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Soil Carbon Sequestration Through Water Management and Soil Conservation in Semi-Arid Environments

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Abstract

Semi-arid regions cover 17.7% of Earth's land area. Water management and soil conservation can increase agronomic productivity, enhance soil carbon (C) pool and improve soil quality. The rate of C sequestration ranges from 0 to 200 Kg C/ha/yr for SOC, and 5 to 10 Kg C/ha/yr for secondary carbonates. While mitigating the climate change, SOC sequestration also enhances agronomic productivity; through improvements in soil structure, increase in plant-available water reserves, increase in use efficiencies of water and nutrients, and reduction in severity and intensity of drought stress; by 30 to 300 Kg of grains/ha/Mg of SOC. The potential of soil C sequestration in 2310 million hectares of semi-arid land is 125 to 600 Tg C/yr with trading value of $0.5 billion to $1.2 billion/yr.

Introduction

Semi-arid environments cover a total of 2310 Mha or 17.7% of Earth's land area. Of this, 510 Mha are in Africa, 690 Mha in Asia, 310 Mha in Australia, 110 Mha in Europe, 420 Mha in North America and 279 Mha in South America. These regions are characterized by an aridity index (P:PET ratio) of 0.20 to 0.50 (Lal, 2000; 2003; 2004). Water management is crucial to extending the growing period and enhancing biomass productivity. These regions are also prone to soil degradation and desertification. (UNEP, 1992, Dregne, 2002).

Water conservation, water harvesting and supplemental irrigation are important to enhancing productivity. In-situ water conservation implies reducing losses due to surface runoff and soil evaporation and maximizing water retention in the root zone. In contrast, water harvesting is a technique that maximizes runoff from a designated area and collects in a reservoir for use as irrigation, animal and human consumption. Water harvesting is defined as the collecting and storing of precipitation from land that has been treated to increase runoff of rain and snowmelt. Water harvesting for crop production is called runoff farming. Supplemental irrigation is application of water to agricultural/plantations land either by lifting groundwater, or using surface water from rivers, lakes, etc. The low and highly variable crop yields (often < 1 Mg/ha) can be increased by 2 to 3 times through water management practices, especially water harvesting and supplemental irrigation. Soil C sequestration implies: (i) transfer of atmospheric CO_2 into SOC pool through land application of biomass/biosolids, (iii) formation of secondary carbonates to enhance SIC pool, and (iii) leaching of bicarbonates into the ground water in irrigated lands. The objective of this report is to discuss the impact of water management and soil conservation on C sequestration and soil quality enhancement in semi-arid climates.

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Materials and Methods

This report is based on the collation, synthesis and extrapolation of data available in the literature on the impact of water management and soil conservation on soil quality and C sequestration. The focus of the report is primarily on the croplands and rangelands of the developing countries. The data on SOC and SIC pools for the region are obtained from Eswaran et al. (2000). The site specific data on rates of SOC and SIC sequestration through water management and soil conservation are extrapolated to semi-arid regions globally to compute the potential of C sequestration in these regions.

Results and Discussion

(a) Desertification Control:

Establishment of a perennial vegetation cover is important to mitigating desertification. Vegetative cover may be obtained through establishment of suitable grasses, legumes or trees (Table 1). In addition to the general cover, contour hedges, strips and windbreaks established with these species can be extremely effective in erosion control. The potential of soil C sequestration through desertification control is 0.4 to 1.1 Pg C/yr (Lal, 2001). This estimate does not include C sequestration in biomass.

