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THE EFFECTIVENESS OF PLANT COVER IN REDUCING EROSION OF STEEP SLOPES AND ITS USE FOR RECULTIVATION OF MINING WASTE DUMPS

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Abstract
By a conceptual model it is evaluated, how and in which relative extent the vegetation reduces the surface layer erosion under rainwater. In consideration of the Hungarian climatic conditions, two mechanisms are taken into account: 1. the striking and splashing effect of raindrops (the soil structure breaks apart to small particles, and these are subsequently moved airborne downslope), 2. sheet erosion (the rainwater moves down the hill and carries small pieces of soil with it). The model provides a mathematical expression for the soil volume eroded per unit time. The vegetation diminishes the erosion through 4 different parameters in this expression: α: the plants retain this proportion of rainfall, therefore it cannot cause erosion, z: friction coefficient (roughness) by which the vegetation increases the friction work of flowing water, hereby reducing the available energy for the erosion, σ: specific erosion work, which is increased by the plants because their roots, rhizomes and stolons hold together the soil against external forces, b_1: specific splash erosion is diminished by the plants because their shoots and leaves reduce the raindrops' kinetic energy. According to these parameters, four indices are introduced and their 5 scale evaluation for 475 vascular plant species (with regard to their growth forms) is attempted. The results could help to select species and assemble plant communities for recultivation purposes.
***Keywords**: erosion, vegetation, model, indicator, recultivation*

1. INTRODUCTION

The environmental impacts of mining within the confines of Pécs (Hungary) were examined by Lehmann [1]. Morphological, microclimatic, hydrologic, pedologic and botanical modifications were distinguished. The most adverse states of ground were revealed on steep slopes of mine walls and waste dumps, because of the intense surface as well as linear soil erosion and extreme microclimatic conditions. The aim of present study is to evaluate by a conceptual model, how and in which relative extent the vegetation reduces the surface layer erosion under rainwater.

2. MATERIALS AND METHODS

In the course of surface layer erosion nearly uniform carrying down of soil happens, or at most a shallow network of water-courses is formed. It is produced by several partial processes.

Micro-solifluction: a thin layer of the fluid (pulpy) soil surface moves down the slope toward the local erosion basis, at a significant area [2]. In Hungary this happens only at the most rainy regions, and can be entirely prevented by perennial vegetation, therefore it is not treated here in detail.

The striking and splashing effect of raindrops (in the beginning, the dry soil granules burst into small particles, then the pulpy soil surface splashes, and resulting particles are subsequently moved airborne downslope).

The sheet erosion: the rainwater moves down the hill and, due to its kinetic energy, carries small pieces of the sloppy soil toward the local erosion basis).

As only the surface downslope flowing water can cause sheet erosion, first of all the local water balance will be studied. A mathematical model taking into account these processes is presented. It provides an expression for the soil volume eroded per unit time.

For the evaluation of plant species by virtue of this model, data pertinent to growth forms in [3-5], besides the author's own observations are used.

3. RESULTS AND DISCUSSION

The model

As only the surface downslope flowing water can cause sheet erosion, first of all the local water balance will be studied.

From the perspective of downslope flowing part (w) of rainfall at unit surface and unit time, the following components are taken into account:

P: rainfall at horizontal surface unit at unit time

α: the proportion of rainfall retained by the vegetation,

Q: rainfall infiltrating into soil at t time. It is given by an empirical formula [6]:

$$Q = S \cdot \sqrt{t} + A \cdot t \qquad (1)$$

Its time derivative is needed for the water balance equation. Taking all described above into account,

$$w = \left(P \cdot [1 - \alpha] - \frac{S}{2 \cdot \sqrt{t}} - A \right) \cdot \cos\beta \qquad (2)$$

where β is the angle of the slop. The expression is valid for time

$$t > \frac{S^2}{4[P \cdot (1-\alpha) - A]^2}$$

and

$$P \cdot (1-\alpha) > A,$$

otherwise w = 0 (the full rainfall infiltrates).

Further notations:

l : distance from the slope top downward,

d : width of the slope,

S,A : proportion factors of the empirical infiltration formula (1),

ρ_v : water density,

ρ_h : density of the slope substance,

g : gravitational acceleration

σ : specific work of erosion

μ : specific work of drift transport

z : proportion factor of drag

E : energy for the striking and splashing effect of raindrops

γ_0 : proportion factor of resistance of water sheet against the striking raindrop

B : volume of eroded substance at unit time

b : specific soil erosion (ablated substance at unit surface and time)

b_0 : specific erosion by washing out,

b_1 : specific raindrop erosion at the slope top.

