Reducing Concentrated Flow Erosion in Arable Fields by Double Sowing of Small Grains

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Abstract: Large areas of Northern Europe are intensively cultivated and seriously affected by physical degradation and water erosion. Prevention and control measures for concentrated flow exist, often based on an increase in vegetation cover, but because of practical reasons they are only reluctantly implemented by farmers. Moreover, the importance of the roots of the vegetation with respect to soil erosion by concentrated flow is often forgotten or ignored. Therefore, an attempt is made to explore the impact of plant root characteristics on concentrated flow erosion resistance, and to investigate an alternative strategy for soil erosion reduction in cereal fields, namely multiple sowing of small grains (e.g. wheat, barley, …) in zones prone to soil erosion by concentrated flow. Multiple sowing refers to sowing more than once in the zone of concentrated flow. This technique is based on an increased root density in the topsoil layer during the early crop growth stages when the aboveground biomass is still fairly limited.

The first results from the field measurements indicate that a doubling of the root mass in the topsoil can reduce soil loss by ca. 50% in the early plant growth stages, without negative effects on cereal production. Moreover, it was found that in the early growth stages of cereals, roots are relatively more important for reducing soil erosion rates than in later plant stages when the aboveground biomass overrules the effects of the plant roots. The relationship between soil loss by concentrated flow and root density in the topsoil is exponentially declining, but the degree of soil erosion reduction by roots will be strongly conditioned by their spatial arrangement and rooting properties. Cereal roots are of the fibrous root type with fine diameters and produce a dense root mat just below the soil surface. Therefore, multiple sowing in concentrated overland flow zones may be a viable soil erosion control technique in cereal fields affected by concentrated flow erosion.

Keywords: crop roots, small grains, concentrated flow erosion, erosion control technique

1 Introduction

Large areas of the European loess belt are intensively cultivated and seriously affected by physical soil degradation and water erosion (e.g. De Ploey, 1986; Poesen, 1993; Boardman *et al*., 1994), often leading to the development of rills, ephemeral gullies and bank gullies. Despite the fact that soil erosion by water causes considerable on-site and off-site problems, farmers in Europe are reluctant to adopt prevention and control measures when such measures require additional labour and material inputs. Yet, the use of erosion prevention measures in the source areas of soil erosion is to be preferred over off-site measures, because soil conservation is critical for long-term sustainable use of cropland. Several prevention and control measures for ephemeral gully erosion exist, often based on an increase in soil cover. The importance of plant cover in reducing soil erosion rates by water is sufficiently demonstrated in literature. On the other hand, the effects of the below-ground biomass on soil erosion rates are often forgotten or ignored. However, root density in the topsoil also contributes to soil strength (Li Yong et al., 1991; Tengbeh, 1993) and may therefore be a key factor in the control of soil erosion by concentrated flow on fields with sparse cover (e.g. seedbeds).

Given that the present understanding of root effects on concentrated flow erosion rates is very limited, the objective of this paper is (1) to explore the impact of plant root characteristics on concentrated flow erosion resistance and (2) to evaluate the new technique of multiple sowing of small grains in areas of concentrated flow with respect to its effectiveness to soil erosion reduction and to grain production. Multiple sowing refers to sowing more than once in the zone of concentrated flow. This technique is based on an increased root density in the topsoil layer.

2 Study area, materials and methods

Field measurements on the relationship between vegetation characteristics (roots and shoots) and concentrated flow channels were conducted in the Belgian Loess Belt. Sites with a contrasting vegetation cover density, where an ephemeral gully or rill eroded by concentrated flow crossed these vegetation covers, were selected for assessment of the most important characteristics of soil, topography and vegetation in order to explain the differences in concentrated flow channel dimensions. Grasses, winter cereals and fallow were the actual crops.

In addition to these field measurements, farmers were asked to sow small parcels (alternating single and double) in the area of concentrated flow, using small grains (such as wheat, barley, …). The results presented here are from 1 field, were winter triticale was sown at a normal rate of 120 kg/ha (ca. 300 seeds/m²). Distance between planting lines was 17 cm and plowing depth amounted to 25 cm. Drainage area is 0.99 ha, and slope of the soil surface 8.5%. Four parcels were created: zones 1 and 4 were sowed at a normal rate, whereas zones 2 and 3 were sown double. An ephemeral gully and several rills developed through these small parcels, perpendicularly to the sowing lines, after a cumulative rainfall of ca. 150 mm since time of sowing. During winter time, soil, topography and vegetation characteristics were measured, together with the channel dimensions. At time of harvest, triticale samples were taken to assess the specific cereal production (global grain weight, total dry biomass and hectolitre weight).

