Soil Conservation in Nigeria

Past and present on-station and on-farm initiatives

SOIL AND WATER CONSERVATION SOCIETY®

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FOREWORD

Rattan Lal

Of the projected increase in world population of about 3 billion between 2008 and 2050, about half of it may occur in Africa where soil resources are already under great stress. The agrarian stagnation, plaguing food security in sub-Saharan Africa (SSA) since the early 1970s, may exacerbate with the projected climate change along with the attendant increase in risks of soil and environmental degradation. Soil degradation and desertification are already severe issues in SSA, where smaller size and resource-poor farmers follow extractive farming practices. These farmers can neither afford the much needed off-farm input essential to sustainable use of soil and water resources, nor are they sure of their effectiveness because of the harsh climate, structurally fragile soils, unfavorable land tenure situations, and the human dimensions issues of gender and social inequity. Because of the increase in population, the per capita arable land area in many countries of SSA is declining rapidly. The per capita land area (ha) in 1960, 1990, and 2025, respectively, is 0.14, 0.08, and 0.03 for Congo; 0.50, 0.29, and 0.11 for Ethiopia; 0.31, 0.13, and 0.05 for Tanzania; 0.50, 0.28, and 0.14 for Zimbabwe; and 0.68, 0.34, and 0.14 for Nigeria. The problem of land scarcity for food crop production is aggravated by rapid urbanization, conversion to nonagricultural uses, and severe soil degradation. Land area affected by soil degradation in Africa is estimated at 227 Mha by water erosion, 186 Mha by wind erosion, 19 Mha by physical degradation, and 62 Mha by chemical degradation, of which 15 Mha is by salinization. Crop yields and agronomic productivity are also constrained by recurring drought stress exacerbated by scarcity of renewable fresh water resources and highly variable/unpredictable rains. Per capita renewable fresh water availability (m^3 per person y^{-1}) in 1950, 1995, 2025, and 2050, respectively, was 5,967, 1,950, 807, and 517 for Ethiopia; 2,730, 1,787, 1,034, and 803 for Zimbabwe; and 8,502, 2,506, 1,175, and 827 for Nigeria. The minimum per capita renewable fresh water required is 1,000 m^3 y^{-1}. Many countries in Sahel (e.g., Senegal, Burkina Faso, Mali, Chad, Niger, Ethiopia, Sudan, Somalia) are prone to severe drought stress and water scarcity.

The Green Revolution in Asia, brought about during the 1970s because of the adoption of improved varieties grown on irrigated soils with increasing use of fertilizers and other amendments, bypassed SSA. There was a linear increase in food grain production in South Asia with increase in cropland area under irrigation and with increase in use of chemical fertilizers. In contrast, crop yields in SSA stagnated since the 1970s at about 1 t ha^{-1} for cereals, about 300 kg ha^{-1} for grain legumes, and 3 to 5 t ha^{-1} for roots and tubers (e.g., cassava, yam, and sweet potato). Low yields are attributed to low rate of fertilizers (<10 kg ha^{-1}) and low/no supplemental irrigation, severe elemental depletion with negative nutrient budget of –40 to –50 kg ha^{-1} y^{-1} on a continental scale. The problem of drought stress and nutrient depletion is accentuated by high losses of water runoff and severe losses of soil erosion even on gentle slopes of <7%. Soil's susceptibility to losses of water runoff and soil erosion is exacerbated by mechanical soil disturbance caused by inappropriate/excessive tillage and removal/burning of crop residues with little or no protection of the fragile soil against erosivity of raindrop impact, shearing force of the flowing water, and blowing wind. Erosion-induced losses in productivity are especially high for soils with root-restrictive layers (due to unfavorable physical and chemical soil properties) and with low external input.

Thus, there is a strong need for identification and adoption of conservation-effective measures in SSA. A widespread adoption of appropriate technologies, in relation to site-specific biophysical factors and socioeconomic and the human dimensions issues, is crucial to advancing sustainable use of soil and water resources and achieving food security in SSA. It is precisely in this connection that the report *Soil Conservation in Nigeria: Past and Present On-Station and On-Farm Initiatives* by Junge et al. is timely and highly pertinent. Nigeria, with a population of about 150 million, is the most populous country in SSA. Despite highly diverse and favorable soil and water resumes, and highly trained/scientific human resources, agronomic yields are low and perpetual food deficit has plagued the nation. The time to act decisively on implementing recommended management practices (RMPs) is now.

