Anti-erosion effectiveness of selected crops and the relation to leaf area index (LAI)

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ABSTRACT

This paper presents results of an experiment carried out in 2000–2003 in the mountain region (southern Poland, 545 m a.s.l.) to determine the effect of over-ground parts growth of fodder beet, winter triticale and horse bean on the intensity of soil losses. The research was conducted on the hillside with a 16% slope with the simulated rainfall (105 mm; 1.75 mm/min) applied at seven developmental stages of the plants. It was stated that soil protective efficiency of the fodder beet, horse bean and winter triticale started at about 60, 30 and 15% of covering the soil surface, respectively. The influence of over-ground parts of the plants (x) on the soil erosion (y) can describe the following regression equations: for fodder beet: $y = -9.37x + 29.4$ ($R^2 = 0.677$; $n = 82$); for horse bean: $y = -8.44x + 26.41$ ($R^2 = 0.698$; $n = 96$); for winter triticale: $y = -4.98x + 15.61$ ($R^2 = 0.66$; $n = 112$). The obtained results made possible verification of the nomograms determining the value of the C indicator (cropping factor, i.e. index of soil coverage and cultivation calculated as a ratio of soil mass eroded from the field covered with specific crop to mass of soil eroded from black fallow with a 9% slope angle) present in USLE equation (Universal Soil Losses Equation, method commonly recommended by FAO for studies on erosion) for tested plants under similar conditions.

Keywords: LAI (Leaf Area Index); water erosion; simulated rainfall; fodder beet; winter triticale; horse bean

Soil erosion is a great problem in agriculture on a global scale and the annual losses of soil amounted to 75 billion tons (Pimental et al. 1995, Crosson 1997). These losses depend on the intensity of water percolation into the soil which is significantly influenced by tillage treatments and also by the slope of the terrain, rainfall intensity, cropping system and soil surface cover by the plants (Matula 2003, Kováč et al. 2005). Changes of soil covereerage significantly affect soil quality (Foody 2002). The area of vegetation per unit ground area (m^2/m^2) is defined as Leaf Area Index (LAI). LAI measurement is a very important parameter to estimate soil surface coverage and plant productivity (Turner et al. 1999).

Wischmeier and Smith (1974) proposed the empirical model of USLE (Universal Soil Equation), method commonly recommended by FAO for studies on erosion bases on the equation:

$$E = R \times K \times LS \times C \times P$$

where: E – soil loss, i.e. average mass of eroded soil from area unit (Mg/ha/year); R – rainfall erodibility factor (Je/year; Je – unit of erodibility = MJ/ha.cm/h); K – soil erodibility factor, i.e. soil susceptibility to surface runoff (Mg.ha.h/MJ/ha/cm); LS – topographic factor, calculated as a ratio of the soil mass eroded from the field with studied plot with given length and slope angle to mass of soil eroded from black fallow with a 9% slope angle (no unit); C – cropping factor, i.e. index of soil coverage and cultivation calculated as a ratio of soil mass eroded from the field covered with specific crop to mass of soil eroded from black fallow with a 9% slope angle (no unit); P – conservation factor, i.e. index of anti-erosion measures calculated as a ratio of soil mass eroded from the field with anti-erosion cultivation to mass of soil eroded from black fallow with cultivation along the slope with a 9% angle (no unit).

To successfully introduce of this method in Europe it is necessary to verify its indicators in this part of the world. The necessity of such verification was pointed out by Schwertmann et al. (1987) a long time ago. One of the factors responsible for erosion intensity of soil cultivated in agriculture is the kind of plant cover. Plant ability to counteract the erosion depends mainly on the rate of over-ground parts growth, what protects the soil against splashing and decision of interception. Among generally available scientific papers concerning the indicator value of plant cover C (index of soil coverage and cultivation is a ratio of soil mass eroded from the field covered with specific crop to mass of soil eroded from black fallow with a 9% slope angle) in USLE pattern, very few publications describe precisely and dynamically the influence of growth of over-ground parts during their characteristic developmental stages on their soil-protective efficiency. It refers, among others, to sugar beet (Bollinne 1985) and also to spring wheat and spring barley (Rejman et al. 2001).

