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Research and practical experiences with vegetative barriers for water erosion control in Venezuela

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ABSTRACT

The data obtained from erosion plots under natural and simulated rainfall through different experiments within the period 1980-1998, are summarized using the Universal Soil Loss Equation (USLE) ¨CP¨ factor as an indicator of water erosion control efficiency by vegetative barriers. Different plant materials, mainly grasses (*Andropogon gayanus, Cenchrus ciliaris, Cymbopogon citratus, Vetiveria zizanioides, Trixacum laxum, Nephrolepis* sp. *and Agapanthus africanus*) were evaluated under different experimental conditions. Variations in slope gradient, agroecological conditions, land use and soil management between barriers, as well as different lengths of slope, plant age and success of establishment, influence the efficiency of vegetative barriers for water erosion control. CP values ranged from less than 0.001 when the barriers were associated with high levels of residue cover and permanent crops up to more than 0.53 when vegetative barriers are alone (bare soil on the upside of the vegetative barrier) and recently established. *Vetiveria zizanioides* and *Trixacum laxum* were the most efficient grasses to reduce water and soil losses, but the other plants demonstrated good potential in particular land use systems and circumstances. Additional information related to vegetative barriers behavior and performance was collected in order to assess criteria for its selection and best management when used for water erosion control. A table is presented as a guideline to design vegetative barriers spacing considering rainfall erosivity, soil erodibility and crop-management intensity. Practical experiences using vegetative barriers within farmers fields and rehabilitation processes of degraded lands, have demonstrated the high potential of this soil conservation technology to help develop sustainable land use systems.

INTRODUCTION

Land degradation results from different processes that decrease resource productivity and its potential to be productive for humankind. It is necessary to confront these processes, whether they are natural or human induced. Soil and water conservation can be defined as a set of actions, measures and strategies, to mitigate or avoid soil and water degradation as well as improvement and restoration of these resources. Also included is the use of soil and water resources in such a way that they yield the maximum social benefit through the sustained flow of their basic functions. This will optimize and diversify the development of options for present and future generations and give support for sustainable development.

Among soil conservation practices, vegetative barriers and surface cover by residues or cover crops, have a greater potential due to their high efficiency in erosion control, and at the same time, they have a low cost. Mechanical structures like terraces are usually relatively expensive. Young, (1989), Foster et al. (1982), Hudson (1971) among others, have emphasized the cover approach as an erosion control strategy, more efficient than the barrier approach. However, Rodríguez and Fernández (1992) found that the combination of both strategies is desirable, especially when there is a risk of extremely erosive rains and the surface of the soil is not protected, which is the case in many agricultural systems. If terraces and walls are expensive, vegetative barriers can be economical and highly efficient. Gupta (1992) mentioned that agronomic practices could be between 10 and 100 times more economical than mechanical practices and also very effective. Recent research in Honduras demonstrates that surface cover alone was insufficient to control erosion related to surface water erosion in large scale field plots (Thurow and Smith, 1998).

Vetiver (*Vetiveria zizanioides*), one of the grasses evaluated in this research, has been successfully used in Venezuela on field and experimental plots. The dense vegetative structure and the deep vertical roots are great advantages for Vetiver barriers (Grimshaw, 1989). It is also fire, grazing and flood resistant, it does not become a weed, occupies a small proportion of the land and adapts to many agroecological conditions. Truong (1993) referred to literature reports showing higher efficiency of Vetiver barriers (Pvb=0.28) as compared with Leucaena barriers (Pvb=0.53) and terraces (Pvb=0.28). He also referred other reports comparing Vetiver barriers (Pvb=0.15) with Pennisetum hedges (Pvb=0.40). Xie (1997) found that for Fujian province in China, the cost of Vetiver barriers was only 10% that of rock walls.

The objectives of this research were: a) To integrate existing information about research and practical experiences with vegetative barriers, as a soil conservation practice, to control surface water erosion in different experimental settings and agroecological conditions in Venezuela, b) To collect additional information on

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Table 1. Characteristics of erosion plots sites.