Table 1. Suitable grasses and trees for desertification control

Grasses	Legumes	Trees	
Axonopus micay	*Arachis spp*	*Acacia spp*	*Simmondsia chinensis*
Boutelous gracilis	*Cajanus cajan*	*Albizia lebbeck*	*Tamarindus indica*
Brachiaria brizantha	*Centrosema spp*	*Azadirachta indica*	*Terminalia arjuna*
Brachiaria mutica	*Desmodium buergeri*	*Capparis decidua (Kair)*	*Tectona grandis*
Cenchrus ciliaris	*Lupinus angustifolius*	*Casia siamea*	*Vernomia anthelmintica*
Eragrostis curvula	*Medicago sativa*	*Casuarina equisetifolia*	*Vernomia galamenis*
Euchlaena mexicana	*Mucuna utilis*	*Dalbergia sissoo*	*Zizyphus mauritiana*
Leptochloa fusca	*Phaseolus acontifolius*	*Eucalyptus spp*	
Panicum antidotala	*Phaseolus acutifolius*	*Khaya spp*	
Panicum coloratum	*Pueraria spp*	*Lesquerrel fendleri*	
Paspalum decumbens	*Stizolobium deeringianum*	*Leucaena leucocephala*	
Paspalum conjugatum	*Stylosanthes guianensis*	*Parkia spp*	
Paspalum notatum	*Trifolium alexendrium*	*Pongami pinata*	
Pennisetum purpureum	*Tylosema esculentum*	*Prosopis africana*	
Setaria spp	*Vigna catjang*	*Prosopis chilensis*	
Sorghum sudanense	*Vigna radiata*	*Prosopis cineraria*	
Vetiver spp	*Vigna unguiculata*	*Prosopis juliflora*	
	Voandzeia subterranean	*Prosopis tamerugo*	

(b) Adoption of RMPs on Agricultural Lands:

Important RMPs for enhancing agricultural productivity are outlined in Fig. 1. These include ground cover management, water management, soil fertility management and erosion control. Adoption of these practices can enhance cereal yield by 20 to 25% or more. In some severely degraded soils, increase in productivity can be drastic. Increase in crop grain yield is associated with improvements in soil structure and water holding capacity, and increase in water and nutrient use efficiencies. The rate of C sequestration can be enhanced through conservation tillage and mulch farming, integrated nutrient management, and water harvesting technologies. It is important to maintain a positive nutrient balance in the soil.