The objective of the performed research was to determine the influence of growth of over-ground parts of the fodder beet, winter triticale and horse bean on the reduction of soil losses intensity.

MATERIAL AND METHODS

A field experiment was conducted on a hillside with a mean slope of 16% in the years 2000–2003 in the Mountain Experimental Station in Czyrna near Krynica (545 meters above sea level, West Beskid, southern Poland). A multiple year mean sum of rainfall amounted to 838 mm, and the mean annual temperature was 6.1°C. The results presented in this paper are part of a bigger experiment where crops were cultivated in the following crop rotation: 1. fodder beet; 2. spring barley; 3. horse bean; 4. potatoes; 5. winter triticale. Herbicide fallow was the control object. A detailed description of climate and soil parameters can be found in earlier publication (Klima 2002).

One-factor field experiment was set up by means of randomizing blocks with four replications. Each year of the experiment every tested plant (fodder beet, winter triticale, horse bean) was cultivated on small plots in four replications. A single experimental plot was 22.13 m long (parallel to the land slope) and 1 m wide. On such plots, simulated rainfall was applied during the experiment. Measurements using simulated rainfall were carried out seven times each year of the experiment. Józefiaciuk's sprinkling machine (Józefaciuk and Józefaciuk 1996) was applied at the area 0.66 m^2. Every successive rainfall was carried out above

Table 1. Growing stages of plants in which measurement of soil erosion was performed

Fodder beet acc. to Gasowski and Ostrowska (1993)		Winter triticale acc. to Zadoks et al. (1974)		Horse bean acc. to Gasowski and Ostrowska (1993)	
growing stage and scale code of the stages	mean of number of days since sowing time	growing stage and scale code of the stages	mean of number of days since the revival of spring vegetation	growing stage and scale code of the stages	mean of number of days since sowing time
germination (03*)	9	beginning of spring propagation (21*)	2	germinal root visible (05*)	14
sprouts (10)	17	beginning of tillering (30)	11	2^{nd} leaf developed (21)	32
development of three pairs of leaves (24)	28	first awns visible (49)	46	6^{th} leaf developed (31)	54
7^{th} leaf is 8 cm long (31)	59	full flowering (64)	58	9^{th} leaf developed (44)	75
11^{th} leaf is over 10 cm long (35)	87	late milk maturity (77)	86	first petals of corolla (57)	99
interrows close-up (42)	99	hard wax maturity (87)	100	flowering of first bunches (62)	116
three week after interrows close-up (44)	120	dead maturity (92)	114	pods visible in five bunches (76)	131

*Scale code of growing stages for fodder beet and horse bean are done acc. to Gasowski and Ostrowska (1993) and for winter triticale acc. to Zadoks et al. (1974)

the previous measurement at a distance of about 2 m. The simulated rainfall classified as type III of torrential rainfalls (B3) was applied during seven developmental stages of the studied plants (Table 1). Degree III B3 rainfall is the rainfall of 105 mm with intensity of 1.75 mm/min, it is a torrential rain, totaling between 60 and 120 mm and with maximum intensity of 1.4–2.2 mm/min. Surface runoff was intercepted by a 1 m wide metal catcher. The catcher carried off the runoff into a container placed beneath the ground level. Topsoil moisture expressed in percent by volume (volume fraction) was determined each time prior to the measurement, i.e. seven times during the measuring season and ranged between 18 and 42%, on an average 27%. For the measurement of over-ground area of the studied plants, Sun Scan Canopy Analysis System apparatus for LAI was used. LAI was determined on every field directly before sprinkling. Thus, in every year of the performed studies (2000–2003) four measurements of intensity of soil losses and LAI there were taken at each of seven developmental stages of the studied crop plants, which have been shown in Table 1.

The experimental plots have been set up on acid Eutri-Gleyic Cambisols (pH in KCl equalled 5.0), developed from eluvium of flysch rocks contained 3.1% of organic matter. The granulometric composition was as follow: 28% of sand, 29% of silt and 43% of clay particles, which classified of soil as medium skeletal loam. The indicator value of soil susceptibility to runoff (silt to colloidal clay ratio) was 2.1. The slope gradient of experimental fields was determined by means of numerical terrain model using two computer programmes: SURFER (licence number 19498) and DIDGER (licence number D-5010).