Locality	Life zone	Average annual rainfall mm	Annual EI_{30} MJ mm / ha h	Soil	Erodibility "K" Mg ha^{-1} / MJ mm /ha h	Landscape	Slope range
Maracay	Premontane dry forest †	922	6230	Cumulic Haplustoll	0.014-0.044	Piedmont	6-17 %
Chaguaramas	Dry tropical forest †	821	5610	Typic Haplustalf	0.036-0.060	Hills	4-6 %
Yaritagua	Dry tropical forest	842	4510	Oxic Paleustalf	0.023	Valley	4 %
Petaquire Bajo Seco experimental station UCV	Transition Lower montane dry to moist forest	860	2613	Aquic Paleudult, Orthoxic Tropudult	0.013-0.028 0.001-0.011	Mountain slope	15-36 % 42-70 %

† Extreme storms occur more frequently.

vegetative barriers in order to assess criteria for its selection and best management when used for water erosion control, and c) To establish some practical guidelines to design vegetative barriers spacing in different agroecological conditions.

Experiments Location and Method

Experiments were conducted under natural and simulated rainfall to evaluate water erosion control efficiency by vegetative barriers, using erosion plots with different dimensions, collector designs, variations in slope gradient and located in four different agroecological sites (see table 1). Different plant materials, mainly grasses "Pasto sabanero" (*Andropogon gayanus*), "Cadillo bobo" (*Cenchrus ciliaris*), "Lemon grass" (*Cymbopogon citratus*), "Vetiver" (*Vetiveria zizanioides*), "Guatemala grass" (*Trixacum laxum*), "Fern" (*Nephrolepis* sp), and "Lily" (*Agapanthus africanus*) under different cropping/cover and management systems between barriers were evaluated. USLE factors were used as a framework for data processing and report.

Páez and Rodríguez (1984) and Páez (1995), based on USLE factors (Wischmeier and Smith, 1978), established a criteria for land evaluation and classification with regard to soil vulnerability to water erosion. The system is based on the assignment of maximum "CP" values of land units "CP_{max}". High "CP_{max}" values represent a low vulnerability or low conservation and management requirements; and low "CP_{max}" values indicate a severe vulnerability and high requirements of soil and water conservation measurements. It is derived from an equation where $CP_{max} = T/RKLS$, the relation between soil loss tolerance and the potential erosion within a land unit using USLE terms.

The degree of protection offered by different cropping/cover systems and practices can be evaluated independently and establish "C" values (crop and management), "P" values (practices) or "CP" values (crop/cover and practices). In this case, high values of "C", "P" or "CP" represent a low soil protection from surface water erosion processes and, on the contrary, low values indicate an efficient protection. As a general rule of land management this most be accomplished:

$$\underset{\text{(land use type)}}{CP} \leq \underset{\text{(land unit)}}{CP_{max}} \text{ or } \underset{\text{(soil losses)}}{A} \leq \underset{\text{(soil loss tolerance)}}{T}$$

Through literature revision of previously published data, the information obtained is summarized using USLE "CP" factor (Wischmeier and Smith, 1978) as an indicator of the degree of efficiency of surface water erosion control by vegetative barriers associated with different crop/cover and management systems.

Due to cost and time limitations it is not possible to generate a bigger set of data under natural rainfall, so, the use of a rainfall simulator is needed to obtain a wider range of experimental values. Variable slope conditions, mulch cover level between vegetative barriers, different kinds of vegetative barriers, and different slope lengths were evaluated using a runoff generator. A nozzle-type rainfall simulator was used (Rodríguez and Rodríguez, 1989, Rodríguez, 1997).

Additional information related to vegetative barriers behavior and performance was collected in order to assess criteria for its selection and best management when used for water erosion control.

