Managing Natural Resources for Sustained Sorghum and Millet Production

A. S. R. Juo and R. C. Schwartz[1]

Summary

In agricultural terms, natural resource conservation implies management of soil, water and vegetation resources for sustained land productivity. Land productivity is generally determined by inherent soil fertility, external input, and effectiveness of soil and water conservation practices used. Sorghum and millet are well-adapted to regions of limited rainfall. Sorghum is cultivated mainly on high base status and organic matter-rich Mollisols in the southern Great Plains of the United States, on high base status Alfisols in China and India, and on low base status Alfisols and Entisols in West and East Africa. Millet is primarily grown on sandier soils in the lower rainfall region of the Sahel. Phosphorus deficiency is a widespread soil fertility problem in sub-Saharan Africa. Current strategies and approaches to soil and water management for sustained sorghum production in North America give emphasis to reducing cost of external inputs, conserving groundwater storage and prevent groundwater pollution. For many developing countries, rejuvenation of degraded land and intensification of indigenous farming systems are more pressing issues. Future agricultural development needs to place more emphasis on managing all landscape units within a watershed.

Introduction

The impact of agriculture upon natural resources is a major concern throughout the world. A critical problem confronting both developing and developed nations is the long-term physical and chemical deterioration of the soil as a result of non-sustainable agricultural practices. Such degradation of the natural resource base magnifies shortfalls in agricultural production in a large part of the semiarid tropics where population exceeds estimated carrying capacity of the land under existing levels of technology and management (FAO/UNFPA/IIASA, 1982). Since sorghum and millet are important food and feed crops in the semiarid regions of the world, the development of viable and sustainable agriculture systems suitable for their production is crucial. Sorghum and millet are known for their ability to use soil, water and nutrients more efficiently than other cereals under drought conditions. If managed properly, these crops can contribute significantly to meet basic food needs and at the same time enhance the natural resource base in the semiarid regions of the world.

In order to adequately assess the role of sorghum and millet in natural resource conservation, it is necessary to characterize the climatic, edaphic and socio-economic conditions representative of a particular agroecological region. In this paper, we attempt to address important edaphic factors affecting sorghum and millet production with special references to regions where population has exceeded the land carrying capacities under traditional low input farming systems.

Soil Resources

Sorghum and millet are extensively cultivated throughout the drier regions of the world as human food and animal feed. There are seven important sorghum producing countries, namely, India, China, United States, Mexico, Argentina, Nigeria and Sudan. Together, they produce over 80 percent of the world's sorghum crop (Myers and Asher, 1982). Millet is generally cultivated in poorer soils and in areas with less rainfall because the crop uses water more efficiently than sorghum. The principal soils used for the production of sorghum are Vertisols, Alfisols and

[1] Department of Soils and Crop Sciences, Texas A&M University, College Station, TX 77843

Table 1. Major grain sorghum producing countries and predominant soils used.

Country	% of world sorghum		Predominant soils used (U.S. Soil Taxonomy)
	Production	Area	
India	17	31	Vertisols, Alfisols
China	16	16	(Alfisols, Mollisols)
United States	27	11	Mollisols
Mexico	6	3	Vertisols, Alfisols, Mollisols
Argentina	11	5	Mollisols
Nigeria	6	12	Alfisols
Sudan	4	5	Alfisols, Vertisols
Burkina Faso	1	2	Entisols, Alfisols
Niger	1	2	Alfisols
Ethiopia	1	2	Entisols, Alfisols, Vertisols
Australia	1	1	Vertisols
Total	91	90	—

Source: Myers and Asher, 1982.

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Mollisols, however much diversity exists which encompasses a wide range of soil types (Table 1).

Large areas of Vertisols used for sorghum production are found in United States (mainly Texas), India, Sudan and Ethiopia (FAO, 1965; Sivakumar and Virmani, 1982; Myers and Asher, 1982). In semiarid regions, these cracking clay soils typically occupy lower topographic positions of inland valleys or depressions. These soils are composed of high activity clays, predominantly montmorillonite, and therefore have high cation exchange capacities (CEC). Other notable features of Vertisols include a high water-holding capacity, low hydraulic conductivity, and special management problems related to tillage and drainage (Wilding and Puentes, 1988).