The supposed relationship between the last three quantities:

$$b(l) = b_0 + b_1 \cdot e^{-\gamma \cdot \sqrt[3]{l}} \tag{3}$$

This can be seen by taking into account that the raindrop can only reach the slope surface lower down through the water sheet flowing downslope. Upon the raindrop moving by speed v, a drag proportional to v^2 acts, therefore

$$\frac{dv}{dt} = -\frac{\gamma_0}{2} \cdot v^2 \tag{4}$$

Solving this differential equation,

$$v = \frac{2 \cdot v_0}{\gamma_0 \cdot v_0 \cdot t + 2} \tag{5}$$

where v_0 is the speed of the raindrop when it reaches the surface of water sheet. The expression shows how the drop speed depends on the time underway in the water sheet. Integrating this expression we obtain the path traversed by the drop as

a function of time. The inverse function gives the time span needed to cross the water sheet of width h:

$$t_1 = \frac{2}{\gamma_0 \cdot v_0} \cdot \left(e^{\frac{\gamma_0 \cdot h}{2}} - 1 \right) \tag{6}$$

The kinetic energy of drop is diminished by the work against drag. The energy remaining for the raindrop erosion:

$$E = \frac{1}{2} \cdot m \cdot v_{0^2} - \int_0^{t_1} \frac{1}{2} \cdot m \cdot v^2 \cdot \gamma_0 \cdot v \cdot dt \tag{7}$$

Substituting (5) for v and performing the integration

$$E = \frac{1}{2} \cdot m \cdot v_0^2 \cdot e^{-\gamma_0 \cdot h} \tag{8}$$

that is the energy for the raindrop erosion decreases exponentially with the width h of water sheet. However the latter changes with distance on the slope, because the quantity of water flowing through the cross-section accumulates downslope,

$$h = \frac{w \cdot l}{u} \tag{9}$$

but the u flow velocity also changes. Water is a Newtonian viscous fluid [7] in present cases of interest, so

$$\frac{du}{dz} = \frac{\rho_v \cdot g \cdot \sin\beta}{\eta}(h - z) \tag{10}$$

where z is the distance perpendicular to the slope, and η is the coefficient of viscosity. Taking into account the no-slip condition we obtain after integration

$$u = \frac{\rho_v \cdot g \cdot \sin\beta}{\eta}\frac{h^2}{2} \tag{11}$$

and putting this into (9) provides the expression for width h of water sheet as a function of distance l on the slope:

$$h = \sqrt[3]{\frac{2 \cdot w \cdot l \cdot \eta}{\rho_v \cdot g \cdot \sin\beta}} \tag{12}$$

So the drop erosion as a function of distance:

$$cs(l) = b_1 \cdot e^{-\gamma \cdot \sqrt[3]{l}} \tag{13}$$

where

$$\gamma = \gamma_0 \cdot \sqrt[3]{\frac{2\eta \cdot tg\beta}{\rho_v \cdot g}\left(P \cdot [1 - \alpha] - \frac{S}{2 \cdot \sqrt{t}} - A\right)} \tag{14}$$

(13) provides the second term in equation (3). The volume of eroded substance at unit time, on the slope of length l and width d

$$B = d \cdot \int_0^l b(x)dx = b_0 \cdot d \cdot l + \frac{3b_1 \cdot d}{\gamma^3} \cdot \left[2 - e^{-\gamma \cdot \sqrt[3]{l}}\left(\gamma^2 \cdot \sqrt[3]{l^2} + \gamma \cdot \sqrt[3]{l} + 2\right)\right] \tag{15}$$

According to (11) and (12) the flow velocity as a function of distance on the slope

$$u(l) = C \cdot \sqrt[3]{l^2} \tag{16}$$

where

$$C = \sqrt[3]{\frac{\rho_v \cdot g \cdot \sin\beta \cdot w^2}{2\eta}} \tag{17}$$

The quantity of water flowing at unit time on a slope of length l and width d is $w \cdot l \cdot d$. So, considering also (12), its potential energy changes at unit time by

$$\int_o^l \rho_v \cdot w \cdot d \cdot g \cdot \sin\beta \cdot C \cdot \sqrt[3]{x^2}\,dx = \frac{3}{5} D \cdot \sqrt[3]{l^5} \tag{18}$$

where

$$D = \rho_v \cdot g \cdot w \cdot d \cdot \sqrt[3]{\frac{\rho_v \cdot g \cdot \sin^2\beta \cdot w^2}{2\eta}} \tag{19}$$

The erosion power of flowing water:

$$\sigma \cdot b_0 \cdot l \cdot d \tag{20}$$

The drift power

$$\int_0^l \mu \cdot b(x) \cdot d \cdot \rho_h \cdot g \cdot u(x) dx = \int_0^l \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot (b_0 + b_1 \cdot e^{-\gamma \cdot \sqrt[3]{x}}) \cdot \sqrt[3]{x^2} dx =$$

$$\mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot \left(\frac{3b_0}{5} l \cdot \sqrt[3]{l^2} + b_1 \cdot I_2 \right) \tag{21}$$

where

$$I_2 = \frac{72}{\gamma^5} - \left(\frac{3}{\gamma} \sqrt[3]{l^4} + \frac{12}{\gamma^4} l + \frac{36}{\gamma^3} \sqrt[3]{l^2} + \frac{72}{\gamma^4} \right) e^{-\gamma \sqrt[3]{l}} \tag{22}$$

The drag (e.g. [8]) power:

$$\int_0^l \frac{1}{2} \cdot \rho_v \cdot u^3 \cdot d \cdot z dx = \int_0^l \frac{1}{2} \cdot \rho_v \cdot C^3 \cdot z \cdot d \cdot x^2 dx = \frac{1}{6} \cdot \rho_v \cdot C^3 \cdot z \cdot d \cdot l^3 \tag{23}$$