RESULTS

A summary of research experiences under natural rainfall with vegetative barriers in Venezuela is presented in table 2. It can be observed the high efficiency of vegetative barriers under different agroecological conditions and crop/cover and management systems between barriers. Vegetative barriers evaluated alone or associated with crop/cover and other management practices and spaced by different intervals, show varied "CP" values lower than 0.001 when associated with large mulch levels or permanent crops and as high as 0.53 when they are alone and during first period of establishment. Higher values were found during 1997 and 1998, due to a low rain period, which affected good establishment of vegetative barriers. Vegetative barrier efficiency is increased the longer the establishment period is. This can be inferred from 1980, 1981 and 1982 experiments with *Cenchrus ciliaris* and bare soil between barriers where "CP" factor was progressively decreasing through time due to the increased compaction and density of the barrier. In

Table 2. Evaluation of water erosion control efficiency by vegetative barriers (VB) under natural rainfall and different agroecological conditions.

Vegetative Material	Locality	Year	Life zone / soil	Land slope	Plot length (m)	Slope length between vegetative barriers (m)	Land use And soil management between Vegetative barriers	CP Factor	Source
Cadillo bobo *(Cenchrus ciliaris)*	MARACAY	1980 1981 1982	Premontane Dry forest Soil: Cumulic Haplustoll	15%	22	11.5	Bare soil (1 VB)	0.53 0.37 0.25	Páez, 1980 Rodríguez, Lizaso and Páez, 1982 Páez and Rodríguez, 1989
		1985		15%	20 10	20 10	Maize Conventional tillage (1 VB)	0.09 0.07	Páez and Rodríguez, 1992, 1995
Pasto sabanero *(Andropogon gayanaus)*	CHAGUA-RAMAS	1985	Tropical dry forest Soil: Typic Paleustalf	4%	20 30	20 30	Sorghum conventional tillage (1 VB)	0.22 0.27	Páez and Rodríguez, 1992, 1995
Pasto sabanero *(Andropogon gayanus)*	YARITAGUA	1985	Tropical dry forest Soil: Oxic Paleustalf	4%	15 20 30	15 20 30	Maize conventional tillage (1 VB)	0.12 0.12 0.25	Páez and Rodríguez, 1992, 1995
Vetiver *(Vetiveria zizanioides)*	PETAQUIRE Bajo Seco Experimental Station UCV	1984 - 1985	Transition Lower montane dry to moist forest Soil: Aquic Paleudult	15%	20	10	Sequence carrot-lettuce on broad seed beds (2 VB)	0.008	Fernández, N. 1989
		1986		15%	20	10	Sequence cabbage and cauliflower with furrows (2 VB)	0.001	Fernández, N. 1995a
		1988		15%	10	10	Sequcuence carrot-lettuce with different land preparation systems (1 VB)	0.13	Rodríguez, Fernández N. And Fernández, A. 1995 Rodríguez and Fernández, N. 1992
		1989 1st cycle		15%	10	10	Beat on flat bed	0.01	Syoufi, 1990
		1989 2nd cycle		15%	10	10	Wheat on contour lines conventional tillage	0.11	Urbina and Rodríguez, 1995
		1989 1990 1991 1992	Transition Lower montane dry to moist forest Soil: Ortoxic Tropudult	42%	11	10	Peach on individual terraces	<0.001 0.004 <0.001 <0.001	Syoufi, 1990 Urbina, 1990 Castillo, M. 1991 Fernández, N. 1995a and 1995b

Table 2 continued.