Alfisols are a major soil group used for sorghum production in India, China and East and West Africa. Alfisols (mainly Kandiustalfs) found in subhumid and semiarid tropics are characterized by moderate clay contents in the subsoil horizons, low nutrient reserve, low organic matter content, and low to moderate water retention capacities (Abrol, 1988; Sivakumar and Virmani, 1982). Unlike the relatively fertile, high base saturation, and typically alkaline or calcareous Ustalfs of United States and China, Ustalfs in West Africa are acidic, poorly buffered soils with low inherent fertility and have a low cation exchange capacity. Kaolinite is the dominate mineral in the clay fraction. Moreover, phosphorus deficiency is a prevailing fertility problem in the sandy Alfisols and Entisols throughout the Sahelian region (Sivakumar and Virmani, 1982; Wilding and Hossner, 1987; Bationo, et al., 1986).

Pearl millet often replaces sorghum on sandier soils in Africa and India. It is cultivated predominantly on Entisols (Psamments) and Alfisols (Kandiustalfs) and Aridisols in the sub-Sahelian region of Africa and low rainfall areas in India (Norman et al., 1984). Sandy Entisols (Psamments) are common on the northern fringes of the Sahel in Africa where the growing period is short. The available moisture holding capacity of Psamments is very low, which places a severe limitation on millet production especially during the drought years.

Mollisols are well-structured, dark-colored soils rich in organic matter and calcium. In the Great Plains of United States, monoculture sorghum is cultivated on Mollisols (Ustolls). A high level of grain production is maintained through the use of high-yielding dwarf cultivars, nitrogen fertilization and supplemental irrigation. The crop is grown for export and

consumed locally as cattle feed (Maunder, 1972).

Water Resources

In terms of agriculture, a great part of earth's land surface suffers from water deficiency. This is particularly true in sub-Saharan Africa where current population has already exceeded the region's land carrying capacity under traditional systems of food production (Harrison, 1983). Water resources in drier regions are generally limited. Data given in Table 2 indicate water availability in Africa for agriculture. The deficit is the difference between potential and actual evaporation. The availability, which can be positive or negative, assumes that the total runoff can be used to offset the deficit. All parts of Africa show negative availability, especially in the arid internal runoff areas (IAHS, 1984; Wright, 1986). These data indicate the limited renewable water resource in the continent. Consequently, agricultural development should make the best use of rainfed agriculture.

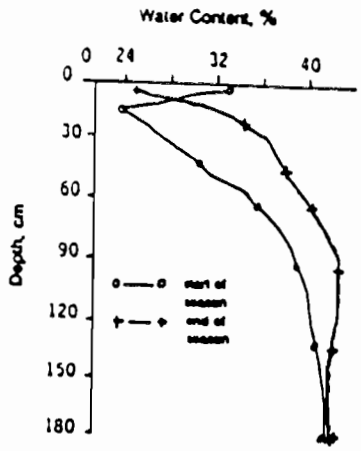
Table 2. Water resources availability in Africa (Wright, 1986).

	Runoff mm	Deficit mm	Availability +ve; -ve
Atlantic Ocean slope			
External runoff	241	980	- 739
Internal runoff	11	2160	-1969
Indian Ocean slope			
External runoff	84	1070	- 986
Internal runoff	46	1200	-1154
Continent	141	1300	-1159

Water resources include surface water and groundwater. With the exception of a few large perennial rivers (e. g. Nile and Niger), most rivers and streams in major sorghum and millet producing areas are seasonal, derived by local runoff. Irrigated agriculture in the fertile valleys along large perennial rivers have been an integral part of several ancient civilizations such as China and Egypt. But in modern times, efforts to develop large irrigation schemes in Africa and elsewhere have been very costly and in most instances, unsuccessful.

Because of large evaporation losses, developing surface water storage in lower rainfall areas is also economically disadvantageous. Soil management practices and cropping systems that can make more efficient use of rainfall and available soil moisture are probably the most desirable. A good example is the presence of substantial amount of available soil moisture in the subsurface layers of a Vertisol at the end of a short-cycle cereal crop (Fig. 1). To utilize the residual soil moisture, a longer duration deep-rooting legume, such as pigeon pea, may be planted as a intercrop or a relay crop with the main season cereal (sorghum or maize). Such a system, though labor-intensive, would increase total grain and biomass yields and help maintain soil fertility.

Figure 1. Water contents beneath a maize crop grown on a Vertisol at the start and end of the rainy season (ICRISAT, 1978 as cited by Onken and Wendt, 1989).



