SOIL AND WATER QUALITY MANAGEMENT THROUGH VETIVER GRASS TECHNOLOGY

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Abstract

Soil quality and water quality are concepts related with the functions of these natural resources within the environment. Indicators and indexes can be linked with standards for the multiple uses of these resources and can be used as guides for land use and land management planning, from the field to the watershed levels. The design of a resource management system must accomplish the standards fixed for one or more particular resource uses. Vetiver grass technology (VGT) must be designed keeping in mind this requirement. Experimental data from erosion plots, under natural and simulated rainfall, are used to exemplify how VGT helps maintain soil and water quality. Sediment loads are reduced up to 90% in plots with vetiver grass hedgerows compared with those without cover and vetiver hedgerows. Organic matter loads are reduced up to 57% and total P up to 70%. Loads of highly soluble elements like calcium are not significantly reduced. When VGT is combined with another technology, like residue management, risks of failure are diminished. Some indexes like the soil productivity index 'IP', soil loss tolerance 'T' and 'CP' factors (USLE) are used to illustrate design procedures to use VGT in agricultural systems. The advantages of using simulation models and the need for soil and water quality monitoring, at field and watershed levels, are briefly discussed in the realm of natural resource planning and management. An international effort to supply less developed countries, mainly in tropical areas, with these tools and procedures will help reach higher soil and water quality standards at the global level.

Introduction

Depletion of natural resources at the global level is of major concern for public and private institutions, as sustainable development relies on environmental quality. The productivity and health of ecosystems depend on the quality of natural resources. Comprehensive approaches to design and implement resource management systems are needed to reach adequate standards of quality that sustain and enhance cultural and natural systems.

This paper highlights the importance of the design and implementation of resource management systems, taking into account soil and water quality standards as a guide for land use and land management planning. VGT, a powerful alternative for soil and water quality management, particularly in tropical and subtropical countries, must be implemented keeping in mind resource quality standard principles. Some ideas to fulfil these requirements when applying VGT are proposed.

Basic Concepts and Approaches

Soil quality is defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin 1994). Quality is specific for each kind of soil and is defined with regard to the function fulfilled by the soil. Functions of soil as proposed by Karlen et al. (1997) are:

- Sustaining biological activity, diversity and productivity;
- Regulating and partitioning water and solute flow;
- Filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition;
- Storing and cycling nutrients and other elements within the earth's biosphere; and
- Providing support of socio-economic structures and protection for archaeological treasures associated within human habitation.

The dynamics aspects of soil quality, resulting from the changing nature of soil properties that are influenced by human use and management decisions, constitute the main concern for the design and implementation of resource management systems. Most proposed measures of soil quality use soil-quality indicators as surrogates of the soil to function. They are selected on the basis of their ease of measurement, reproducibility, and to what extent they represent key variables that control soil quality. Indicators can be combined to generate quality indexes for particular functions of soil.

Similarly, water quality can be broadly defined as the physical, chemical and biological composition of water as related to its intended use for such purposes as drinking, recreation, irrigation and fishery. The term may be applied to a single characteristic of the water or to a group of characteristics combined into a water quality index (USDA-NRCS 1996). Specific parameters are surrogates of water quality for intended uses. Water quality management in the context of the watershed approach is driven by the TMDL concept. TMDL (total maximum daily load) is the maximum quantity of a pollutant that can enter a water body without adversely affecting the beneficial uses of that body. In this perspective, all point and non-point sources of pollution in a watershed, as well as the physical characteristics of the water body itself, are inextricably linked (Jarrel 1999).

As can be seen, it is a complex task to establish soil and water quality standards, because there are many parameters or indicators to measure, and resource function responses may vary for different quality levels. Nevertheless, it is the only way to assure that resource management systems, a combination of conservation practices, are well selected and designed, and after they are implemented, monitoring results of soil and water quality will help decide how much impact these systems have had on the health of these resources.

VGT must be designed keeping in mind soil and water quality requirements for the specific site conditions where it is intended to be implemented. Its interactions with other conservation practices can enhance the efficiency of the resource management system, reducing risks of failure and helping maintain the onsite and offsite health of resources.