Vegetative Material	Locality	Year	Life zone / soil	Land slope	Plot length (m)	Slope length between vegetative barriers (m)	Land use And soil management between Vegetative barriers	CP Factor	Source
Vetiver *(Vetiveria zizanioides)*	PETAQUIRE Bajo Seco Experimental Station UCV	1990	Transition Lower montane dry to moist forest Soil: Aquic Paleudult	15%	10	10	Potatoe in furrows within ridges	0.006	Castillo, M. 1991
		1991		15%	10	10	Carrot, beet and leek (2 cycles)	0.0016	Fernández N. 1995b
		1992		15%	10	10	Mulch 1.5 to 5 Mg/ha	<0.001	Fernández N. 1995c

Vegetative Material	Locality	Year †	Life zone/ soil	Land Sope	Plot length and slope length between vegetative barriers (m)	Land use and soil management between vegetative barriers	CP Factor	Source
Fern (*Nephrolepis sp.*)	PETAQUIRE Bajo Seco Experimental Station UCV	1997	Transition Lower montane dry to moist forest Soil: Aquic Paleudult	15–20%	10	Carrot on flat bed	0.31	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.48	Rodríguez et al. ‡
		1998 2nd cycle				Bare soil	0.92	
Lemmon grass (*Cymbopogon citratus*)		1997				Carrot on flat bed	0.30	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.23	Rodríguez et al. ‡
		1998 2nd cycle				Bare soil	0.70	
Guatemala grass (*Trixacum laxum*)		1997				Carrot on flat bed	0.19	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.36	Rodríguez et al. ‡
		1998 2nd cycle				Bare soil	0.45	
Lily (*Agapanthus africanus*)		1997				Carrot on flat bed	0.31	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.19	Rodríguez et al. ‡
		1998 2nd cycle				Bare soil	0.05	
Vetiver recently established (*Vetiveria zizanioides*)		1997				Carrot on flat bed	0.31	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.30	Rodríguez et al. ‡
		1998 2nd cycle				Bare soil	0.35	
Vetiver well established (> 10 years) (*Vetiveria zizanioides*)		1997				Carrot on flat bed	0.003	Andrade, 1998
		1998 1st cycle				Lettuce on flat bed	0.036	Rodríguez et al.‡
		1998 2nd cycle				Bare soil	0.037	

† Rainfall amount and erosivity were extremely low during 1997-98 due to El Niño effects

‡ Rodrígiuez, O., M. Ramírez and J. Mendoza (1999, unpublished data)

1997 and 1998, it could be observed that efficiency of the recently established Vetiver barrier was at least ten times lower than that of the already established Vetiver barrier. The old one is thicker and more dense that is the recently established one, and has developed, through time a terrace, which modify slope behind the barrier, and affect the runoff/infiltration ratio. Vegetative barriers demonstrated a high potential for water erosion control in all agroecological conditions where they were evaluated.

Fernández (1989) reported "Pvb" lower than 0.1 with Vetiver barriers protecting vegetable plots during low erosivity rainy seasons. Syoufi (1990), Urbina (1990) and Castillo (1991) working with the same plots found an efficiency value "Pvb" of 0.03 with a Vetiver barrier protecting a peach plot, a permanent crop established on an steep slope (> 60 %). Wolde and Thomas (1989) using *Setaria anceps* and varying barrier width from 1.5m to 0.5m derived "Pvb" values from 0.36 to 0.18 and mentioning that other grasses of denser growth could reach a higher efficiency. This is the case for Vetiver, once established. In