The energy balance equation based on (10-13) relating to unit time:

$$\frac{3}{5} D \cdot \sqrt[3]{l^5} =$$

$$\sigma \cdot b_0 \cdot l \cdot d + \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot \left(\frac{3b_0}{5} l \cdot \sqrt[3]{l^2} + b_1 \cdot I_2 \right) + \frac{1}{6} \cdot \rho_v \cdot C^3 \cdot z \cdot l^3 \cdot d \tag{24}$$

from which

$$b_0 = \frac{\frac{3}{5} D \cdot \sqrt[3]{l^5} - \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot b_1 \cdot I_2 - \frac{1}{6} \cdot \rho_v \cdot C^3 \cdot z \cdot l^3 \cdot d}{\sigma \cdot l \cdot d + \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot \frac{3}{5} l \cdot \sqrt[3]{l^2}} \tag{25}$$

Substituting into (11) and using (2) we obtain the following expression for the volume of eroded substance at unit time, on the slope of length l and width d:

$$B = \frac{\frac{3}{5} D \cdot \sqrt[3]{l^5} - \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot b_1 \cdot I_2 - \frac{1}{6} \cdot \rho_v \cdot C^3 \cdot z \cdot l^3 \cdot d}{\sigma \cdot l \cdot d + \mu \cdot d \cdot \rho_h \cdot g \cdot C \cdot \frac{3}{5} l \cdot \sqrt[3]{l^2}} \cdot d \cdot l +$$

$$\frac{3b_1 \cdot d}{\gamma^3} \cdot \left[2 - e^{-\gamma \cdot \sqrt[3]{l}} \left(\gamma^2 \cdot \sqrt[3]{l^2} + \gamma \cdot \sqrt[3]{l} + 2 \right) \right] \tag{26}$$

where

$$\gamma = \gamma_0 \cdot \sqrt[3]{\frac{2\eta \cdot w \cdot \sin \beta}{\rho_v \cdot g}}$$

$$C = \sqrt[3]{\frac{\rho_v \cdot g \cdot \sin \beta \cdot w^2}{2\eta}}$$

$$D = \rho_v \cdot g \cdot w \cdot d \cdot \sqrt[3]{\frac{\rho_v \cdot g \cdot \sin^2 \beta \cdot w^2}{2\eta}}$$

$$w = \left(P \cdot [1-\alpha] - \frac{S}{2 \cdot \sqrt{t}} - A \right) \cdot \cos\beta$$

The term $\frac{S}{2 \cdot \sqrt{t}}$ may be important only for a relatively short time, thus usually can be neglected for long rainfalls.

According to this model, the vegetation diminishes the erosion through 4 different parameters in expression (26): α: the plants retain this proportion of rainfall, therefore it cannot cause erosion, *z:* friction coefficient (roughness) by which the vegetation increases the friction work of flowing water, hereby reducing the available energy for the erosion, σ: specific erosion work, which is increased by the plants because their roots, rhizomes and stolons hold together the soil against external forces, b_1: specific splash erosion is diminished by the plants because their shoots and leaves reduce the raindrops' kinetic energy.

Evaluation of some plant species according to the model parameters

According to these parameters, four indices are introduced and their 5 scale evaluation for 475 vascular plant species (with regard to their growth forms) is attempted. In the followings, the evaluation of 474 vascular plant species (with regard to their growth forms) is attempted. Of course, the exact quantitative effect of vegetation on the parameters α, z, σ and b_1 could be elucidate only by experiments.

However, the plant's growth form, morphologic, habit features and position, role in the vegetation make it possible to find out some supposed orders in respect of the effect on the parameters in question. For sake of simplicity, this effects will be evaluated at a 5 grade scale (1: small, 2: slight, 3: medium, 4: strong, 5: excellent).

In regard of the index IA, the effect on α parameter (ability to retain rainfall), first of all species with dense foliage and shoot system, able to prostrate on soil, for example densely tufted species are efficient. Their connected plant cover carries off a part of the rainfall at its own surface without touching the slope soil. When the precipitation is plentiful, some part of the retained amount gradually falls on the soil. In forests, an unbroken forest litter renders additional protection in such cases.

The index IZ refers to parameter z (roughness). Chiefly, dense growing species are important in this regard. These exert namely considerable drag on the flowing water.

IS indicates the enhancing of parameter σ (specific erosion work). It is greater for plant species developing dense, ramifying, powerful root system and/or subterranean shoot system near the surface, exerting intense resistance against forces of erosion.

The ability to diminish parameter b_1 (specific splash erosion) is taken into account by index IB. In particular, species with great leaf, dense foliage, and ramifying shoot system put a stay upon movement of the falling raindrops. These structures are more efficient, if they are placed rather low, because the raindrops can accelerate between them and the soil surface. Therefore, all other things being equal, a lower tree is more favourable than a long-boled tree.

The results of evaluation of plant species in the abovementioned respects are contained in Table 1.