VGT as An Aid to Support Soil and Water Quality

From experiments carried out at the Bajo Seco Experimental Station field, Central University of Venezuela, in the mountainous north-central region of Venezuela, some results will be discussed to illustrate the role of vetiver grass hedgerow technology as an aid to support soil and water quality. Erosion plots, under natural and simulated rainfall, were located on a 15-percent slope on an Aquic Paleudult loamy, sandy soil. A carrot-lettuce crop sequence was assigned to plots under natural rainfall, representing the high intensive vegetable horticultural system predominant in the Petaquire watershed. Total rainfall was 746 mm during the evaluation period for these plots.

Table 1 shows the soil and water losses from erosion plots under natural rainfall, as well as organic matter and nutrient losses. Major reductions in soil and water losses and in organic and mineral elements were obtained when vetiver grass hedgerows were present. In addition, tillage and land preparation treatments like contour furrows influence the experiment outcome and can improve the performance of the barriers. Sediment loads were reduced up to 90% when comparing plots with vetiver grass hedgerows with those without cover and vetiver hedgerows. Organic matter loads are reduced up to 57% and total P up to 70%. Loads of highly soluble elements like calcium were not significantly reduced. Losses of sediments, water, OM and nutrients were very high under the carrot-lettuce crop sequence, due to the low cover and protection offered by the crops and the enormous input amounts used in highly intensive horticulture. There is an urgent need in resource management systems for this agricultural system in order to maintain soil productivity and reduce contaminant loads in water streams and reservoirs. Vetiver grass hedges, together with other management practices, substantially reduce soil losses and other pollutant loads.

When VGT is combined with another technology, like residue management, risks of failure are diminished. In Fig.1, the effect of mulch with and without vetiver hedgerows is illustrated from results obtained in plots under simulated rainfall (Rodriguez 1998). Soil loss was significantly reduced in all cases. Runoff was significantly reduced only when mulch alone or combined with hedgerows was tested. The importance of vetiver hedgerows as a soil conservation practice is highlighted, especially

Table 1. Soil, water, organic matter and nutrient losses from erosion plots under natural rainfall and different treatments during a carrot-lettuce crop sequence period

Plot treatment *	Sediment yield (mg/ha)		Runoff (%)		OM (kg/ha)		P (kg/ha)		Ca (kg/ha)		K (kg/ha)	
Bare soil	95.0		64.1		3275		18.94		162.79		8.29	
NP-F	88.7	61.2	50	34.8	4055	2976	22.5	14.6	356	239	31.0	21.9
NP-CF	29.2		28.1		2243		9.7		190		13.3	
NP-BB	65.7		26.3		2631		11.6		170		21.3	
VGH-F	20.2	12.5	21.9	13.1	1132	1407	3.4	5.7	243	175	8.9	9.2
VGH-CF	8.7		9.7		1697		8.1		158		10.6	
VGH-BB	8.6		7.7		1391		5.6		125		8.2	

NP: No practice F: Flat soil bed C: Contour furrows VGH: Vetiver grass hedge BB: Broad soil bed

on conditions where abundant soil residues are not available, or when crop management practices do not allow to protect the soil surface during particular periods, as in horticultural crops. If exceptional rains occur when crop cover and residue are absent, the presence of a hedgerow is necessary to reduce risks of failure of the resource management system. Thurow and Smith (1998), working on larger erosion plots in Central America, found a similar advantage. In areas protected with residue and crop cover, when hedgerows of vetiver are also present and mass movement erosion processes can occur, risks of failure are reduced.

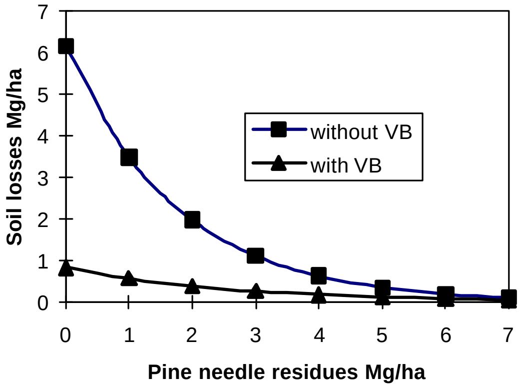

Fig. 1. Absolute soil loss curves with vegetative barrier (vetiver) or no barrier for different residue (pine needle) levels obtained under simulated rainfall in very wet soil moisture conditions. Rodríguez (1998)

Design of A Resource Management System Using VGT

Páez and Rodríguez (1984) and Páez (1995), based on USLE factors (Wischmeier and Smith 1978), established a criterion 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 ‘Cpmax’. High ‘Cpmax’ values represent a low vulnerability or low conservation and management requirements; and low ‘Cpmax’ values indicate a severe vulnerability and high requirements of soil and water conservation measurements.