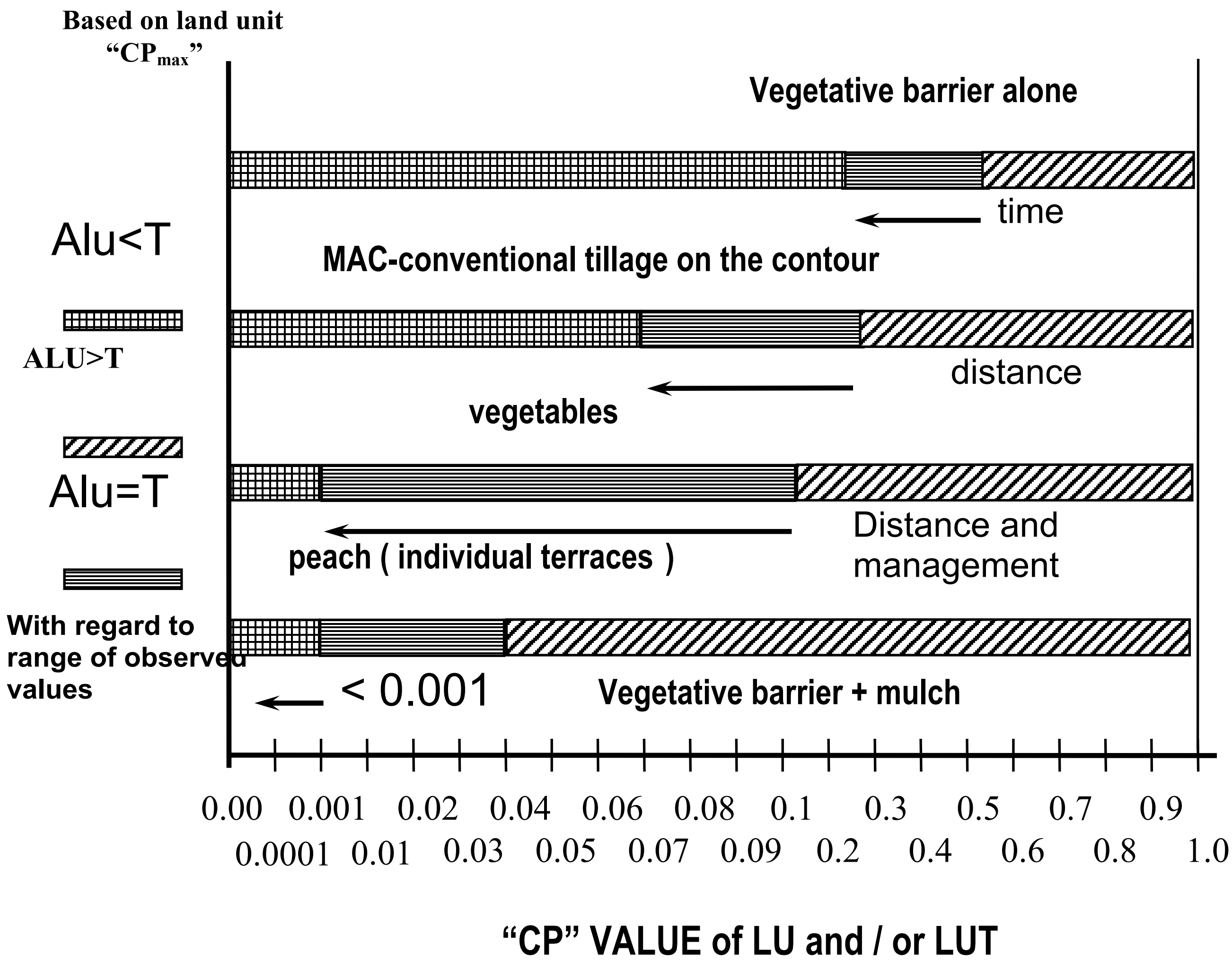

Figure 1. "CP" factor range (horizontal lines bar) of vegetative barriers associated with different crop/cover systems for 1980-1992 experiments (LU=Land unit, LUT=Land utilization type, Alu=Soil loss for the land unit, T=Soil loss tolerance). Arrows represent the variation of "CP" factor within the observed range as influenced by time, distance, management or residue level.

most cases evaluated, there is a "Pvb" lower than this is, due to its morphological characteristics: dense and massive root system, stiff and erect leaves and stems.

In Table 3, "CP" values (soil loss ratios) obtained under simulated rainfall for different vegetative barriers and two slopes are presented. The lack of correlation between the ratio (LS 26 %)/(LS 15%) and the ratio of soil loss on 26% and 15% slopes seems to indicate a poor behavior of the USLE in these conditions. Standardized soil loss ratios of vegetative barriers varied between 0.11 for Vetiver to 0.55 for Lemon grass.