3 Results

3.1 Impact of vegetation characteristics on soil erosion

Several studies stress the importance of topographic parameters (i.e. soil surface slope (S) and contributing drainage area (A)) in explaining the dimensions of the eroded channel (Govers, 1985; Vandaele *et al.* 1996). Since both parameters control flow intensity, the multiplication of them yields a flow intensity indicator (AS). The cross-sectional areas of the eroded channels were plotted against this flow intensity indicator. As differences in topsoil properties between the studied sites are relatively small (data not shown), differences in concentrated flow channel cross-sections could be essentially attributed to differences in vegetation properties (root and shoot characteristics).

3.2 Shoots

Although strongly conditioned by some outliers, and based on a limited number of data points, fitted regression lines in Fig. 1a indicate that plant shoot density classes can be an explanatory variable for the observed differences in eroded channel cross-sections. A good plant cover – or high shoot density – considerably reduces soil erosion by concentrated flow. This can be drawn from the fact that the slope of the regression equation for high shoot densities (i.e. 0.01) is not significantly different from zero. High root densities correlate with grassed fields or meadows. On the other hand, low shoot densities (corresponding to the fallow fields) do not offer sufficient resistance to scouring, resulting in rather high channel cross-sections (Fig. 1a).

Transformation of the information given in fig. 1a to fig. 1b is done by calculating channel cross-sections at three given values of flow intensity indicator (i.e. AS equalling 1,000, 3,000 and 5,000 m² as indicated by the vertical arrows in Fig. 1a), using the 3 fitted curves for median shoot densities. The resulting relationship between channel cross-sections and shoot densities can be described as exponentially declining for the medium to high values of the flow intensity indicator (Fig. 1b). For the low value of AS, a linear trend is observed (Fig. 1b). The same trends appears when using vegetative cover as explanatory variable (data not shown). An exponential decrease in soil loss with increasing percentage canopy cover has been suggested by different authors (e.g. Rickson and Morgan, 1988; Snelder and Bryan, 1995).

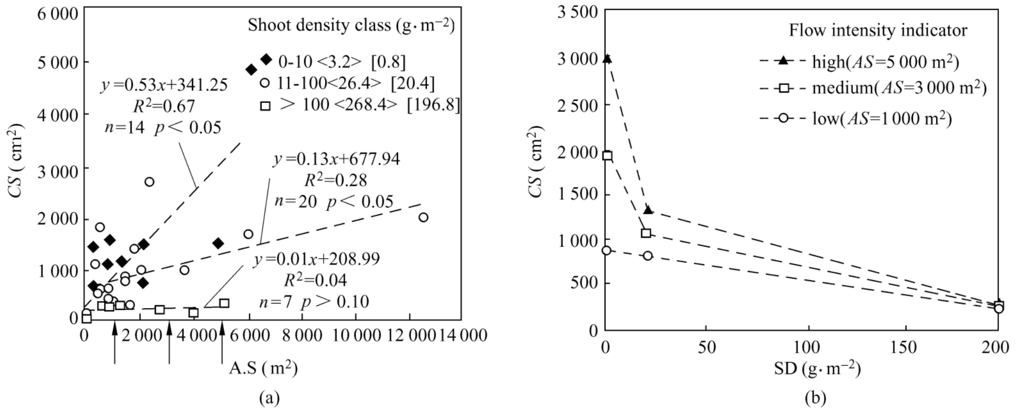

Fig. 1

(a) Shoot density class (*SD*, g • m^{-2}) as explanatory variable of the relationship between eroded channel cross-sectional area (*CS*, cm²) and flow intensity indicator (*AS*, m^2; *S* expressed as m • m^{-1}). Range, mean (between quotes) and median (between straight brackets) of the three shoot density classes are indicated as well. Arrows, pointing at the *X*-axis, indicate selected flow intensity indicator values used in Fig. 1b.

(b) Eroded channel cross-sectional area (*CS*, cm^2) predicted by median shoot densities (*SD*, g • m^{-2}) in Fig. 1a for selected values of flow intensity indicator.

3.3 Roots

In Fig. 2a the relationship between eroded cross-sectional areas and flow intensity indicator is explained by different root densities. Considering the striking parallelism of Fig. 1a and 2a, it becomes clear that plant roots can play an as important role with respect to soil erosion by water as plant stems and leaves. This reflection is even strengthened when comparing Fig. 1b and 2b. Likewise, an exponential decline in soil erosion can be seen, but whereas in Fig. 1b plant shoot density is the explanatory variable, it is plant root density in Fig. 2b. These results are in agreement with the study of Dissmeyer and Foster (1985), who similarly indicated an exponentially declining relationship between soil loss and percentage of bare soils with fine roots.