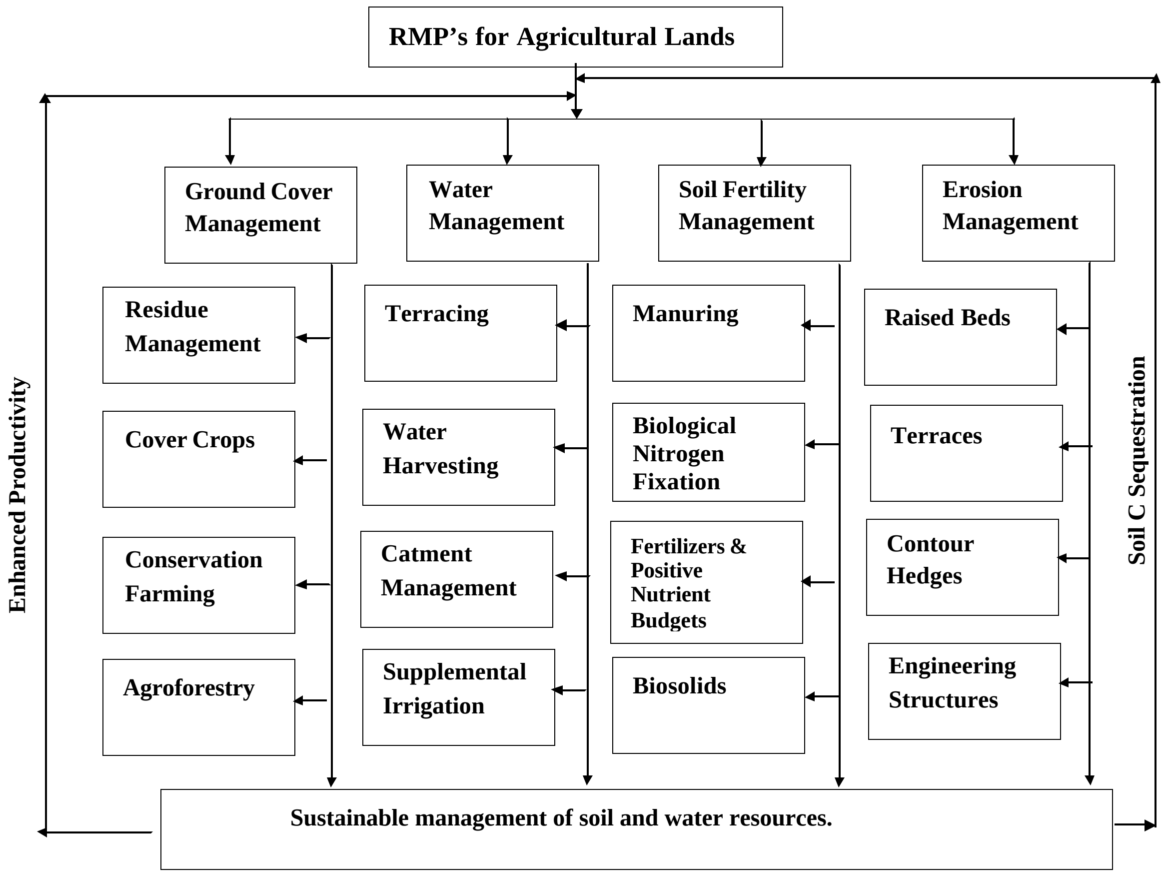

Fig. 1. Recommended management practices for agricultural ecosystems in semi-arid regions.

(c) Water Management:

Drought stress is an important factor responsible for the wide gap between the actual yield and the agronomic potential. The yield gap is much wider for developing than developed countries. Low and erratic rainfall are not the only reasons for frequent and severe drought stress. Losses of water due to surface runoff and high evaporation, and high incidence of weeds are other factors responsible for drought stress. Low water use efficiency is also due to low availability of plant nutrients and soil compaction leading to inhibited root system development.

(d) Potential of Soil Carbon Sequestration:

Total C pool in soils of the semi-arid environments to 1-m depth is estimated to comprise 337 Pg of SOC and 134 of SIC (Eswaran et al., 2000). Adoption of a restorative land use for desertification control and RMPs on agricultural lands can enhance NPP, return biomass to the soil, increase SOC pool and improve soil quality. The mean rate of C sequestration may be 50 to

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250 Kg C/ha/yr as SOC and 5 to 10 Kg C/ha/yr as SIC (Lal, 2004). Much higher rates of SOC sequestration have been reported for irrigated soils of favorable fertility (Follett et al., 2005). Thus, total potential of C sequestration in 2310 Mha of semi-arid tropics may be as much as 125 to 600 Tg C/yr. At a soil C trading rate of $4 to 20/Mg of C, the economic value of trading C credits is $0.5 billion to $1.2 billion/yr. Trading C credits is another source of income for the resource-poor farmers. Income thus generated can be used to invest in soil restoration. Soil C is a commodity which can be traded in national and international markets. Adoption of RMPs can also be called "farming carbon". In addition, there are also ancillary benefits of erosion control, reduction in sediment load, increase in biodiversity, and overall improvement in the ecosystems. Increase in agronomic yield due to increase in SOC pool can be 30-50 Kg/ha/Mg of SOC for wheat and rice, 20-30 Kg/ha/ for beans and 200-300 Kg/ha for corn and sorghum. Thus, the strategy of enhancing SOC pool is also important to advancing global food security, especially in Sub-Saharan Africa and South Asia.

Conclusions

Soils and ecosystems of the semi-arid environments are prone to degradation and desertification. The biomass productivity is limited by lack of water. Soils are depleted of their organic matter pool and are prone to physical, chemical and biological degradation. Desertification control, restoration of degraded soils and ecosystem and adoption of RMPs can enhance soil C pool, reduce CO_2 emission, and advance food security. Soil C sequestration through water management and soil conservation provides additional income to resource-poor farmers. Recommended management practices which lead to "farming carbon" include conservation tillage and mulch farming, growing cover crops, use of biosolids, integrated nutrient management, and water harvesting and conservation. It is the much-needed incentive to invest in land restoration, soil quality improvement and mitigating climate change. Commoditization of soil carbon, by creating mechanisms to trade carbon credits in national and international markets, is a high priority for semi-arid regions.

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