Fig. 1 illustrates the effectiveness of vegetative barriers associated with different crop/cover systems that together represent a LUT (land utilization type). Its efficiency is a function of different factors affecting soil water erosion (time of establishment, barrier type, distance between barriers and crop/cover and land management system between barriers). Low "CP" values represent higher levels of efficiency. The shorter the distance between barriers in mechanized annual crops (MAC), the higher the vegetative barrier efficiency is. When the vegetative barrier is alone, time of establishment is the main factor affecting efficiency, being older barriers more efficient, and when combined with vegetables, efficiency was a function of distance between barriers as well as of other management factors. When barriers were combined with a permanent crop like peach, efficiency was very high and, and finally, the combination of barriers with high residue levels resulted in an increased efficiency at higher levels of residues. If the land unit (LU), have a "CP$_{max}$" or a conservation requirement lower than the

Table 3. Absolute cumulative soil loss values (Mg ha^{-1}), relative soil losses for the two slopes, and standardized soil losses for the different vegetative barriers treatments evaluated under field simulated rainfall. (Average values for three soil moisture conditions and two replicas). Rodríguez, 1997.

Vegetative barrier (VB) treatment	Soil loss (1) (Mg ha^{-1}) 15% slope	Soil loss (2) (Mg ha^{-1}) 26% slope	(LS 26% 5m) / (LS 15% 5m)†	(2) / (1)	Standardized soil loss ratio‡	Duncan group
No VB	16.81	35.52	1.43	2.11	1	A
Lemon grass	11.98	16.06	1.43	1.34	0.55	B
Lily	7.58	7.62	1.43	1.01	0.31	C
Fern	4.22	1.55	1.43	0.37	0.25	D
Vetiver	1.13	4.91	1.43	4.35	0.11	D

† LS (15% slope gradient, 5 m length) =1.87. LS (26% slope gradient, 5 m length) =2.68
‡ Standardized soil losses to 9% slope and 22.1 m slope length in reference to the no VB treatment using USLE equation.

Table 4. Field behavior parameters of vegetative barriers measured 7 months after planted in Bajo Seco´s site conditions. Andrade (1998).

Vegetative barrier	Plant height cm			Number of slips			Distance between plants cm			Root † development	
	Previously planted at a distance (cm) of									Depth cm	Dry matter g
	10	15	20	10	15	20	10	15	20		
Lily (*Agapanthus africanus*)	35	37	35	1	1	1	6	10	13	37	22
Fern (*Nephrolepis sp.*)	16	20	20	3	4	5	6	9	16	14	6
Imperial grass (*Axonopus Scoparius)*	39	41	41	9	9	10	2	6	13	99	37
Lemmon grass (*Cymbopogon Citratus)*	62	65	65	11	15	18	3	7	13	103	38
Vetiver (*Vetiveria zizanioides*)	66	60	60	11	15	12	2	7	13	171	100
Guatemala grass (*Trixacum laxum*)	72	85	85	4	7	8	5	7	15	178	143

† Root depth and dry matter were evaluated 8 months after planted in 1.8 m height and 0.25 m diameter cylinders

"CP" offered by the LUT, then soil losses "A", go beyond the tolerance threshold "T". If both "CP" are the same, then "A"="T and if "CP_{max}" is greater than "CP", then "A" is lower than "T". The last two conditions are acceptable from an ecological point of view and suggest that the land use system meets the conservation requirements of LU, keeping erosion under acceptable limits. A condition where "A" is higher than "T" indicates a miss match between LUT and LU, which requires adjustments or changes to avoid land degradation due to surface water erosion.

Fig. 2 shows that in absence of residues or when residue cover is very low, the vegetative barrier protects the slope. This is a common case during the tillage period and the initial steps of crop development where crop/cover system protection is very low. Fig. 3 shows the slope length effect of the slope to be protected on vegetative barrier efficiency as well as its interaction with residue cover on surface (5 Mg ha^{-1} pine needles). As the slope is longer, the lower the efficiency when residues are absent. With a high residue level the length of slope effect is almost imperceptible. Vegetative barriers when combined with a high residue level are very efficient at all slope lengths evaluated.