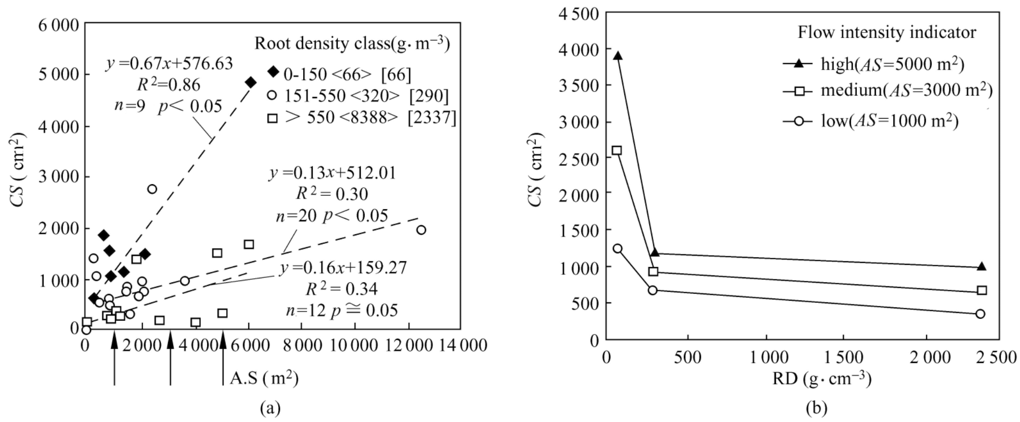

Fig.2

(a) Root density class (*RD*, g • m^{-3}) as explanatory variable of the relationship between eroded channel cross-sectional area (*CS*, cm^2) and flow intensity indicator (*AS*, m^2; *S* expressed as m • m^{-1}). Range, mean (between quotes) and median (between straight brackets) of the three root density classes are indicated as well. Arrows, pointing at the *X*-axis, indicate selected flow intensity indicator values used in Fig. 2b.

(b) Eroded channel cross-sectional area (*CS*, cm^2) predicted by median root densities (SD, g • m^{-3}) in Fig. 2a for selected values of flow intensity indicator.

3.4 Balance between root and shoot effects

The striking parallelism between the influence of roots and shoots on concentrated flow erosion is partly due to the inherent correlation between shoot and root densities. In constant environmental conditions, there is a linear relationship between the logarithm of shoot and root masses during vegetative growth, often expressed as the root-to-shoot ratio (Russel, 1977). For cereals, this ratio is not constant, but varies within the growing season. For cereals the masses of roots and shoots increase in parallel during the vegetative stage, meaning that the shoots and roots increase at the same growth rate, but by anthesis (i.e. the opening of flowers) the root-to-shoot ratio diminishes because old roots are not being replaced anymore by the growth of new roots (Barraclough *et al*., 1991), whereas shoots continue to grow and produce seed heads. Typical root-to-shoot ratios for cereals during the first two months of growth range between 6.04 and 7.3 (Glínski and Lipiec, 1990). The root-to-shoot ratio of grass in the vegetative phase is constant under constant conditions.

3.5 Implications

As a corollary of this parallelism, the effects of vegetation on soil erosion consist of complementary effects of plant roots and shoots. Soil erosion reduction by vegetation is thus a result of the combined effect of roots and shoots, whereby the main controlling factor depends on the plant growth stage. Fig. 3, which is based on a combination of the available data (only high flow intensity indicator values are represented), indicates that plant roots account for the majority of possible erosion reduction in the early plant stage, whereas plant shoots gradually increase their impact on soil erosion reduction with time. The importance of plant roots on soil erosion decreases with time and shifts towards a constant value at time of maximal root densities. This sharply contrasts with the rather constant increase in erosion reducing capacity of plant shoots up to plant maturity. An increasing shoot density not only implies an increase in vegetative cover, which dissipates the energy of falling raindrops, but also – in case of cereals and grasses – an increase in stem density and stem rigidity. Rigidity and number of stems impede the water flow and dissipate its energy. Since the stem elongation phase takes place rather late in the growing cycle of cereals and grasses, the date at which the effect of the plant stems on soil erosion by concentrated flow overrules the effects of plant roots in Fig. 3 is situated near the end of the growing cycle.