The use of groundwater for domestic and small-scale irrigation schemes offers an attractive alternative in the arid and semiarid lands. Shallow groundwaters are important sources for small holders because of the low cost of development. However, it is important to point out that usable storage of shallow groundwater in the semiarid regions is small and recharge is a critical factor to be considered when tapping shallow groundwater for domestic and irrigation uses.

There have been two approaches to developing surface and ground water resources for agriculture: (i) The development of large-scale, full water irrigation systems with supply from major perennial rivers or large fossil aquifers. (ii) The development of small-scale, supplementary irrigation systems using dispersed water sources integrated with traditional farming systems. The current thoughts of researchers and planners in the developing countries favor the second approach. However, its practical and economic feasibility for widespread development has yet to be established (Wright, 1986). For example, the most important components of water resources for small-scale development are extended river flow and shallow groundwater. Nevertheless, both of these sources are susceptible to deterioration which may be caused by degradation of land and vegetation within a catchment area. Rapid runoff and reduced infiltration of a degraded landscape would seriously affect recharge. Thus, an integrated land and water use based on topography, soil, hydrology and vegetation of an entire watershed area offers the best hope for agriculture and natural resource management in the semiarid regions.

Technological Options

The unique ability of sorghum and millets to endure long periods of soil moisture stress and other adverse climatic and edaphic conditions fosters their wide acceptance and use in semiarid environments. However, sustainability of sorghum and millet production in the dryland regions of the world is threatened by increased degradation of natural resource base. In the Great Plains region of United States, irrigation and nitrogen fertilization have caused significant depletion and contamination of groundwater resources. Thus, increased attention has now been given to re-introducing rainfed cultivation using soil and water conserving practices such crop rotation, furrow diking and conservation tillage practices to enhance soil moisture storage (Hons, 1988).

In the less developed countries, sorghum and millet are invariably intercropped with grain legumes and other cereals on small farms (1 to 3 ha) with little or no external inputs. Crop yields are low due to low soil nutrient and water availability. Farmers generally plant the crop at low density to minimize competition for nutrients and water. Such low input cropping systems are generally sustainable as long as the short cropping cycle (1-2 years) is followed by a long fallow phase (15 years or more). Nevertheless, increasing land pressure during the past decades has caused farmers to shorten the length of fallow. Consequently, land productivity declined rapidly due to soil erosion and loss natural vegetation.

There is ample evidence that in many areas of the semiarid regions of the world, efforts to fulfill the basic human requirements for food and fiber is resulting in a steady loss of long-term soil productivity. An appropriate question therefore is "how can the cultivation of sorghum and millet be incorporated into land management systems which can sustain crop yield and enhance land productivity?" The remainder of this paper will be focused on this concern.

Cropping Systems

Although sorghum and millet are best adapted to drought conditions, grain yield depends upon the amount of water available during the reproductive phase. In rainfed agriculture, adjustment in the time of planting, breeding short-cycle cultivars, and reducing evaporation losses are probably more practical measures to sustain optimum yield.

Both sorghum and millet are quite adaptable to various multiple cropping schemes which are employed primarily in the tropics (Ntare et al., 1989; Venkateswarlu, et al., 1981; Shetty,1988). Due to preferential flow which occurs in Vertisols, antecedent moisture content is often the major factor controlling infiltration rates. Hence, intercropping systems which increase the utilization of soil moisture during peak periods of rain on these soils can contribute to reduced runoff and erosion rates (Mullins et al., 1987). It also reduces the risk of complete crop failure due to drought and pest damages. In regions where residue and vegetative cover is particularly sparse during highly erosive periods, sorghum or millet windbarriers can be utilized to reduce wind erosion. In the southern Great Plains of North America. Such a practice can be used in conjunction with tillage practices to control wind erosion

during the fallow period (Bilbro and Fryrear, 1988).

