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### ► To cite this version:

J. Y. Wu, D. Huang, W.J. Teng, V.I. Sardo. Grass hedges to reduce overland flow and soil erosion. Agronomy for Sustainable Development, 2010, 30 (2), 10.1051/agro/2009037 . hal-00886503

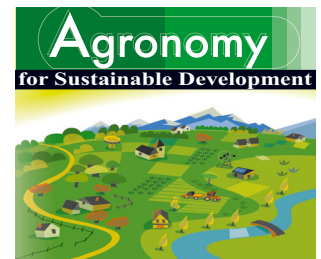
**HAL Id: hal-00886503**

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## Research article

# Grass hedges to reduce overland flow and soil erosion

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(Accepted 21 September 2009)

**Abstract** – Overland flow and the consequent soil erosion are worldwide problems that are particularly acute in the Chinese Loess Plateau. Negative consequences are *in situ* erosion and land impoverishment, and even more serious damage such as physical and chemical pollution in downstream areas. Land impoverishment is due to the loss of fertile topsoil with its load of organic matter and nutrients. Nonetheless, the overland flowing water could be beneficial by helping to reduce the drought risk, if it could be controlled and encouraged to infiltrate the soil. Grass hedges are a cheap and effective structure for controlling overland flow and for filtering nutrients and pollutants, but research has mainly focused on their use in tropical, subtropical and Mediterranean environments. Here, two grass species were tested for their ability to reduce overland flow and soil erosion. Simulated rainfall was applied during sets of three 1-h runs to evaluate the effects of protective grass hedges. We tested two different grasses, *Pennisetum alopecuroides* and *Arundinella hirta*, under three rain intensities of 14, 22 and 36 mm h<sup>-1</sup>, and 5–20% slope gradients on overland flow and soil loss. Plots without grass hedges were used as control. Our results show that grass hedges reduced overland flow by 72% for *Pennisetum* and by 36% for *Arundinella* on average. Such native, non-invasive, perennial grasses proved to be very promising for use in conservation practices.

filter strips/ soil erosion/ rain simulator/ overland flow/ natural engineering

## 1. INTRODUCTION

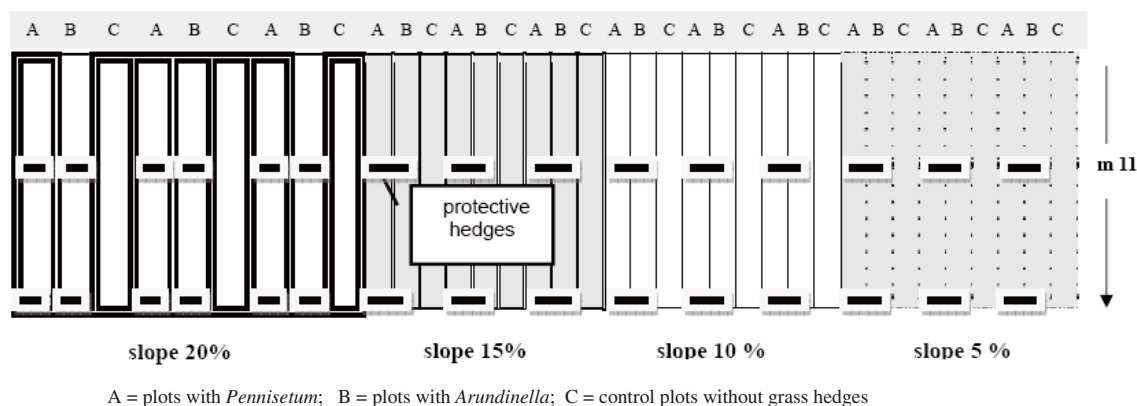
Overland flow, soil erosion and drought are major, often interlinked problems attracting widespread attention in China and worldwide (FAO/UNDP/UNEP, 1994). At present, approximately one-third ( $3.67 \times 10^6$  km<sup>2</sup>) of China's total area is suffering from soil erosion, generally associated with drought problems due to the soil impoverishment in organic matter and good-structured horizons; especially in the Yellow River catchments and in the Loess Plateau region, soil erosion is progressing at an alarming rate and 60% of these areas are severely eroded (Liu et al., 2004; Huang et al., 2005). Damage is classified as “*in situ*”, including the loss of fertile soil horizons, and “*ex situ*”, including physical and chemical pollution downstream (e.g. Duràn Zuazo et al., 2008). By investigating the action of grass hedges on overland flow and soil loss reduction it is hoped that a better understanding of the related mechanisms can be achieved, which can lead to more effective strategies in controlling soil erosion and storing rainfall in the future. The interest in such investigations is also fuelled by the obvious link between a reduced overland flow and a parallel

