F, \quad (2)$$

where:

- W_{max} is the volume of the maximum surface water runoff at the end of a particular slope, m^3;
- h – the height of the surface water runoff at the end of the slope, m;
- F – the slope area, m^2.

Kostyakov A.N. (1951) suggests the following expression for determining the volume of the maximum surface water runoff at the end of a particular slope:

$$W_{max} = \frac{2}{3} hLB , \quad (3)$$

where:

- $h = \sqrt{\frac{L(i-k)}{k_1}}$ is the height of the surface water runoff with a slope length of L, m;
- L – the length of the slope, m;
- B – the width of the slope, m;
- i – the rainfall intensity, m/s;
- k – the speed of water absorption in the soil, m/s;
- $k_1 = \frac{87\sqrt{J}}{Y}$ - permanent factor;
- J – the gradient of the slope, %;
- Y – the slope roughness factor (determined according to a table in conformity with the condition of the soil).

Dividing the value obtained in that way for W_{max} by the volume of the maximum quantity of water, which can be taken by a water runoff stemming (erosion control) earth works (a cut, a furrow, a combination of a furrow and a cut, etc.) results in obtaining the total number of these works along the whole length of the slope.

$$n = \frac{W_{max}}{W_{п.с.}}, \quad (4)$$

where:

- n – the minimum number of the necessary water runoff stemming (erosion control) works formed on a particular slope;
- W_{max} - the volume of the maximum surface water runoff at the end of a particular slope, m^3;
- $W_{п.с.}$ - the volume of the maximum water quantity which can be taken for the rainfall duration by a water runoff stemming earth works formed on a particular slope, m^3.

After rendering an account of the above the optimum interspacing between the water runoff stemming earth works on a slope can be determined through the expression:

$$l_{оп} = \frac{L}{n}, \quad (5)$$

where:

- L - the length of the slope, m.

The final formula for determining the optimum interspacing between the water runoff stemming (erosion control) earth works formed on a particular slope is obtained after substituting expression (4) in (5)

$$l_{оп} = \frac{L.W_{п.с.}}{W_{max}}. \quad (6)$$

The volume of the maximum water quantity ($W_{п.с.}$) which can be taken by each of the water runoff stemming earth works during the rainfall is of different value and is determined as follows:

- **for a single cut with a dead-furrow at its bottom**

$$W_{пр.} = B(F_{пр.} + 2k\chi_{пр.}.t) \quad , \tag{7}$$

where:

- $W_{пр.}$ – the volume of the maximum water quantity taken by a single cut with a dead-furrow at the bottom formed on a particular slope during the rainfall, m^3;
- B – the width of the slope on which the surface water runoff is formed (the length of the cut), m;
- $F_{пр.}$ – the vertical section of the cut with a dead-furrow at the bottom, m^2;
- k – the speed of water absorption in the soil, m/s;
- $\chi_{пр.}$ – the wet perimeter of the cut with a dead-furrow, m;
- t – the duration of collecting the water quantity in the cut with a dead-furrow at the bottom (rainfall duration), s.

In this formula the speed of water absorption in the soil (k) is multiplied by the number of 2 as it has been found out that at applying the erosion control method of cutting with dead-furrows at the bottom the absorption speed increases twice [Dimitrov P.D. (1994)].

- **for a single cut**

$$W_{бр.} = B(F_{бр.} + k\chi_{бр.}.t), \tag{8}$$

where:

- $W_{бр.}$ - the volume of the maximum water quantity which is taken by a single cut formed on a particular slope during the rainfall, m^3;
- B - the width of the slope (the furrow length), m;
- $F_{бр.}$ - the vertical section of the furrow, m^2;
- k - the speed of water absorption in the soil, m/s;
- $\chi_{бр.}$ - the wet perimeter of the furrow, m;
- t - the duration of collecting the water quantity in a single furrow (rainfall duration), s.

- **for the combination of a furrow, a cut and a dead-furrow**

$$W_{б\ пр} = W_{бр} + W_{пр}\ , \tag{9}$$

where:

- $W_{б\ пр}$ is the volume of the maximum water quantity taken by a combination of a furrow, a cut and a dead-furrow at the bottom formed on a particular slope during the rainfall, m^3;
- $W_{бр}$ - is the volume of the maximum water quantity taken by a single furrow formed on a particular slope during the rainfall, m^3 ;
- $W_{пр}$ - is the volume of the maximum water quantity taken by a single cut with a dead-furrow at the bottom formed on a particular slope during the rainfall, m^3.

- **for two parallel cuts with dead-furrows at their bottoms**

$$W_{п.пр} = 2W_{пр} + l_{пар}Bkt \, , \qquad (10)$$

where:

- $W_{п.пр}$ - the volume of the maximum water quantity taken by two parallel cuts with dead-furrows at their bottoms formed on a particular slope during the rainfall, m^3 ;
- $W_{пр}$ - is the volume of the maximum water quantity taken by a single cut with a dead-furrow at the bottom formed on a particular slope during the rainfall,m^3
- $l_{пар}$ - the interspacing between the two parallel cuts, m;
- B - the width of the slope (the length of the parallel cuts), m;
- k - the speed of water absorption in the soil, m/s;
- t - the duration of collecting the water quantity in the two parallel cuts with dead-furrows (rainfall duration), s.

TABLE 1. VALUES OF THE VERTICAL SECTIONS AND WET PERIMETERS OF SOME WATER RUNOFF STEMMING EARTH WORKS USED IN BULGARIA

No in order	Water runoff stemming earth works	Working depth (m)	Vertical section F (m^2)	Wet perimeter χ (m)
1.	A single cut with a dead-furrow at the bottom	0,40	0,023	0,94
2.	A single cut with a dead-furrow at the bottom	0,25	0,009	0,60
3.	A single furrow	0,16	0,056	0,65
4.	A furrow, a cut and a dead-furrow	0,16/0,25	0,079	1,54
5.	Two parallel cuts with dead-furrows at the bottom	0,40	0,046	1,88

It is possible to obtain final determination of the optimum interspacing between the different water runoff stemming earth works after taking into consideration expressions (3), (6), (7), (8), (9) and (10) as well as the data from Table 1 for the values of their vertical sections and wet perimeters.

3. CONCLUSION

In conclusion the following inferences can be drawn:

1. Dividing the length of the slope into separate portions of minimum sizing and forming water runoff stemming earth works (single cuts with dead-furrows at their bottoms, single furrows, a combination of a furrow, a cut with dead-furrows and two parallel cuts with dead-furrows at their bottoms) is carried out for preventing soil water erosion on slopes.
2. The optimum interspacing between the water runoff stemming earth works formed transversely to or along the horizontals of the slope with different soil types can be determined accurately enough through a theoretical approach, the essence of which lies in limiting the maximum volume of the surface water runoff at the end of the slope and taking it by preliminary calculated number of earth works.

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