The last column (Σ) contains an integrated evaluation of a certain kind. This is valid only if the indices are taken into account with equal weights, and should be treated with reservations. Of course, departures are possible, depending on the concrete field situation.

Table 1: Five scale species indices IA, IZ, IS, IB and Σ

Species	IA	IZ	IS	IB	Σ
Acer campestre*	3	2	5	3	3
Acer tataricum*	2	2	3	4	3
Achillea collina	1	2	3	2	2
Achillea pannonica	1	2	3	2	2
Achillea setacea	1	2	2	2	2
Acinos arvensis	1	4	4	2	3
Aconitum anthora	1	1	3	3	2
Adonis vernalis	1	2	4	2	2
Agrimonia eupatoria	1	3	2	3	3
Agropyron repens	2	2	3	3	2
Agrostis capillaris	1	2	3	3	2
Ailanthus altissima	1	1	5	3	2
Aira caryophyllea	1	3	3	2	2
Ajuga genevensis	1	3	3	2	2
Ajuga reptans	1	2	4	2	2
Alcea biennis	1	1	3	3	2
Allium flavum	1	1	1	1	1
Allium oleraceum	1	1	1	1	1
Allium scorodoprasum	1	1	1	1	1
Allium sphaerocephalon	1	1	1	1	1
Allium vineale	1	1	1	1	1
Althaea cannabina	1	3	3	3	2
Althaea hirsuta	1	2	2	2	2
Alyssum alyssoides	1	1	3	1	1
Alyssum montanum	1	2	3	2	2
Alyssum turkestanicum	1	1	3	1	1
Amaranthus patulus	1	1	2	3	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Amorpha fruticosa	1	4	5	4	3
Ambrosia artemisiifolia	1	1	3	2	2
Anacamptis pyramidalis	1	1	1	1	1
Anemone sylvestris	1	3	3	3	2
Anchusa barrelieri	1	2	3	2	2
Anchusa italica	1	2	3	3	2
Anchusa officinalis	1	1	2	3	2
Androsace maxima	1	2	1	1	1
Anthemis tinctoria	1	2	3	2	2
Anthericum ramosum	1	2	2	2	2
Anthoxanthum odoratum	2	3	5	2	3
Anthyllis vulneraria	1	3	1	3	2
Arabidopsis thaliana	1	1	2	1	1
Arabis auriculata	1	1	2	1	1
Arabis glabra	1	2	2	2	2
Arabis hirsuta	1	2	3	2	2
Arabis turrita	1	2	3	2	2
Arenaria leptoclados	1	2	2	1	1
Arenaria serpyllifolia	1	2	2	1	1
Arrhenatherum elatius	1	2	3	3	2
Artemisia campestris	1	4	3	2	2
Artemisia scoparia	1	1	2	2	1
Artemisia vulgaris	1	1	3	2	2
Asperula cynanchica	1	4	5	2	3
Asplenium adianthum-nigrum	1	3	4	2	2
Asplenium javorkeanum	1	3	5	3	3

Asplenium ruta-muraria	1	3	4	2	2
Asplenium trichomanes	1	3	4	2	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Asplenium viride	1	3	4	2	2
Aster amellus	1	2	3	2	2
Aster linosyris	1	1	3	1	1
Astragalus austriacus	1	2	2	2	2
Astragalus cicer	1	3	3	3	2
Astragalus onobrychis	1	3	2	3	2
Atriplex sagittata	1	1	2	3	2
Berberis vulgaris	1	2	5	5	3
Betonica officinalis	2	5	3	3	3
Berteroa incana	1	1	2	2	1
Betula pendula*	1	1	3	2	2
Bombycilaena erecta	1	2	1	1	1
Botriochloa ischaemum	2	3	4	3	3
Brachypodium rupestre	3	2	3	4	3
Brassica elongata	1	2	2	2	2
Brassica nigra	1	2	2	2	2
Briza media	3	5	5	1	3
Bromus erectus	1	4	4	3	3
Bromus inermis	1	2	2	3	2
Bromus hordaceus	1	2	2	2	2
Bromus japonicus	1	2	2	2	2
Bromus secalinus	1	2	2	3	2
Bromus squarrosus	1	2	2	2	2
Bromus tectorum	1	2	3	3	2
Buglossoides purpureo-coerulea	1	3	3	3	2
Bupleurum affine	1	1	1	1	1
Bupleurum falcatum	1	2	2	3	2
Bupleurum praealtum	1	1	1	2	1
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Calamagrostis epigeios	3	3	3	4	3
Calepina irregularis	1	2	1	2	1
Camelina microcarpa	1	1	2	1	1
Campanula bononiensis	1	1	3	3	2
Campanula cervicaria	1	1	3	3	2
Campanula glomerata	1	1	2	3	2
Campanula rapunculus	1	1	2	2	1
Campanula rotundifolia	1	3	4	2	2
Campanula sibirica	1	2	2	2	2
Capsella bursa-pastoris	1	2	1	1	1
Cardaminopsis arenosa	1	2	3	2	2
Carduus acanthoides	1	2	2	2	2
Carex caryophyllea	2	5	4	2	3
Carex divulsa	1	3	3	3	2
Carex flacca	1	2	3	3	2
Carex hirta	1	2	3	3	2
Carex humilis	3	4	5	3	4
Carex montana	3	4	5	3	4
Carex muricata	1	3	3	3	2
Carex praecox	1	2	3	2	2
Carex tomentosa	1	1	3	2	2
Carpinus betulus*	5	4	5	5	5
Carthamus lanatus	1	1	2	2	1
Carlina vulgaris	1	2	2	2	2
Centaurea biebersteinii	1	2	2	2	2