increased availability to crops of stored rainfall water, particularly useful in semi-arid lands (Duràn Zuazo et al., 2008).

More or less narrow, nearly parallel strips (“hedgerows”) of stiff-stemmed grass, planted approximately along the contour lines, can reduce soil erosion caused by flowing water (Becker, 2001) and reduce pesticide transport downstream (Lacas et al., 2005). Grass hedges facilitate deposition of eroded materials by reducing the carrying capacity of overland flow and encourage water infiltration into the soil. The effectiveness of the grass hedges is influenced by the length, width and thickness of the vegetative filter, the characteristics of the runoff area, the precipitation intensity and the slope gradient (Robinson et al., 1996; Gilley et al., 2000).

Most researchers used vetiver grass (*Vetiveria zizanioides* L.), eastern gamagrass (*Tripsacum dactyloides* L.) and other perennial grasses with stiff, erect and coarse stems (e.g. Lahmer, 2004; Rachman et al., 2004, 2005; Janushaj, 2005); such species belong to warm-season grasses, and show a good protective action in tropical, subtropical and Mediterranean areas. Recently a number of studies have been conducted in southern China to evaluate grass hedges' effects on soil erosion (Liu et al., 2004; Li, 2005) but there are no documents concerning the grass species potentially suitable for forming

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**Figure 1.** Layout of the experimental field: 36 plots resulting from 3 protections  $\times$  3 replicates  $\times$  4 slopes.

hedges in northern China, where winters are typically dry and temperatures can fall below  $-20^{\circ}\text{C}$ . As a result, the selection and testing of two grasses was the first objective of the present study, while an additional objective was to obtain more information on hedgerow impact on runoff, erosion and rainfall storage under contrasting conditions in order to improve the system design and management.

*Pennisetum alopecuroides* L. and *Arundinella hirta* (Thunb.) Koidz are probably the two most promising candidates for hedgerows in northern China as based on previous research conducted locally (Wu, 2003; Wu et al., 2005), since both of them are native, perennial and non-invasive species, have practically no natural enemies and are tolerant to the local climate extremes. Additionally, these species can be easily established and have sufficient stem strength to remain erect against flowing water. As a consequence, their effectiveness in reducing overland flow and soil loss under different slope gradients and rainfall intensities was investigated.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The study was conducted at the National Experiment Station of Precision Agriculture, Beijing, P. R. China ( $116^{\circ} 26' \text{E}$ ;  $40^{\circ} 10' \text{N}$ ). The study area is located in the Northern China plain and is characterised by a continental, semi-humid climate. Maize, soybean and wheat are the dominant crops. Annual precipitation averages 630 mm, 75% of which falls between June and August, and the mean annual temperature is  $11.8^{\circ}\text{C}$ . The mean daily temperature is below zero in the months of December, January and February, with a mean minimum of  $-8.1$  in January. The average frost-free growing season extends for about 190 days, from mid-April to mid-October. The soil is a loess with 33.4% sand, 52.9% silt and 13.7% clay; its mean constant infiltration rate as measured by means of double-ring infiltrometers is about  $13 \text{ mm hr}^{-1}$ , while the bulk density is  $1.50 \text{ g cm}^{-3}$ .