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 must be accomplished:

$$\text{“CP”}_{\text{(land use type)}} \leq \text{“CPmax”}_{\text{(land unit)}} \text{ or } A_{\text{(soil losses)}} \leq T_{\text{ (soil loss tolerance)}}$$

Soil loss tolerance must be assigned taking into account the onsite and offsite effects of soil erosion. For onsite effects, the IP index can be used to assess the impact of erosion in soil productivity. It was originally developed in the United States, but adapted for tropical mountainous conditions in Venezuela by Delgado (1997). ‘T’ values can be assigned for a selected period, assuming a level of productivity decline. Long-term assessments usually select 50 to 100 years as planning horizon. Zero to ten-% productivity decline is assumed in most cases. These quality indexes are directly related to the productivity function of soils and indirectly to the impact on the quality of water and other natural resources. The application of principles mentioned above will be illustrated through the following example.

Two soils were selected in different locations of Venezuela, Macapo and Petaquire. The main characteristics and conditions are shown in Table 2. They are found in different life zones and agricultural systems. Tolerance values (‘T’) to soil erosion were assigned through vulnerability curves (Fig. 2) which were originated using the ‘I’ index, assuming 5% productivity loss and a planning horizon of 100 years. As can be seen in Fig. 2, the soil in Petaquire has an initial lower ‘IP’ index. This is because this soil has a higher acidity and a lower available water capacity, which are parameters used to calculate the ‘I’ index (Delgado 1997). The Petaquire land unit has a lower erosion risk than the Macapo land unit, as indicated by its higher ‘Cpmax’ value (Table 2). In both farming systems ‘C’ values exceed the land unit ‘Cpmax’, leading to a progressive degradation of the land unit resources.

Table 2. Main characteristics of soils and site conditions including USLE factors

Land unit/ site	Life zone	Average rainfall mm	Annual EI_{30} MJ mm/ ha	Farming system/ ‘C’ factor	Soil taxonomy/ erodibility ‘K’ factor	Landscape and slope conditions	Soil loss tolerance ‘T’ mg/ha	CP max[1/]
Petaquire	Transition lower montane dry to moist forest	860	2613	Intensive vegetable horticulture (IVH) C = 0.18	Typic Haplustult K=0.017	Mountain slope s = 40% l = 50m	14	0.036
Macapo	Pre-montane dry forest	1516	5629	*Conuco* [2/] maize-cassava (CMC) C=0.45	Typic Haplustept K=0.023	Mountain slope s = 40% l = 50m	16	0.014

[1/] *‘CPmax’ = T/RKSL*
[2/] *Conuco: Slash-and-burn traditional mixed-crop system*

Four scenarios were developed for each land unit. One was built assuming current conditions, and the other three incorporating VGT. Vertical intervals of 4 m and 2 m were tested, and a combination of mulch (50-percent residue cover level) in addition to VGT with a vertical interval of 2 m was also included. The main factors and conditions for each scenario are summarized in Table 3, as well as the main outcomes. Current scenarios for Macapo and Petaquire sites had a negative impact, both onsite and offsite. Soil losses exceeded more than ten times soil loss tolerances, and a huge amount of sediments were delivered to streams and water bodies. VGT, included in the other three scenarios, reduced significantly soil losses and sediment delivery. When a VI of 4 m or 2 m was used, soil loss tolerances were slightly exceeded. Mulch combined with VGT was the scenario where less erosion occurred and less sediment was delivered.