The numerical terrain model consisting of *x, y, z* 5622 points set on the experimental field, was obtained by digitalisation of contur lines on the topografic map. Statistic calculations and chards were made using STATISTICA computer programme (licence number BXXP3080075221FAN5).

RESULTS AND DISCUSSION

A dependency between growing of the studied plant aboveground parts and the runoff intensity was described using simple regression. On the other hand characteristics of curves show a relationship between the number of vegetation days and the runoff intensity, and between the number of days and LAI were described by multiple regression (Figures 1–3).

From the results obtained it was stated that the soil-protective efficiency of fodder beet starts when beet plants cover at least 60% of soil, which is equal of LAI value of 0.6 (Figure 1). As far as horse bean is concerned the value equalled about 40%

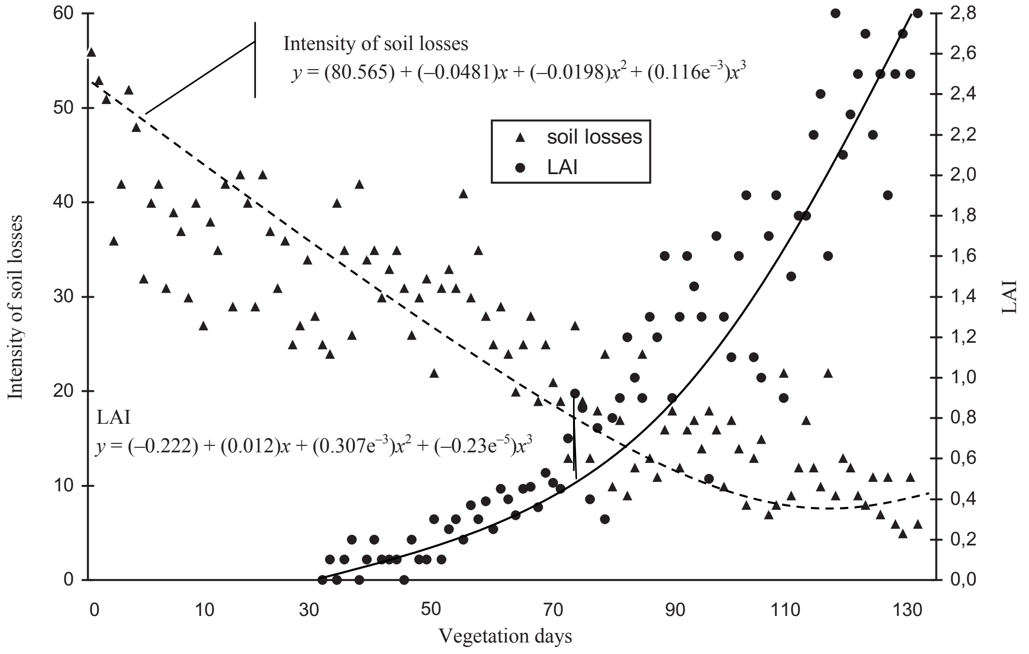

Figure 1. Changes of leaf area index values (m^2/m^2) (LAI) and intensity of soil losses (g/m^2) within the vegetation period of fodder beet