**Table I.** The morphological characteristics of soybean and grasses.

Plant	Canopy coverage (%)	Height (cm)	Density (stems)
<i>Pennisetum</i>	98	78	1220
<i>Arundinella</i>	94	69	875
Soybean	83	62	20

### 2.2. Experimental design and treatments

The experimental design included three independent variables: soil protection (*Pennisetum*/*Arundinella*/no hedges); slope gradients (5, 10, 15 and 20%); and precipitation intensity (14, 22 and  $36 \text{ mm h}^{-1}$ ) - all in three replicates. An experimental field was established in 2005: the plot size was  $1.6 \times 11.0$  metres, and nine of them were installed for each slope category, deriving from 3 plots protected with *Pennisetum*, 3 plots with *Arundinella* and 3 with no protection, which resulted in a total of 36 plots, as illustrated in Figure 1.

In April 2006 two 0.5-m-wide grass hedges per plot were planted perpendicular to the slope, one at the bottom of the plot and the other at mid-slope. The two hedges were separated by soybean rows parallel to them and spaced 40 cm apart, which gave nearly complete soil cover, in excess of 80%. Information on plant coverage, density and height is reported in Table I.

A rainfall simulator was designed and installed (Xianfei Agricultural Engineering Hi-Tech Co., Beijing, P. R. China) which provides near-natural rainfall drop size and velocity. Three types of nozzles were used in the simulator (PROS-17, PROS-15 and microsprinklers 102 Lh-1, HUNTER COMPANY, USA), and the working pressures ranged between 0.16 and 0.22 MPa. The rainfall coefficient of uniformity, measured according to the Christiansen method (Christiansen, 1942), averaged 86%. The simulations were conducted according to the standard procedure, under three different soil moisture conditions. For each precipitation intensity three one-hour runs were applied: the first one at low soil moisture conditions ("dry run"); a second application at the same intensity was conducted approximately 24 hours later ("wet run"), and a third run one hour after the wet run completion ("very wet run").

The interval among the different sets of three runs was 10 days, sufficient to let the soil surface dry up, and no rains occurred during the whole period of the experiment. Three rain intensities were tested: 14, 22 and 36 mm hr<sup>-1</sup>. The low precipitation intensity of 14 mmh<sup>-1</sup> was adopted just for the sake of experimental completeness, in order to explore a range of intensities whose lowest value slightly exceeded the soil intake rate, while 36 mm hr<sup>-1</sup> corresponds approximately to the mean value of local maximum rain intensity for one-hour storms.

A total of 324 plot/events were observed, resulting from 3 runs × 3 rain intensities × 36 plots, but for the statistical analysis only the 216 events related to the wet and very wet runs were considered. Because water was promptly absorbed during the dry runs, the runoff was in fact minimal or nil when the 14 mm h<sup>-1</sup> treatment was applied: for this reason, and in compliance with the commonly accepted procedures, the statistical analysis was based only on data obtained during the wet runs and the very wet runs.

Standard procedures were used to calculate overland flow and soil loss (Meyer, 1960). The rainfall intensity and total amount was monitored through rain gauges and flowing water was collected after each run in containers located at the bottom of each plot. Besides measuring the total runoff, one-litre water samples were collected from each container after thorough mixing and analysed. A paper filter was used to separate the soil from water and the sediment dry weight was obtained by storing the paper filter in an oven at 105 °C until a constant weight was reached.

Antecedent soil moisture and soil bulk density were not considered as independent variables since in former experiments – they gave non-significant results (Lahmer, 2004; Janushaj, 2005).