Centaurea jacea	1	2	2	3	2
Centaurea pannonica	1	2	2	3	2
Centaurea sadleriana	1	2	1	3	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Centaurea scabiosa	1	2	1	3	2
Centaurea spinulosa	1	2	1	3	2
Centaurea triumfettii	1	2	2	3	2
Cephalaria transsylvanica	1	2	3	3	2
Cerastium brachypetalum	1	1	2	1	1
Cerastium fontanum	1	3	3	2	2
Cerastium glomeratum	1	1	2	1	1
Cerastium pumilum	1	1	2	1	1
Cerastium semidecandrum	1	1	2	1	1
Cerinthe minor	1	2	2	2	2
Chamaecytisus austriacus	1	3	3	3	2
Chamaecytisus ratisbonensis	1	3	3	3	2
Chamaecytisus supinus	1	3	3	3	2
Chenopodium opulifolium	1	2	2	2	2
Chondrilla juncea	1	2	1	2	1
Cirsium pannonicum	1	1	3	3	2
Cleistogenes serotina	1	2	3	2	2
Clematis recta	1	2	3	4	2
Clinopodium vulgare	1	2	3	2	2
Colchicum autumnale	1	1	1	3	1
Colutea arborescens	1	3	2	4	2
Consolida orientalis	1	1	2	2	1
Convolvulus arvensis	1	2	2	2	2
Convolvulus cantabrica	1	2	3	2	2
Cornus mas	3	1	5	4	2
Cornus sanguinea	3	3	4	4	3
Coronilla coronata	1	3	2	3	2
Cotinus coggygria	3	4	5	5	4
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Cotoneaster tomentosus	1	3	5	4	3
Crataegus monogyna	3	2	5	4	3
Crepis nicaeensis	1	2	2	2	2
Crepis praemorsa	1	2	2	3	2
Crepis pulchra	1	2	2	2	2
Crepis rhoeadifolia	1	2	1	2	1
Crepis setosa	1	2	2	2	2
Crepis tectorum	1	2	2	2	2
Cruciata laevipes	1	3	4	2	2
Cruciata pedemontana	1	2	1	1	1
Cuscuta epithymum	1	1	1	1	1
Cynodon dactylon	1	3	3	2	2
Cynoglossum hungaricum	1	3	2	3	2
Cynoglossum officinale	1	3	2	3	2
Cytisus scoparius	1	4	5	4	3
Dactylis glomerata	2	4	3	4	3
Dantonia decumbens	1	2	4	2	2
Daucus carota	1	1	2	3	2
Dianthus armeria	1	2	3	2	2
Dianthus giganteiformis	1	3	1	2	2
Dictamnus albus	1	3	3	4	3
Doronicum hungaricum	1	1	3	3	2
Dorycnium germanicum	1	3	3	3	2
Dorycnium herbaceum	1	3	3	3	2

Draba muralis	1	1	2	1	1
Draba nemorosa	1	1	2	1	1
Echinops sphaerocephalus	1	1	2	3	2
Echium italicum	1	2	2	3	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Echium vulgare	1	2	2	3	2
Equisetum ramosissimum	1	2	3	2	2
Erigeron acer	1	1	4	2	2
Erodium ciconium	1	3	2	2	2
Erodium cicutarium	1	3	2	2	2
Erophila spathulata	1	1	2	1	1
Erophila verna	1	1	2	1	1
Eryngium campestre	1	1	1	4	2
Erysimum diffusum	1	1	3	1	1
Erysimum odoratum	1	2	3	2	2
Euonymus europaeus	1	3	5	4	3
Euonymus verrucosus	2	3	5	5	4
Euphorbia cyparissias	1	1	4	2	2
Euphorbia epithymoides	1	2	2	3	2
Euphorbia esula	1	1	3	3	2
Euphorbia salicifolia	1	2	3	3	2
Euphorbia seguierana	1	3	2	2	2
Euphorbia virgata	1	1	2	3	2
Falcaria vulgaris	1	1	2	3	2
Fallopia convolvulus	1	1	2	2	1
Festuca dalmatica	3	4	5	3	4
Festuca heterophylla	3	4	5	3	4
Festuca pseudovina	3	4	5	3	4
Festuca rubra	2	4	3	3	3
Festuca rupicola	3	4	5	3	4
Festuca valesiaca	3	4	5	3	4
Filago arvensis	1	1	1	1	1
Filago lutescens	1	2	1	1	1
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Filipendula vulgaris	1	4	3	3	3
Fragaria viridis	2	2	3	4	3
Fraxinus ornus*	3	2	5	4	3
Fumana procumbens	1	3	2	1	2
Fumaria parviflora	1	2	1	1	1
Fumaria rostellata	1	2	1	1	1
Fumaria vaillantii	1	1	1	1	1
Gagea pratensis	1	1	1	1	1
Galium erectum	1	2	4	1	2
Galium glaucum	1	2	4	2	2
Galium lucidum	1	2	4	1	2
Galium mollugo	1	2	4	2	2
Genista pilosa	1	3	4	1	2
Genista tinctoria	1	3	3	2	2
Geranium columbinum	1	3	2	2	2
Geranium dissectum	1	3	2	2	2
Geranium pusillum	1	2	2	2	2
Geranium sanguineum	1	4	3	3	3
Geranium rotundifolium	1	3	2	2	2
Glechoma hederacea	1	2	3	3	2
Globularia punctata	1	3	3	3	2
Gypsophila muralis	1	2	2	2	2
Helianthemum canum	1	5	3	3	3