Cereal-legume rotation and intercropping was a common cropping system practiced in North America some years ago. But the practice was replaced by cereal monoculture since the introduction of large mechanical harvesters (Harvey, et al., 1961; Francis, 1986). Intercropping is however, still a common practice on small-holding farms in the semiand tropics. Sorghum or millet is often intercropped with cowpea, beans, pigeon pea, and groundnuts. However, the choice of cropping system is determined by a combination of physical and socio-economic factors, such as soil characteristics, length of growing season, market, and local consumption preferences. For example, cowpea is often intercropped with millet on the sandy soils in Niger and northern Nigeria. The short rainy season and high insect pressure often result in low grain yield. However, cowpea fodder is a highly valued commodity which is sold at the local market as livestock feed during the dry season. Thus, farmers prefer to grow viney cultivars which can produce large quantities of biomass. Under such circumstances, the goal of improving a millet/cowpea intercropping system should be placed on increasing cowpea total biomass yield for fodder and green manure. On fertile soils with an adequate moisture supply, high-yielding, erect-type cowpea cultivars may be grown. Optimum rates of pesticides or other biological pest control methods are also needed to ensure acceptable grain yield.

In India and Central America, where soils and rainfall are more favorable, sorghum is intercropped with pigeon pea (redgram), mungbean (greengram), common beans and groundnuts. The efficient use of nutrient, water and light resources may be illustrated by the sorghum/pigeon pea intercropping on a Vertisol in the dryland region of India (Natarajan and Wiley, 1980). Using the respective sole crop population, 180,000 plants per ha for sorghum and 50, 000 plants per ha of pigeon pea, the intercrop sorghum produced as much grain yield as the sole crop (4.5 t/ha) and the total productivity or yield advantage of the system was 63 percent (LER = 1.63) higher than that of sole cropping (Table 3). Although pigeon pea growth was greatly reduced at first, it compensated in growth after the harvest of

Table 3. Yield and land equivalent ratio (LER) in sorghum/pigeon pea intercropping (Natarajan and Wiley, 1980).

	Grain yield, kg/ha		LER
Crop	Sorghum	Pigeon pea	
Sole crop	4467	1017	1.00
Intercropping	4312	671	1.63

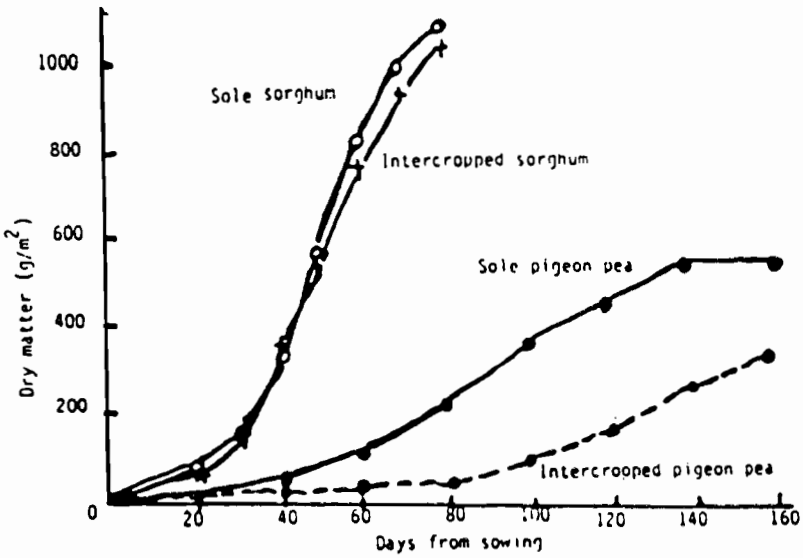
sorghum and produced 53 per cent of the sole crop dry matter (Fig. 2). Thus, the selection of a long duration legume intercropped with a short-cycle cereal such as sorghum on Vertisols and other fine-textured soils can make efficient use of residual soil moisture, produce high total yield, and improve soil productivity.

Soil Conservation Practices

Sorghum and millet are typically cultivated in regions which suffer from rainfall deficiencies which are often intensified by periodic droughts. A consequence of drought stress is a low level of residue production by crops which can result in severe wind and water erosion . Thus, in order to minimize soil erosion, effective soil and land management practices are required which maximize infiltration, ensure the safe disposal of excess rainfall and make efficient use of soil water. Crop management practices (e.g., residue management, multiple cropping) alone can make a significant contribution towards alleviating soil erosion, however in semiarid regions where vegetative and residue cover is difficult to maintain, mechanical soil and water conservation practices are often required.