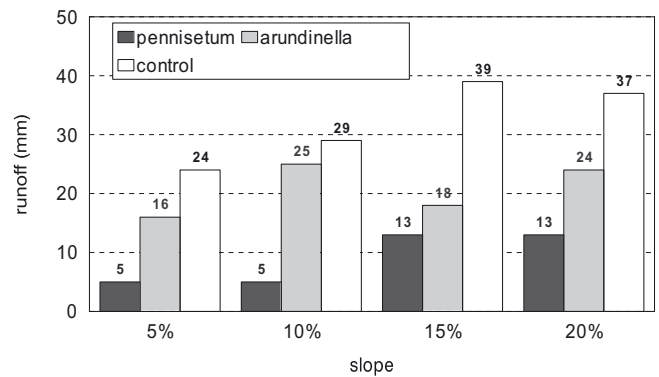
SPSS 10.0 and Statgraphics Plus 5 software packages were used for statistical elaboration. Data collected were submitted to analysis of variance (ANOVA) at a  $P \leq 0.05$  level, according to the least significant difference (LSD) test. Multiple linear regression coefficients were computed assuming runoff and soil loss as dependent variables and slope, rain intensity and hedge protection as independent variables. Additionally, the best fitting correlations, other than linear, between runoff and soil loss were determined for a more thorough analysis.

### 3. RESULTS AND DISCUSSION

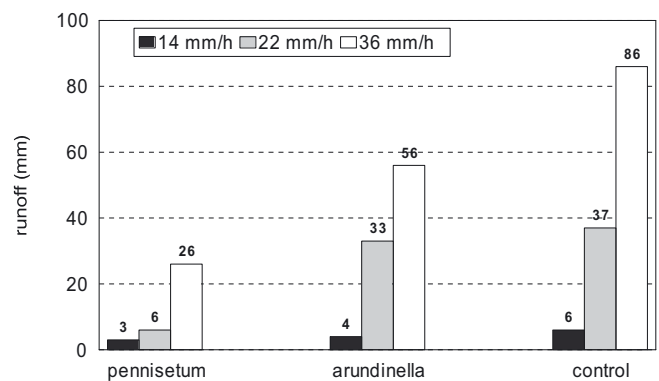
#### 3.1. Grass hedge effects on overland flow

Data referring to overland flow indicate that grass hedges had a significant effect on flow reduction. As the rain simulation tests proceeded, overland flow moved downslope to the grass hedges and backwater began to appear behind them, which provided a longer “opportunity time” for water to infiltrate.

Figure 2a shows the reduction in overland flow due to Pennisetum and Arundinella hedges in the four different slopes during wet and very wet runs: the different efficiency of the two species is evident although it can be argued that it also depends on their different development rate and plant density;



**Figure 2a.** Runoff as influenced by protective hedges and slope-data refer to the average of 18 events.



**Figure 2b.** Influence of precipitation rate and protective hedges on runoff-data refer to the average of 18 events.

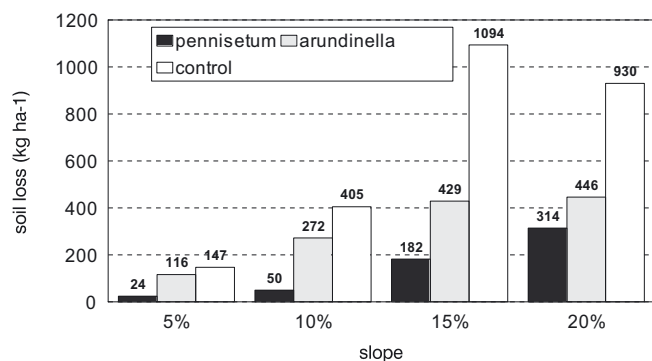
therefore, a better protective action from Arundinella may be expected in the coming years.

Considering the total flow from the four slopes in wet and very wet runs, the reduction obtained through the Pennisetum hedges as compared with control was 72% versus 36% obtained with Arundinella. Seen from a different standpoint, overland flow reduction corresponds to a parallel increase in water storage in the soil, with the dual achievement of reduced erosion and enriched soil moisture. This integrated response to the four slopes can be an interesting indication, more significant than that to the single slopes, when operating on a watershed scale, since it fits a multiplicity of conditions better.