Helianthemum nummularium	1	4	3	3	3
Helianthemum ovatum	1	4	3	3	3
Helichrysum arenarium	1	3	2	2	2
Helleborus odorus	1	2	3	4	2
Heracleum sphondylium	1	2	1	5	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Hieracium bauhini	1	3	3	2	2
Hieracium bifidum	1	2	3	2	2
Hieracium echioides	1	2	3	2	2
Hieracium hoppeanum	1	2	3	2	2
Hieracium cymosum	1	2	3	2	2
Hieracium pilosella	2	2	3	2	2
Hieracium racemosum	1	1	3	3	2
Hieracium sabaudum	1	1	3	3	2
Hieracium umbellatum	1	1	3	3	2
Hippocrepis comosa	1	3	2	3	2
Holosteum umbellatum	1	1	2	1	1
Hypericum perforatum	1	2	3	2	2
Hypochoeris maculata	1	1	2	4	2
Hypochoeris radicata	1	1	2	2	1
Inula conyza	1	1	3	4	2
Inula ensifolia	1	5	3	2	3
Inula hirta	1	5	4	3	3
Inula oculus-christi	1	5	4	3	3
Inula salicina	1	5	4	3	3
Inula spiraeifolia	1	5	4	3	3
Iris graminea	1	4	2	3	2
Iris pumila	1	3	3	2	2
Iris variegata	1	3	2	3	2
Jovibarba globifera	2	4	2	4	2
Juniperus communis*	1	2	5	5	3
Jurinea mollis	1	2	3	2	2
Knautia arvensis	1	3	2	4	2
Koeleria cristata	2	4	4	2	3
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Koeleria glauca	3	5	5	3	4
Laburnum anagyroides	1	2	5	4	3
Lactuca quercina	1	1	3	2	2
Lactuca viminea	1	1	1	2	1
Laser trilobum	1	2	2	4	2
Laserpitium latifolium	1	2	2	4	2
Lathyrus hirsutus	1	1	2	3	2
Lathyrus latifolius	1	3	2	4	2
Lathyrus nissolia	1	1	2	3	2
Lathyrus pannonicus subsp. collinus	1	2	2	3	2
Lathyrus sphaericus	1	2	2	2	2
Lathyrus tuberosus	1	1	2	4	2
Lavatera thuringiaca	1	3	3	4	3
Lepidium perfoliatum	1	2	1	1	1
Lepidium ruderale	1	1	2	1	1
Ligustrum vulgare	1	4	5	5	4
Linaria genistifolia	1	1	2	2	1
Linaria vulgaris	1	2	1	2	1
Linum austriacum	1	3	3	2	2
Linum catharticum	1	2	1	1	1
Linum flavum	1	2	3	2	2
Linum tenuifolium	1	3	2	1	2

Lithospermum officinale	1	2	2	3	2
Lolium perenne	2	4	4	3	3
Lotus corniculatus	1	3	3	2	2
Luzula campestris	1	3	4	2	2
Lychnis coronaria	1	2	3	3	2
Lycium barbarum	3	5	5	5	4
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Marrubium peregrinum	1	3	3	2	2
Medicago arabica	1	2	3	3	2
Medicago falcata	1	3	3	3	2
Medicago minima	1	2	1	1	1
Medicago prostrata	1	3	3	2	2
Medicago rigidula	1	3	3	2	2
Melampyrum arvense	1	1	2	2	1
Melampyrum barbatum	1	1	2	2	1
Melampyrum cristatum	1	1	2	2	1
Mercurialis ovata	1	2	4	3	2
Minuartia rubra	1	2	2	1	1
Minuartia verna	1	3	2	2	2
Muscari botryoides	1	1	3	2	2
Muscari racemosum	1	1	3	1	1
Myosotis discolor	1	1	2	1	1
Myosotis ramosissima	1	1	2	1	1
Myosotis stricta	1	1	1	1	1
Nonea pulla	1	3	2	2	2
Onobrychis arenaria	1	3	2	3	2
Ononis spinosa	1	3	2	3	2
Onosma arenaria	1	3	1	2	2
Orchis simia	1	1	1	2	1
Orchis tridentata	1	1	1	1	1
Orchis ustulata	1	1	1	1	1
Origanum vulgare	1	3	4	3	3
Orlaya grandiflora	1	2	2	2	2
Ornithogalum kochii	1	1	1	1	1
Ornithogalum pyramidale	1	2	1	2	1
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Ornithogalum sphaerocarpum	1	2	1	2	1
Ornithogalum umbellatum	1	1	1	2	1
Orobanche alba	1	1	1	1	1
Orobanche elatior	1	1	1	1	1
Orobanche caryophyllacea	1	1	1	1	1
Orobanche lutea	1	1	1	1	1
Orobanche minor	1	1	1	1	1
Orobanche purpurea	1	1	1	1	1
Orobanche reticulata	1	1	1	1	1
Orobanche teucrii	1	1	1	1	1
Papaver argemone	1	2	1	1	1
Papaver hybridum	1	1	1	2	1
Petrorhagia prolifera	1	2	2	2	2
Petrorhagia saxifraga	1	3	3	2	2
Peucedanum alsaticum	1	2	2	3	2
Peucedanum carvifolia	1	2	2	2	2
Peucedanum cervaria	1	2	2	4	2
Peucedanum oreoselinum	1	2	2	3	2
Phleum phleoides	2	4	4	3	3
Phlomis tuberosa	1	4	3	5	3
Picris hieracioides	1	1	3	3	2