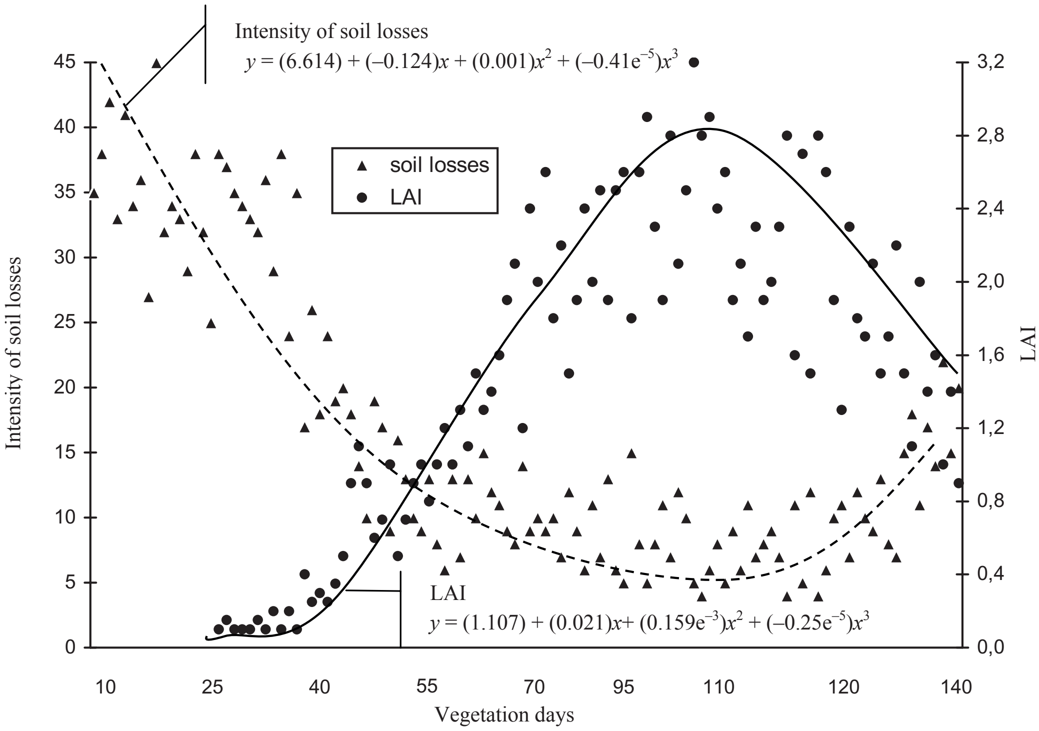

Figure 2. Changes of leaf area index values (m^2/m^2) (LAI) and intensity of soil losses (g/m^2) within the vegetation period of horse bean

(LAI 0.4; Figure 2), whereas the value for winter triticale equaled 16% (LAI 0.16; Figure 3). The earlier research conducted by Klima et al. (2004) showed potato's soil-protective efficiency of 80% (LAI = 0.8), spring barley of 30% (LAI = 0.3) and meadow of 4% (LAI = 0.04).

The influence of over-ground plant parts growth (x) on the reduction of soil losses intensity (y)

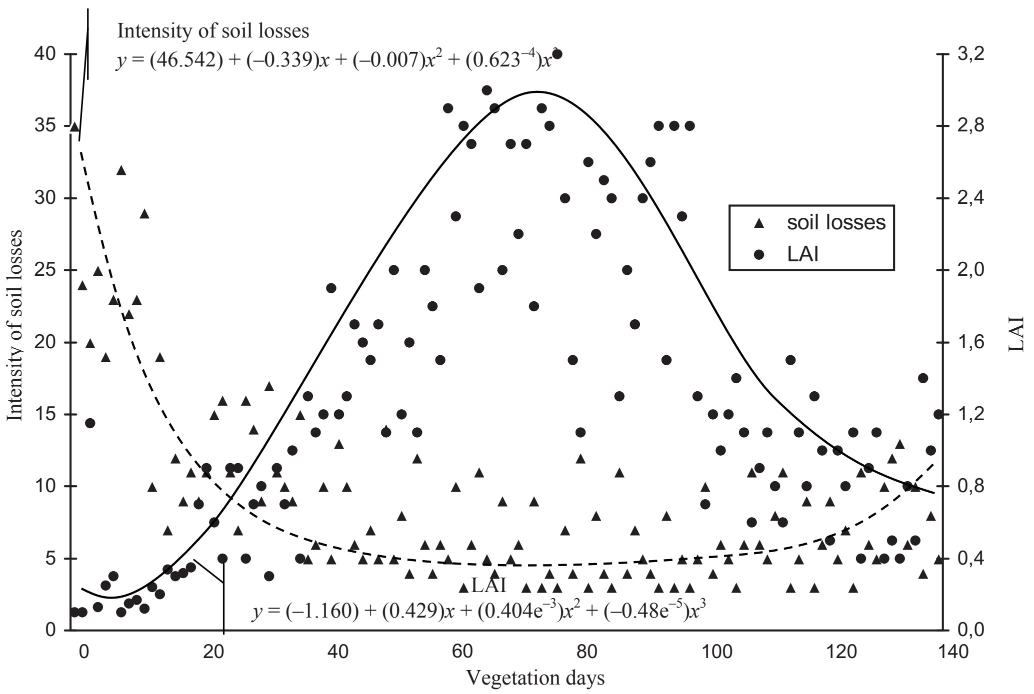

Figure 3. Changes of leaf area index values (m^2/m^2) (LAI) and intensity of soil losses (g/m^2) within the vegetation period of winter triticale