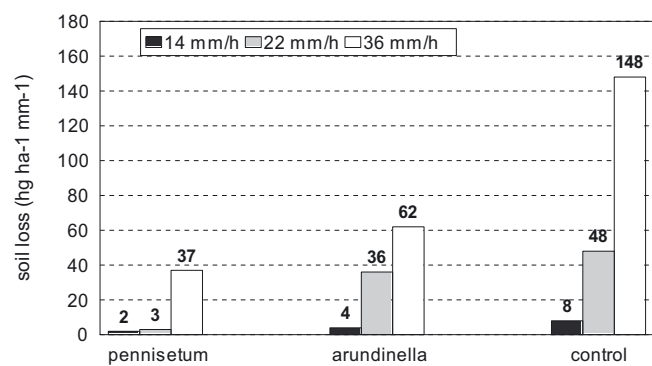
Figure 2b shows the combined action of protecting grass hedges and precipitation rate on runoff: it is easy to appreciate the opposite action of precipitation intensity, enhancing runoff, and grass hedges, reducing it; particularly with Pennisetum. The powerful action of the latter contrasts that of precipitation to the extent that when precipitation passes from 14 to 36 mm h<sup>-1</sup> runoff, although about doubled, does not exceed 6 mm, whereas in the control it passes from 26 to 86 mm.

#### 3.2. Grass hedge effects on soil loss

Variations in soil erosion paralleled to some extent those in overland flow: the results in fact indicated that grass hedges,



**Figure 3a.** Soil loss as affected by protective hedges and slope-data refer to the average of 18 events.



**Figure 3b.** Soil loss as affected by protective hedges and rain intensity-data refer to the average of 18 events.

while decreasing runoff and reducing its carrying capacity, also facilitated the deposition of eroded materials. This protective action is synthesised by the cumulated soil loss reduction in the four slopes, computed over all the events, of 78% with Pennisetum and 51% with Arundinella compared with the control (Fig. 3a).

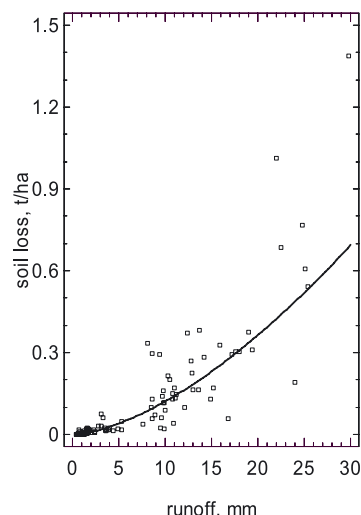
The relative inconsistency of the response of overland flow and soil loss to slope, as evidenced by Figures 2a and 3a, matches the results obtained by Lahmer (2004) and Janushaj (2005) well, confirming that beyond the threshold of about 15% the influence of slope becomes erratic.

Figure 3b shows the effects on soil erosion of the different precipitation intensities and the different protective action of the grass hedges; for a better appreciation, results are expressed as  $\text{hg ha}^{-1}$  of soil loss per mm of simulated rain.

A reduction in soil loss of 94 and 65% for Pennisetum and Arundinella, respectively, can be evidenced when the combined results are considered.

### 3.3. Relationship between overland flow and soil transport

The inspection of the scatterplot in Figure 4 with the relationship between overland flow and soil transport, showing a non-linear increase in soil loss with increasing runoff, led to the exploration of models of correlations other than linear,



**Figure 4.** Regression of soil loss on runoff for wet and very wet runs-data refer to single events.

and a curvilinear model, i.e.  $\ln(\text{soil loss}) = a + b * \ln(\text{runoff})$  gave the best fittings, with  $R^2$  values always explaining more than 80 % of variations: in detail, 84.6 % for wet runs; 81.5 % for very wet runs; and 80.1 % for combined runs. This non-linear relationship between overland flow and soil loss is perfectly explained by the exponential increase with velocity in the “tractive force” and the consequential shear stress of flowing water (e.g. Gustafson, 1941; Kinori, 1970). Figure 4 shows the model derived from combined results ( $n = 216$ ).