Pimpinella saxifraga	1	1	2	2	1
Pinus nigra*	5	5	4	5	5
Pinus sylvestris*	5	5	3	5	4
Plantago argentea	1	1	3	4	2
Plantago lanceolata	1	1	3	4	2
Plantago major	2	1	3	4	2
Poa annua	1	2	2	2	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Poa bulbosa	1	3	4	2	2
Poa compressa	1	2	4	2	2
Poa angustifolia	2	3	4	3	3
Poa nemoralis	1	2	3	3	2
Polygonatum odoratum	1	1	3	3	2
Polypodium vulgare	2	2	4	4	3
Potentilla arenaria	1	3	2	2	2
Potentilla argentea	1	3	2	2	2
Potentilla collina agg.	1	3	2	2	2
Potentilla heptaphylla	1	2	2	2	2
Potentilla inclinata	1	3	2	2	2
Potentilla micrantha	1	3	2	2	2
Potentilla neglecta	1	3	2	2	2
Potentilla recta	1	2	2	3	2
Primula veris	1	3	3	3	2
Prunella laciniata	1	3	3	2	2
Prunus fruticosa	2	5	5	5	4
Prunus mahaleb*	1	2	5	4	3
Prunus spinosa*	2	5	5	5	4
Prunus tenella	1	3	4	4	3
Pseudolysimachion spicatum	1	2	3	3	2
Pulmonaria mollis	1	3	4	4	3
Pulsatilla grandis	1	2	2	2	2
Pulsatilla pratensis	1	2	2	2	2
Pyrus pyraster*	1	1	3	4	2
Quercus cerris*	4	4	4	4	4
Quercus petraea*	4	4	3	4	4
Quercus pubescens*	4	4	5	4	4
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Ranunculus bulbosus	1	1	3	3	4
Ranunculus illyricus	1	1	3	3	4
Ranunculus polyanthemos	1	1	2	3	2
Rapistrum perenne	1	2	3	3	2
Reseda phyteuma	1	2	2	2	2
Robinia pseudo-acacia*	1	1	5	3	2
Rosa canina agg.	1	2	3	3	2
Rosa gallica	1	2	3	4	2
Rosa rubiginosa agg.	1	2	3	4	2
Rosa spinosissima	1	3	5	3	3
Rubus fruticosus agg.	2	3	3	5	3
Rumex acetosa	3	4	3	3	3
Rumex acetosella	1	3	2	2	2
Rumex pulcher	1	2	2	2	2
Salvia austriaca	1	2	2	3	2
Salvia nemorosa	1	3	1	3	2
Salvia pratensis	1	3	2	3	2
Salvia verticillata	1	2	2	3	2
Sanguisorba minor	1	4	3	2	2
Saxifraga tridactylites	1	2	1	1	1