proved in the study can be shown in the following regression equation:

– for fodder beet $y = -9.37x + 29.40$ ($R^2 = 0.677$; $n = 82$)
– for horse bean $y = -8.44x + 26.41$ ($R^2 = 0.698$; $n = 96$)
– for winter triticale $y = -4.98x + 15.61$ ($R^2 = 0.66$; $n = 112$)

at importance level $\alpha = 0.01$

These relations pointed out that an increase of over-ground parts of the individual crop plant caused a decrease of soil losses, e.g. when over-ground parts of fodder beet area increase by 1 m^2 then soil losses decrease by 9.37 g/m^2. The amount of soil loss (mean of 112 plots) received in experiment from fodder beet fields equaled 23.6 g/m^2, from horse bean plots 15.4 g/m^2, and from winter triticale plots 8.1 g/m^2. Therefore it can be stated that winter triticale protected the soil twice as much as the horse bean and three times better than fodder beet.

Very few scientific publications undertake the problem of influence of growth of over-ground plant parts on their soil-protective efficiency (Bollinne 1985). Other works concerning the influence of LAI area on intensity of soil losses, point out that the increase of LAI area is directly proportional to interception (Bui et al. 1992, Foody 2002) and inversely proportional to splashing intensity (Rejman 1990). Nevertheless the authors mentioned above did not describe this interdependence as a mathematical formula, which has been done in this work.

These few works, which describe the soil-protectiveness value of plants dynamically, point out that plant anti-erosion activity begins at 20–30% of soil cover (Rejman 1990, Rejman et al. 2001). The results shown in our work proved that it is a substantial simplification of the problem as the soil protective values vary for various plants. The research showed that for fodder beet the mean value is 60%, for horse bean 40% and for winter triticale 16%. The relatively high value for fodder beet (60% of soil cover) may be connected with the fact that this root-crop plant is cultivated in wide furrows (60 cm), which must be opened twice in May. Such technology is almost a provocative factor for soil erosion. The lowest value for winter triticale soil cover (16%) proves its high value as soil-protective agent, which has been mentioned in several works (Rejman 1990). In modified USLE equation for Bavarian conditions Schwertmann et al. (1987) suggested their own classification of cultivation periods and plant development for the creation of new C indicator charts. Values of this indicator strongly depend on bearings and for this reason it should be worked out for individual latitudes. These values have not been established yet for Polish conditions. In the work of Banasik et al. (1995) we can find the C indicator values for crop cover for the certain months of the year. This is one of typical simplification used for parametrical method of erosion prognosis e.g. in the universal soil losses equation USLE (Wischmeier and Smith 1978) in which the C indicator value is read from nomograms. These simplifications are one of the reasons of lack of precision in erosion prognosis. As was proved in our work, C indicator is not permanent because of LAI value for fodder beet increased in May of 0–0.2, for winter triticale of 1.2–2.2 and for horse bean of 0.1–0.7. Therefore to be able to give more precise soil erosion prognosis using parametrical equations, one should use data of developmental stages of investigated plants. The necessity of this approach was pointed out also by Laflen (1998). The performed studies allow for the conclusion that the results of this work may be useful for verification of nomograms defining the C indicator value present in USLE equation under the similar conditions, for fodder beet, winter triticale and horse bean.

One may conclude that soil-protective efficiency of fodder beet begins when plants cover the soil surface at 60%, and for horse bean and for winter triticale 30 and 16% of soil surface needs to be covered, respectively. The influence of over-ground parts growth of investigated plants on the reduction of soil loss intensity can be shown in the regression equations for individual crop plants.

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