### 3.4. Multiple regressions

Multiple regressions of overland flow versus the predictors “slope”, “rain intensity” and “grass protection” were separately calculated for wet runs, very wet runs and both, and in all cases the values of the coefficients of determination  $R^2$  were rather high (explaining 61.7% of the variability in the case of wet runs, 74.8% in the case of very wet runs and 72.2% for the combined runs), demonstrating that this totally empirical approach can explain to a large extent variations in overland flow. These relationships are also interesting for the estimation of the potential increase in rainfall stored in the soil.

The resulting equation for the combined runs was:

$$\text{Runoff} = -2.96 + 0.12 \text{ slope} + 0.29 \text{ rainfall} - 1.939 \text{ protection} \quad (n = 216).$$

In the above equation runoff is expressed in mm, slope in percent, rainfall in  $\text{mm h}^{-1}$  and protection is indicated as 0 = control; 1 = Arundinella; 2 = Pennisetum, which is the reason why the protection coefficient in the equation has a negative value.

The notoriously more erratic response of soil, influenced by unpredictable events such as sudden lump detachments or formation of rills and preferential flows, did not allow one to reach such high  $R^2$  values for soil loss as in the analysis of overland flow: in the case of the combined runs, in fact, the  $R^2$  value was 55.5 per cent while values of 63.1 per cent and



76.1 per cent, respectively, were attained for wet and very wet runs. The equation for the combined runs, based only on the independent variables “runoff” and “slope”, was:

Soil loss =  $-0.055 + 0.022 \text{ runoff} + 0.003 \text{ slope}$  ( $n = 216$ ).

The units are  $\text{tons ha}^{-1}$  for soil loss, mm for runoff and percent for slope.

The good agreement of the results of the present investigation with those previously found with vetiver grass in a totally different environment (Lahmer, 2004; Janushaj, 2005) gives support to their validity under a rather wide variety of conditions, in spite of the crude “black box” approach.

#### 4. CONCLUSION

Hedges formed by the two native perennial grasses proved to be an efficient conservation structure, since they caused a substantial reduction in overland flow, and the percentage of this reduction increased with precipitation intensity. The results showed that *Pennisetum alopecuroides* performed better than *Arundinella hirta*, although an improvement in the performance of the latter can reasonably be expected with its future growth and thickening. Both grasses being native to northern China are perfectly suitable for that ecological environment.

Grass hedges enabled the accumulation of backwater upstream of the filter strips, which resulted in more rainfall storage, and in sedimentation and substantial reduction in soil loss; the reduction in soil transport resulting from *Pennisetum* hedges was higher than that from *Arundinella*.

Based on the results of 216 events, simple empirical models were elaborated, able to predict to a large extent variations in overland flow and soil transport.

Soil loss was highly correlated with overland flow; the relationships between the two variables could be best described by non-linear (e.g. multiplicative) models, able to explain over 80% of the variations.

The empirical approach of this investigation has the obvious disadvantage of limiting the validity of its conclusions to experimental conditions, but on the other hand it permits one to obtain rapid and reliable responses to acutely felt problems, and as mentioned above, these results closely match those obtained in different environments.

The results achieved in the course of the research may be used as a first approximation in the design of vegetative structures for soil protection and water harvesting.

**Acknowledgements:** This work was supported by the Sino-Italian Fund (2006–2009) and the Key Project of Beijing Technologies Programme (Multiple Protection Strategies on Rain Runoff and Soil Erosion of Miyun Reservoir Watershed 2004–2008, Study on Grassland Restoration and Utilisation of the Degraded Ecosystem Area Z0006321001291).

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