Scabiosa ochroleuca	1	4	2	3	2
Scorzonera laciniata	1	2	1	1	1
Scutellaria columnae	1	3	4	3	3
Securigera varia	1	3	2	3	2
Sedum acre	1	2	2	2	2
Sedum album	1	2	2	2	2
Sedum rupestre	1	2	2	2	2
Sedum sexangulare	1	2	2	3	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Senecio jacobaea	1	1	3	3	2
Senecio vernalis	1	2	1	1	1
Serratula tinctoria	1	1	3	3	2
Seseli annuum	1	1	2	3	2
Seseli hippomarathrum	1	2	2	2	2
Seseli osseum	1	2	2	2	2
Sherardia arvensis	1	2	2	2	2
Sideritis montana	1	1	3	2	2
Silene nutans	1	3	3	2	2
Silene otites	1	2	2	2	2
Silene vulgaris	1	2	2	2	2
Smyrnium perfoliatum	1	1	3	4	2
Sorbus danubialis*	3	2	5	4	3
Sorbus domestica*	2	1	3	3	2
Spiraea media	1	5	5	4	4
Stachys recta	1	1	3	2	2
Stipa capillata	1	4	4	2	3
Stipa pennata	1	4	4	2	3
Stipa pulcherrima	1	4	4	2	3
Sisymbrium altissimum	1	1	3	2	2
Sisymbrium loeselii	1	1	3	2	2
Symphythum tuberosum	1	1	3	4	2
Taeniatherum asperum	1	1	2	2	1
Tanacetum corymbosum	1	2	3	3	2
Taraxacum erythrospermum	1	2	2	2	1
Taraxacum serotinum	1	2	1	2	1
Teucrium chamaedrys	1	2	3	2	2
Teucrium montanum	1	3	3	2	2
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Thalictrum minus	1	3	3	2	2
Thesium linophyllon	1	3	2	2	2
Thlaspi perfoliatum	1	1	2	1	1
Thymus odoratissimus	1	3	3	2	2
Thymus pannonicus	1	3	3	2	2
Thymus pracox	1	3	3	2	2
Tilia cordata*	5	5	3	5	4
Tilia tomentosa*	5	5	5	5	5
Tordylium maximum	1	1	2	4	2
Tragopogon dubius	1	1	2	3	2
Tragopogon pratensis	1	1	2	3	2
Trifolium alpestre	1	2	4	3	2
Trifolium arvense	1	1	2	2	1
Trifolium aureum	1	1	3	2	2
Trifolium campestre	1	1	3	2	2
Trifolium montanum	1	2	3	3	2
Trifolium ochroleucum	1	2	4	3	2
Trifolium repens	1	2	4	3	2
Trifolium retusum	1	2	2	2	2

Trifolium rubens	1	1	2	3	2
Trifolium striatum	1	1	2	2	1
Trinia glauca	1	3	2	2	2
Trinia ramosissima	1	3	2	3	2
Tussilago farfara	1	2	3	3	2
Valerianella carinata	1	1	1	2	1
Valerianella coronata	1	2	1	1	1
Valerianella dentata	1	1	1	2	1
Valerianella pumila	1	1	1	1	1
Species	**IA**	**IZ**	**IS**	**IB**	**Σ**
Verbascum lychnitis	1	2	2	4	2
Verbascum phoeniceum	1	2	2	3	2
Verbascum speciosum	1	2	2	4	2
Verbascum thapsus	1	2	2	4	2
Veronica austriaca	1	1	3	2	2
Veronica chamaedrys	1	2	3	2	2
Veronica dillenii	1	1	1	1	1
Veronica hederifolia	1	1	1	1	1
Veronica officinalis	1	2	3	2	2
Veronica persica	1	1	1	1	1
Veronica praecox	1	1	1	1	1
Veronica prostrata	2	3	2	2	2
Veronica verna	1	1	1	1	1
Viburnum lantana	4	3	4	5	4
Vicia lathyroides	1	2	2	2	2
Vicia grandiflora	1	1	2	3	2
Vicia hirsuta	1	1	2	2	1
Vicia narbonensis	1	1	2	3	2
Vicia tenuifolia	1	2	2	4	2
Vinca herbacea	1	2	3	3	2
Vincetoxicum officinale	1	2	3	3	2
Viola hirta	1	5	3	3	3
Viola kitaibeliana	1	1	1	1	1
Viscaria vulgaris	1	3	3	2	2
Waldsteinia geoides	1	3	3	3	2
Xeranthemum annuum	1	1	2	2	1
Xeranthemum cylindraceum	1	1	2	1	1

*The indicated values are valid only for fully developed plants, together with the litter accumulated below them.

Conclusion

The results could help to select species and assemble plant communities for recultivation purposes. Other ecologically relevant parameters (exposition, base rock, soil, etc.) should be considered too. For reducing erosion (and promoting soil formation) the establishment of layered vegetation as structured as possible, in accordance with the habitat, is suitable.

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References

[1] Lehmann A.: A bányászat hatása a növény- és talajtakaróra Pécs területén. Földrajzi Közlemények (Geographical Review) 1980; XXVIII (CIV): 227-256.

[2] Stefanovits P., Filep Gy., Füleki Gy.: Talajtan. Budapest: Mezőgazda kiadó; 2010, ISBN: 9789632866765
[3] Ellenberg H.: Wiesen und Weiden und ihre standörtliche Bewertung. Stuttgart: Ulmer; 1952
[4] Ujvárosi M.: Gyomnövények. Budapest: Mezőgazdasági Kiadó; 1973
[5] Gencsi L.-Vancsura R.: Dendrológia. Erdészeti növénytan II. Budapest: Mezőgazda Kiadó; 1997
[6] Fattah H.-Upadhyaya S.: Effect of Soil Crust and Soil Compaction on Infiltration in a Yolo Loam Soil. Transactions of the ASAE. 1996; 39(1): 79-84. DOI: 10.13031/2013.27482
[7] Acheson D. J.: Elementary Fluid Dynamics. New York: Oxford University Press; 1990. 397 p. ISBN: 978019859679
[8] Beke J.: A súrlódásos közeg áramlása. In: Sitkei Gy. editor. Gyakorlati áramlástan. Budapest: Szaktudás Kiadó Ház; 1997. 504 p. ISBN: 9789633562139

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