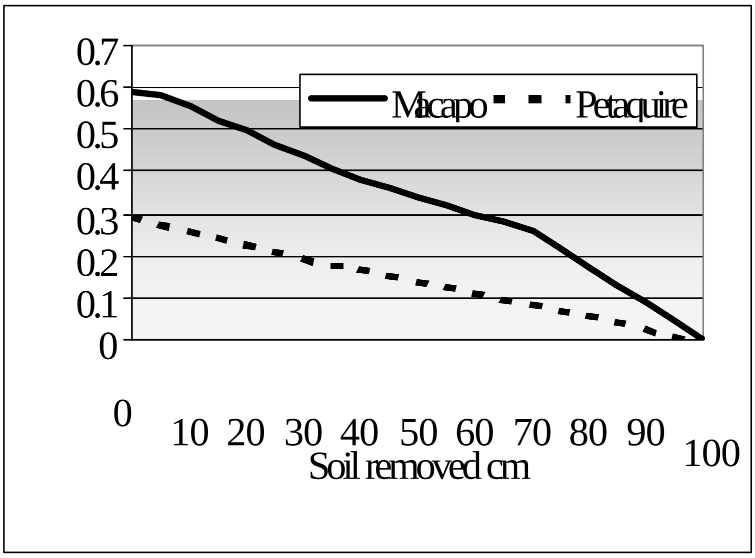

Fig. 2. Vulnerability curves for the soils of the two land units selected

Long-term impact on soil productivity for each scenario can be assessed using the information generated in Table 3 in combination with the vulnerability curves of Figs. 2 and 3 and illustrate the ‘IP’ index evolution under different scenarios for the land units analyzed.

Table 3. Parameters and outcome for different resource management system scenarios

Land unit /site	Crop / resource management system (RMS)	‘RKS’ 1/	‘L’	‘C’	‘Ck’ 2/	‘Ptc’ 3/	Onsite impact ‘A’ soil losses Mg/ha/year	‘Py’ 4/	Offsite impact "Y" sediment yield Mg/ha/year
Peta-quire	IVH / No RMS	257.19	1.5	.45	1	1	173.6	1	173.6
	IVH / VGT-4VI		.7	.45	1	.25	20.25	.05	1.01
	IVH / VGT-2VI		.52	.45	1	.25	15.04	.05	.75
	IVH / VGT-2VI-M		.52	.45	.3	.25	4.51	.1	.45
Macapo	CMC / No RMS	749.61	1.5	.18	1	1	202.4	1	202.4
	CMC / VGT-4VI		.7	.18	1	.25	23.6	.05	1.18
	CMC / VGT-2VI		.52	.18	1	.25	17.54	.05	.87
	CMC / VGT-2VI-M		.52	.18	.3	.25	5.26	.1	.52

1/ ‘RKS’ product of rain erosivity ‘R’, soil erodibility ‘K’ and slope factor ‘S’, USLE (Wischmeier and Smith 1978)
2/ ‘Ck’ = mulch factor for 50% residue level (Wischmeier and Smith 1978)
3/ ‘Ptc’ = terrace and contour effect given as conservation credit for VGT assuming it cuts the slope. This is valid for a barrier after one or two years of establishment (Renard et al. 1997)
4/ ‘Py’ = sediment delivery factor (Renard et al. 1997)

During a 100-year period, soil productivity is sustained within a reasonable level by VGT alone. When VGT is combined with residue cover, the productivity decline is negligible. These trends highlight the role of VGT as the backbone of a RMS, taking into account that vetiver hedgerows are permanent and able to adapt to adverse conditions. VGT, combined with residue management and appropriate tillage operations like contour tillage, can contribute substantially to promote sustainable agricultural systems.

Use of Models and Monitoring Resource Quality

The use of models and monitoring resource quality are basic strategies to study the impact of RMS in several conditions over time. Monitoring techniques have been improved and are now more accessible and reliable, but still expensive and time consuming. Monitoring programs must be selective and account for most representative agro-ecosystems in each country as pilot areas that facilitate model calibration and validation. Assessing frameworks for soil and water quality have been proposed by several resource institutions as a guide for soil and water quality management. Models have the advantage of anticipating resource response to different management systems in variable scenarios and site conditions. This has been illustrated through the use of simple models in the previous section.