Soil and water conservation techniques are well known (FAO, 1977; Barrow, 1987; El-Swaify, 1988; Nair, 1988), but their successful application and transfer to the farmer's fields is determined by many physical, biological and socio-economic factors. It should also be recognized that due to the complex physical and socio-economic factors and the long-term investments involved in carrying out soil conservation programs, success depends heavily upon government involvement and the active participation of communities and land users (Hauck, 1985). Contour tillage techniques aid in the storage of water and the reduction of soil erosion on gentle slopes in temperate climates, however in the tropics under higher rainfall intensities and on steeper slopes, this

Figure 2. Dry-matter production by sorghum and pigeon pea in sole cropping and 2:1 intercropping.



practice has often led to runoff concentration and severe gully erosion (Hudson, 1981). In the West African Sahel suitable alternatives which have proven to be effective include micro-catchment techniques and tied ridges (furrow diking). In the steep lands of Central America, rock barriers and tree legume (e.g. Leucaena spp., Gliricidia spp.) hedgerows and grass (e.g. Panicum) barriers are being tested in farmers fields. Although these practices have the potential to reduce soil erosion, such practices may also need to incorporate technologies which allow safe disposal of runoff (e.g. graded terraces and contour canals) and increase surface cover.

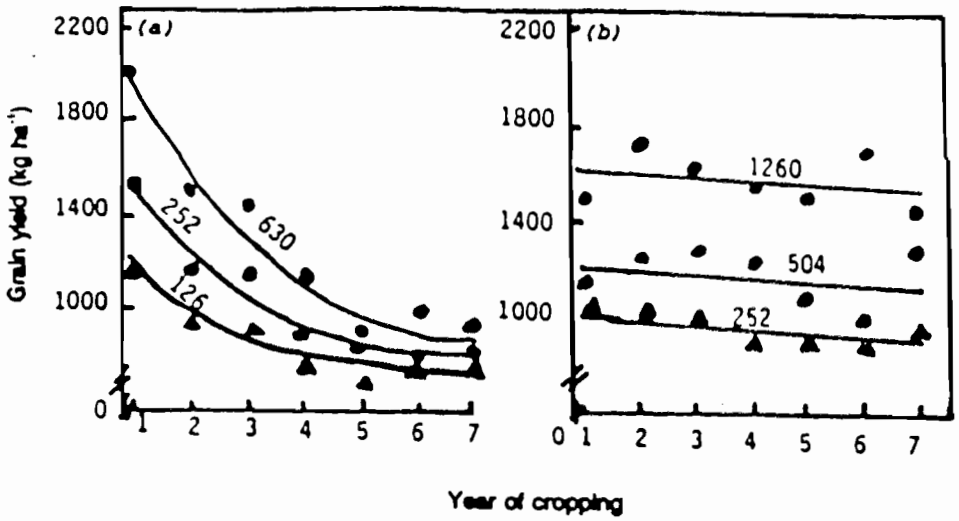
Plant Residue Management

Numerous publications have reported that the use of crop residue mulch improves soil organic matter and nutrient status, reduces erosion, regulates soil temperature and conserves soil moisture. On the other hand, it also may immobilize available nitrogen and harbor plant pests and diseases. In tropical and subtropical regions, the practice of conservation tillage and mulching with crop residues are generally beneficial on sloping lands and on well-drained soils. On poorly-drained, clayey soils, particularly under cooler climates, crop residue mulch may produce adverse effects, such as immobilization of inorganic nitrogen and increased risk of pest and disease infestation. Results on the use of crop residue mulch on well-drained, low fertility soils in the subhumid and semiarid tropics has been beneficial (Juo and Kang, 1987). Generally, slope, soil texture, soil structure and drainage condition are among the key factors determining whether crop residues should be removed, plowed-under or left on soil surface as mulch.

Maintaining crop residues on the soil surface is also a practical means for controlling wind and water erosion. Besides reducing surface sealing and maintaining higher infiltration rates, surface residues generally reduce cumulative seasonal evaporative losses of water from otherwise bare soil surfaces (Unger, 1988; Papendick and Parr, 1989). In general, however, residue maintenance is most effective in reducing evaporation over fine textured soils rather than soils with a sandy surface horizon.

In most parts of the semiarid tropics, however, the above-ground crop residues are harvested for fodder and other household uses. In the kaolin and quartz dominated soils in sub-Saharan Africa, the low level of organic inputs has resulted in serious soil compaction on farm land where ridging and mounding have become essential practices of seedbed preparation. Thus, future soil and crop man-

Figure 3. Grain yield of sorghum in successive years of cropping after initial applications of three levels (kg per ha) of (a) superphosphate and (b) rock phosphate to an Alfisol in northern Australia (Arndt and McIntyre, 1963 as cited by Norman et. al., 1984



agement strategies in the region should give more emphasis to increase total farm biomass production so that the demands for fodder, mulch material and household uses can be met at the same time (Juo and Kang, 1987).