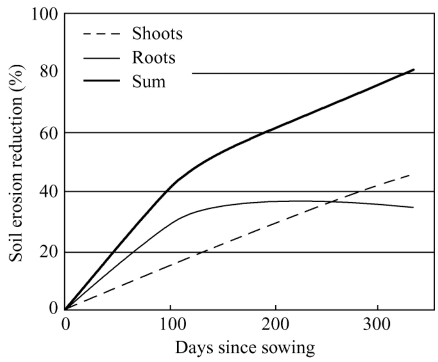

Fig. 3 Temporal variations of the effects of plant roots and shoots on the reduction of soil erosion by concentrated flow (only high flow intensity indicator is presented)

3.6 Multiple sowing of small grains

As Fig. 3 clearly demonstrates the positive effects of roots in the topsoil on resistance to scouring, plant roots could be a key factor in erosion control of concentrated flow channels in the early plant stages. Providing the soil a good root mat could be a valid strategy for controlling or limiting soil erosion in absence of other techniques or in case of low vegetative cover. It is obvious that the influencing role of plant roots on water erosion will largely depend on root type and their spatial distribution. Cereal and grass roots are of the fibrous root type with fine diameters (ca. 0.24 and 0.15 mm) (Van Noordwijk and Brouwer, 1991) and produce a dense root mat just below the soil surface. Winter cereals have one of the most prolific root systems of all arable crops (Barraclough *et al*., 1991) and could consequently be capable of controlling erosion in arable fields that are prone to soil erosion by concentrated flow if sown at sufficiently high rates.

3.7 Soil erosion and vegetation characteristics

Some preliminary results from the single and double sowed triticale field parcels confirm these assumptions. During winter time the triticale roots obviously exerted a strong influence on reducing concentrated flow erosion. Channel cross-sections were largest in zones 1 and 4 where plant density was lowest. Since the aboveground vegetation in the early winter period is relatively limited, the smaller channel cross-sections in zones 2 and 3 can be attributed primarily to the crop root characteristics. Roots can form a dense network that physically binds soil particles, thus creating a mechanical barrier to soil and water movement (Renard *et al*., 1997). Living roots exert strong tensile strengths, promote cohesion and enhance surface roughness. When runoff flows across a soil surface with high root density, the barrier effect and the increased surface roughness reduce the effective scouring force. Moreover, the barrier effect and the elevated surface roughness force the water to spread out over the soil surface, whereby the water depth and hence flow shear stress is reduced. As a consequence, the dimensions of the erosion channels in zone 2 and 3, where the root biomass is highest, are smaller compared to zones 1 and 4.

3.8 Soil loss by concentrated flow

Mean soil loss in the zones of normal sowing (zones 1 and 4) at the end of the growing season was 31.6 ton/ha/y, compared with an average soil loss of 18.3 ton/(ha • y) in the zones of multiple sowing (zones 2 and 3). The average reduction in soil loss by multiple sowing therefore amounts to 42%. This reduction reflects the total reduction in soil loss caused by the triticale roots as well as by the aboveground biomass over the whole growing season. Comparing soil losses in the zones of normal sowing and the zones of multiple sowing in winter time, which reflects only the effects of the triticale roots on the runoff erosion rates, results in an even higher reduction: i.e. 53%.

Therefore, from a soil conservation point of view, the effects of multiple sowing on reducing soil losses by concentrated flow erosion are readily apparent. However, enquiries among farmers indicate that they are seldom concerned about reducing soil erosion on their fields if additional effort is required and if the (short-term) cost-benefits balance is not positive. Therefore, the technique of multiple sowing will only be successful if also benefits in terms of crop yield are apparent.

3.9 Crop yield comparisons

To determine if such benefits can be achieved, crop yields in the studied zones were compared, and the results are promising. Despite the slightly smaller grains in the zones of multiple sowing, overall grain yield did not decrease as a result of higher stem density or increased risk of disease. Consequently, considering that the reduction in grain size in the zones of multiple sowing was compensated for by an increase in the grain yield in these zones, and considering that in the absence of multiple sowing all seedlings are washed away, the benefits of multiple sowing for the farmers are obvious. Compared to the problems experienced by farmers with the implementation of grassed waterways, the method of double sowing has less disadvantages, and might therefore be more acceptable to the farmers.

3.10 Concluding remarks

Since this study demonstrated that the universal exponentially declining trend in soil loss with increasing vegetation can be explained by using the shoot density as well as the root density, reflections should be made about the relative importance of both plant parts, when analyzing and modelling the impact of vegetation on soil erosion rates. Moreover, the temporal character of the separate influences of roots and stems/leaves must be considered. It has been shown that in the early growth stages of cereals and grasses, roots are relatively more important with respect to soil erosion reduction than in later plant stages when the aboveground biomass overrules the effects of the plant roots. Roots can reduce soil erosion by concentrated flow, if present at a sufficiently high density. Of course, the degree of soil erosion reduction by roots is strongly conditioned by their spatial arrangement and the rooting properties (length, diameter, …).