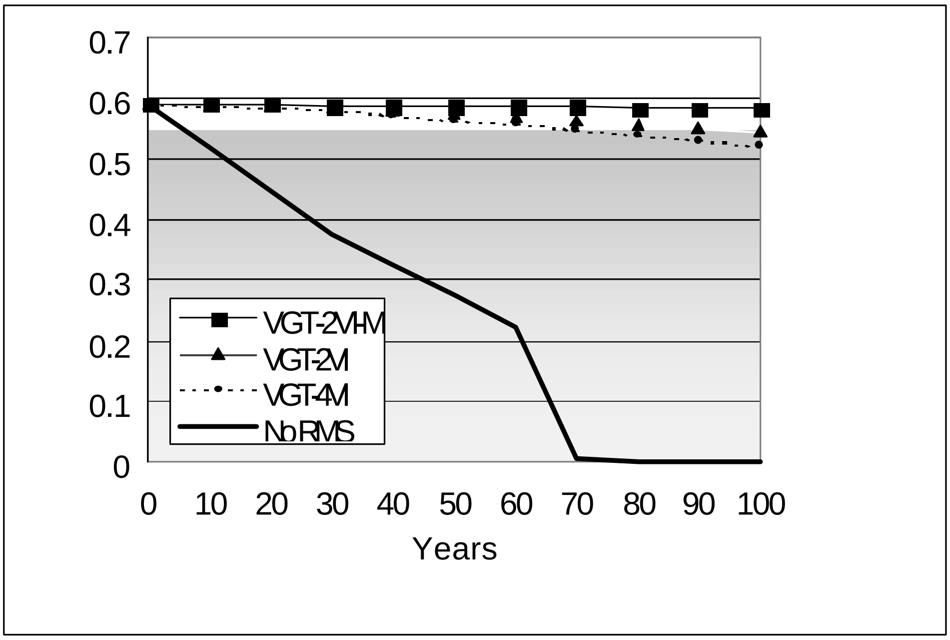

Fig. 3. Evolution of 'IP' index in the Petaquire land unit under different RMS scenarios

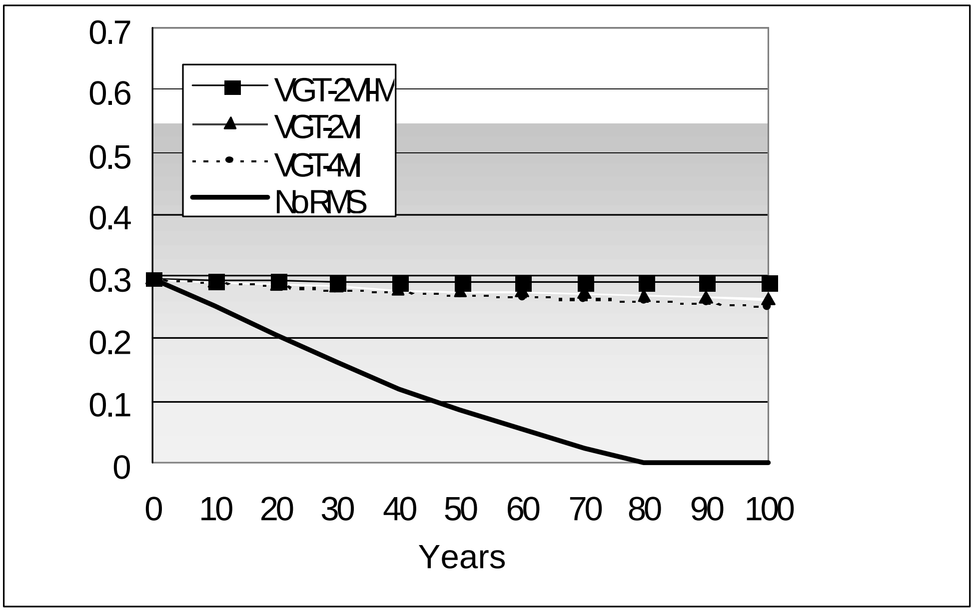

Fig. 4. Evolution of 'IP' index in Macapo land unit under different RMS scenarios

A new modelling technology is already developed and is able to encompass more comprehensive simulation environments, integrating climate, hydrology, crop growth, erosion processes and management practices, allowing to optimize decisions regarding natural resource use. Examples of this relatively new technology are: APEX (Agricultural Policy/Environmental Extender) being developed for use in whole farm/small watershed management (Williams et al. 1998) and SWAT (Soil and Water Assessment Tool) developed for operating at river basin scale (Arnold et al. 1998). They have a daily time resolution and are useful to identify onsite and offsite effects of land use and management changes at different spatial scales.

Conclusion

Proper design and implementation of VGT can be accomplished in a better way if soil and water quality standards are taken into account. Considerations of both the specific site and the land use system where it is applied, as well as the offsite areas benefiting from its application, must be included. VGT is compatible with other management practices, and if combined, risks of failure are diminished and efficiency is improved, becoming part of a resource management system. Because vetiver grass hedgerows are permanent and well adapted to adverse conditions, they can be called the backbone of the resource management system.

An international effort is needed to supply less developed countries, mainly in tropical areas, with better tools, like simulation technology, appropriate procedures for monitoring and assessing the quality of natural resources, and to help develop and implement management systems that protect and enhance natural resources. This will help to reach higher soil and water quality standards at the global level.

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