Table 4 summarizes additional information related to vegetative barriers behavior and performance, collected in order to assess criteria for its selection and best management, when used for water erosion control. Plants used to establish vegetative barriers must be planted as close as possible to obtain a functional barrier in a short time. In Bajo Seco´s site conditions, it must not be more than 10cm. Vetiver and Guatemala grass achieve the greatest root development given them a higher potential strength to cope with surface and shallow subsurface runoff. Plant height can become inconvenient when barriers are placed together with crops, due to competition and shadow effects.

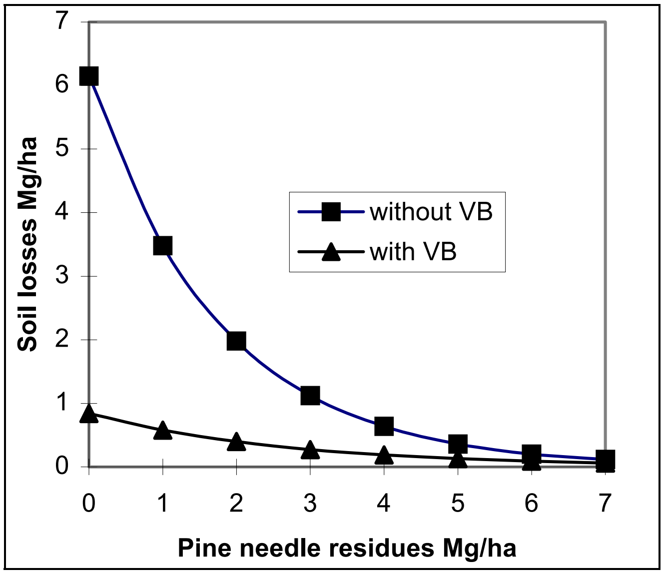

Figure 2 Absolute soil loss curves with vegetative barrier (vetiver) or no barrier for different residue (pine needle) levels obtained under simulated rainfall on very wet soil moisture condition (15 % slope gradient, 5 m slope length, four replicas). Rodríguez (1997).

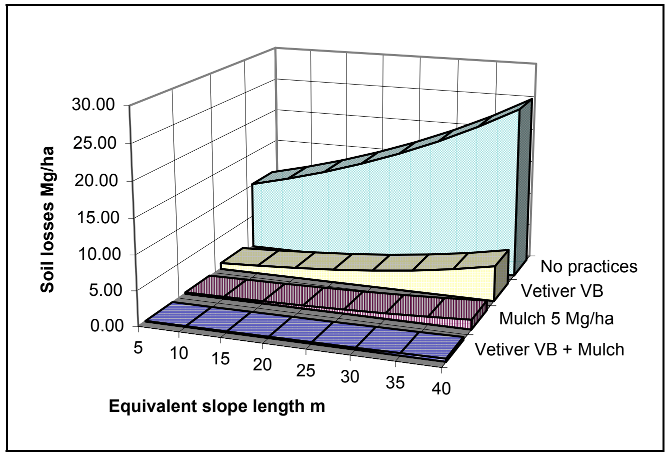

Figure 3. Combined vegetative barrier, residue level (5 Mg/ha) and equivalent slope length effects under simulated rainfall and very wet soil moisture condition on soil losses (15 % slope gradient, four replicas). Rodríguez (1997).

Table 5. Indicative values of vertical interval to be used to design spacing between vegetative barriers as a function of rain erosivity, soil erodibility and crop intensity[†]. Rodríguez, 1997.