This study also demonstrated the potential of multiple sowing of small grains in areas of concentrated overland flow, thus opening the possibility of using this technique for controlling rill and ephemeral gully erosion rates in high-risk zones. The results indicated that the increase of the total root mass of triticale in multiple drilled areas reduced concentrated flow erosion rates by 53% in the early plant stages. Moreover, the results with respect to the grain production are promising. Despite the slightly smaller grains in the zones of multiple sowing, overall grain yield did not decrease as a result of higher stem density or increased risk of disease.

The results obtained in this study are valid for a particular position of treated zones along the concentration flow line. There is no doubt that the results certainly apply to a position located more upstream in the landscape. To what extent the conclusions also hold for more downstream positions is at present not known but needs to be further investigated. Attention should also be paid to the impact of the timing of the rainstorms on controlling erosion. It is obvious that the timing of the rain with respect to drilling operations will be crucial for soil erosion reduction by multiple sowing. The observed differences between single and double sowing in this study are only valid for the specific rainfall that caused them. Consequently, the effectiveness of the roots in reducing soil erosion is strongly conditioned by the plant growth stage.

References

Barraclough P.B., A.H. Wier, H. Kuhlmann. 1991. Factors affecting the growth and distribution of winter wheat roots under UK field conditions. In: McMichael B.L., H. Persson (eds.). Plant roots and their environment. Proceedings of an ISRR-symposium August 21st-26th, 1988, Uppsala, Sweden. Elsevier Science Publishers: Amsterdam. p. 410-417.

Boardman J., L. Ligneau, A. De Roo, K. Vandaele. 1994. Flooding of property by runoff from agricultural land in north-western Europe. Geomorphology. vol. **10:** p. 183-196.

De Ploey J. 1986. Bodemerosie in de lage landen: Een Europees milieuprobleem. Acco: Leuven. 108 p.

Dissmeyer G.E., G.R. Foster. 1985. Modifying the universal soil loss equation for forest land. In: El-Swaify S.A., W.C. Moldenhauer. A. Lo (eds.). Soil Erosion and Conservation. Soil Conservation Society of America: Ankeny. p. 480-495.

Glínski J., J. Lipiec. 1990. Soil physical conditions and plant roots. CRC Press: Florida. 250. p.

Govers G. 1985. Selectivity and transport capacity of thin flows in relation to rill erosion. Catena. vol. **12**(1): p. 35-49.

Li Yong, Zhu Xian-Mo, Tian Ji-Ying. 1991. Effectiveness of plant roots to increase the anti-scourability of soil on the Loess Plateau. Chinese Science Bulletin. vol. **36**(24): p. 2077-2082.

Poesen J. 1993. Gully typology and gully control measures in the European loess belt. In: Wicherek S. (ed.). Temperate plains Environment and Hills, Farm Land Erosion. Elsevier Science Publishers: Amsterdam. p. 221-239.

Renard K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). USDA-ARS, Agriculture Handbook No. 703. U.S. Government Printing Office.

Rickson R.J., R.P.C. Morgan. 1988. Approaches to modelling the effects of vegetation on soil erosion by water. In: Morgan R.P.C., R.J. Rickson (eds.). Agriculture: Erosion Assessment and Modelling. CEE: Luxembourg. p. 237-253.

Russell R.S. 1977. Plant roots system: their function and interaction with soil. McGrax-Hill Book Company: Londen.p. 298.

Snelder D.J., R.B. Bryan. 1995. The use of rainfall simulation test to asses the influence of vegetation density on soil loss on degraded rangelands in the Baringo District, Kenya. Catena. vol. **25**: p. 105-116

Tengbeh G.T. 1993. The effect of grass roots on shear strength variations with moisture content. Soil Technology. vol. **6**: p. 295-387.

Van Noordwijk M, G. Brouwer. 1991. Review of quantitative root length data in agriculture. In: McMichael BL, H. Persson (eds.). Plant roots and their environment. Proceedings of an ISSR-symposium: August 21st-26st, 1988, Uppsala, Sweden. Elsevier Science Publishers: Amsterdam. p. 515-525.

Vandaele K., J. Poesen, G. Govers, B. Van Wesemael. 1996. Geomorphic threshold conditions for ephemeral gully incision. Geomorphology. vol. **16**: p. 161-173.