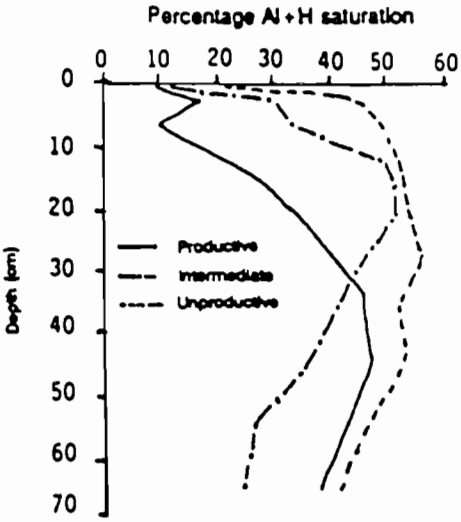
Soil Fertility Maintenance

There are two important soil fertility problems in the sorghum and millet growing areas in semiarid Africa: the widespread phosphorus deficiency on arable land and soil spatial variability.

Although phosphorus deficiency in the Sahelian soils are widespread, fortunately, the coarse-textured, kaolinitic soils have relatively low P-fixing capacity. Therefore, deficiency in most cases, may be ameliorated with applications of 20 to 40 kg of P per ha as superphosphates as demonstrated by a study where millet grain yield in a sandy soil in Niger was increased 3 to 5 fold (Bationo et al., 1986). Thus, to sustain crop yields and maintain soil fertility, phosphate fertilization becomes an essential input in the region. However, imported triple superphosphate fertilizers are expensive and beyond the reach of farmers in the region. Fertilizer subsidies are required initially until soil available phosphate has reached adequate levels. Alternatively, locally produced rock phosphates and partially acidulated rock phosphates can be cheaper sources of P for local farmers. A long-term field experiment conducted on a fine-textured Alfisol in tropical northern Australia reported that rock phosphate showed much greater sustained availability than superphosphate to seven successive annual crops of sorghum (Fig. 3).

It has been reported that marked variability in soil chemical properties over short distances in sandy Sahelian soils can cause significant yield reduction within a farmer's field (Wendt, 1986; Chase et al., 1987; Wilding and Hossner, 1987). Variability in KCl-extractable acidity in soil within short distances was related to the poor crop growth and yield reduction (Fig. 4). The randomly distributed productive and unproductive areas of the field are characterized by gradually declining millet growth. The plants in the most unproductive areas eventually die, leaving patches in the fields devoid of vegetation (Wendt, 1986).

Figure 4. Percentage Al + H saturation with depth along a transect from an unproductive to a productive region (Wendt 1986).



Spatial variability in other soil physical and chemical properties such as micro-relief, crusting, soil texture, organic matter, exchangeable bases and available phosphorus contents may also contribute to millet growth variability in these intensively used sandy soils. Causes of such widespread soil variability may be attributed to both pedogenic and anthropic factors and the potential crop yield loss in the Sahel region is yet to be quantified (Wilding and Hossner, 1987). Liming, phosphate application and addition of plant residue may help correct the problem over time. But economic and practical soil and crop management systems are yet to be developed and tested in the farmer's fields.

Integrated Watershed Management

In terms of natural resource conservation and enhancement, perhaps future agricultural practices should give more emphasis to a holistic approach to managing all landscape units within a watershed. Such an approach is of particular importance to countries and regions with inherent poor land and water resources. Moreover, successful watershed management for agricultural and forestry production is a multidisciplinary effort. Baseline data on climate, soil, hydrology, topography, natural vegetation, present and past land use systems and socio-economic conditions are needed to establish scientific criteria for designing sustainable land management and production systems (FAO, 1977; Barrow, 1887).

Few attempts have been made in developing countries to integrate modern technologies with indigenous knowledge on a watershed basis. The INRAN/TAMU/USAID collaborative project on Integrated Management of Agricultural Watershed (IMAW) in Niger may serve as an example for such an effort (Manu, et al., 1990). In this study, land management units within the watershed are delineated using geographic information systems (GIS). Promising land rejuvenation and crop production practices, including erosion control, water harvesting, agroforestry, phosphate application, alternative cropping systems, etc., are being tested and integrated into indigenous farming systems.

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