Rainfall erosivity range MJ*mm/ha*h	Soil erodibility range (Mg/ha)/ MJ*mm/ha*h	High crop intensity ‡		Medium crop intensity §		Low crop intensity ¶	
		Vertical interval m	Maximum # slope gradient %	Vertical interval m	Maximum # Slope gradient %	Vertical interval m	Maximum # Slope gradient %
Low < 3000	Low < 0.2	4	44	5	58	6	75
	Medium 0.02-0.05	3	31	4	44	5	58
	High > 0.05	2	20	3	31	4	44
Medium 3000-7000	Low < 0.2	3	31	4	44	5	58
	Medium 0.02-0.05	2	20	3	31	4	44
	High > 0.05	1	10	2	20	3	31
High > 7000	Low < 0.2	2	20	3	31	4	44
	Medium 0.02-0.05	1	10	2	20	3	31
	High > 0.05	0.5	5	1	10	2	20

[†]If T < 12 Mg/ha one should move vertically within the column in order to find the vertical interval that better adjust due to the presence of more vulnerable soils to water erosion. The same can apply for less efficient vegetative barriers

[‡]High crop intensity: Annual crops with low or none residue cover

[§]Medium crop intensity: Annual crops with moderate to high residue cover levels; a semi permanent crop with moderate residue cover levels; permanent crops with moderate residue cover levels.

[¶]Low crop intensity: Annual crops with high residue cover levels; a semi permanent crop with high levels of residue cover; permanent crops with high levels of residue cover.

[#]Maximum slope gradient was calculated taking into account a minimum spacing of 10 m between vegetative barriers. This criteria is only applicable to agricultural land. When vegetative barriers are used for other purposes like restoration or bioengineering barriers spacing can become less than one meter.

Therefore, barriers must be pruned frequently or alternatively plant tall and short barriers to avoid excess competition.

Based on the experiences accumulated with vegetative barriers table 5 is presented. It was calculated assuming a soil loss tolerance T=12 Mg ha^{-1}. Table 5 is proposed as a practical guideline to assist farmers in selecting adequate distances between vegetative barriers, considering rainfall erosivity, soil erodibility, and crop management intensity. A minimum distance between vegetative barriers of 10 m is proposed, because of the local conditions of technology and land use. This implies that the slope gradient becomes an impediment when hedgerows must be spaced at less than a 10 m distance. This is the case of agricultural land use, but in case vegetative barriers are used for land restoration and rehabilitation as well as for bioengineering purposes, distance between hedgerows can become less than a meter.

CONCLUSIONS

- Vegetative barriers are a valuable alternative as a complementary soil conservation practice, specially, when the degree of protection offered by the crop/cover system is unsatisfactory, and it is not possible to change land use. Also, when it is necessary to lower non recurrent erosion risks, where surface cover do not protect the land due to the absence of a deep and permanent root system.
- Vegetative barriers efficiency is a function of local physical factors (climate, soil, relief) and other variables like the kind of vegetative barrier used, distance between vegetative barriers, time of barrier establishment and the land use and management practices applied in the space between barriers.
- Vegetative barriers demonstrate a high potential for water erosion control in all agroecological conditions where they were evaluated. Due to their field behavior and performance, Vetiver and Guatemala grass were the most technically efficient barriers, but all barriers evaluated can be useful in particular circumstances and combinations.
- Selection of plants to be used for vegetative barriers establishment will depend on many parameters in order to fit farm/land system conditions as well as land conservation requirements. "CP" values can be used as an indicator of vegetative barrier efficiency to control surface water erosion, but other criterion like agroecological adaptability, non recurrent erosion risks, cost of establishment and maintenance, interaction with crops, alternative uses, among others, are needed to help make an optimal decision.
- Table presented for the assignation of vertical interval (VI) can guide the design of field vegetative barriers, since there is a lack of criteria to define barriers spacing considering physical and technological factors. Farmers and technicians may adapt and/or improve proposed values as field information become available.
- It is necessary to accumulate more experiences with different kinds of vegetative barriers to offer technological alternatives for potential users, whether for agricultural or bioengineering purposes, and to spread information on its application.

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