The report by Junge et al. collates and synthesizes the available literature on the extent and severity of the problem of soil erosion and degradation, and identifies those soils and crop management options that reduce both on-site and off-site effects of accelerated erosion. The report includes important information with regard to the following: (1) history of soil conservation in Nigeria, (2) agronomic soil conservation strategies, (3) conservation tillage and its application to small farms, (4) mechanical and engineering measures, and (5) other approaches including agroforestry and diverse farming systems. Scientific discussion is supported by appropriate data and more than 200 references.

The authors are justified in concluding that biological measures (e.g., mulching, conservation tillage, cover cropping, inter-cropping, and contour hedges of perennials) are effective in reducing risks of water runoff and soil erosion. Adoption of these measures also improves soil quality by enhancing soil organic matter reserves, strengthening nutrient recycling mechanisms, and increasing activity and species diversity of soil fauna (e.g., earthworms, termites, micro-organisms).

The report is very useful to researchers, extension agents, policy makers, and development organizations including bilateral programs and nongovernmental organizations. It also raises an important question about the reasons for lack of adoption of these proven technologies despite the fact that scientific information about their usefulness has been available since the 1960s and 1970s. The answer to this question may lie in two basic premises: (1) soil degradation is a biophysical process but is driven by social, economic, and political forces, and (2) when people are poverty stricken and hungry, they pass on their sufferings to the land. In other words, sermons about land ethics and stewardship of soils and water resources often fall on deaf ears when the immediate basic necessities (e.g., food, feed, fuel, and fiber) are not adequately met.

The issues of lack of resources for soil restoration and adoption of RMPs must also be addressed. The knee-jerk response to solving recurring crises and providing handouts as emergency measures, involving billions of dollars as aid to SSA since the 1970s, has been ineffective and often counterproductive. This well-meaning strategy has jeopardized initiative, created dependency, and killed self pride and dignity. Rather than being given handouts, resource-poor and small land holders in SSA and elsewhere in the developing world must be paid for ecosystem services rendered through the adoption of RMPs. Examples of important ecosystem services for which farmers can be paid include carbon sequestration in soil and terrestrial ecosystems (e.g., forests, rangelands), improvements in water quality, increase in biodiversity, and improvement in aesthetic value of the land.

This report by Junge et al. reinforces once again the fact that restoring soil quality is essential to human survival. Several civilizations that chose not to pay attention to this dictum vanished because they took soils for granted. Political stability and peace are threatened in SSA and Nigeria because of soil degradation, food insecurity, and desperateness caused by the ever-dwindling soil resource. However, there is no cause for delay in taking an appropriate action by the decision makers, farmers, and public at large.

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INTRODUCTION

Land degradation was a significant global issue during the 20th century and remains of high importance in the 21st century as it affects the environment, agronomic productivity, food security, and quality of life (Eswaran et al. 2001). Soil degradative processes include the loss of topsoil by the action of water or wind, chemical deterioration such as nutrient depletion, physical degradation such as compaction, and biological deterioration of natural resources including the reduction of soil biodiversity (Lal 2001).

In Nigeria, West Africa, human-induced soil degradation is a common phenomenon. Its severity is light for 37.5% of the area (342,917 km^2), moderate for 4.3% (39,440 km^2), high for 26.3% (240,495 km^2), and very high for 27.9% (255,167 km^2) (UN Food and Agriculture Organization 2005). Soil erosion is the most widespread type of soil degradation in the country and has been recognized for a long time as a serious problem (Stamp 1938). In 1989, 693,000 km^2 were already characterized by runoff-induced soil loss in the south and 231,000 km^2 were degraded, mainly by wind erosion, in the north. Sheet erosion dominates all over the country, whereas rill and gully erosion are common in the eastern part and along rivers in northern Nigeria (Ologe 1988; Igbozurike 1989).

Redistribution of soil by erosion and deposition is the result of perturbation and a natural landscape-forming process. However, it has been greatly accelerated by human activities in recent decades as the traditional shifting cultivation system has been replaced by more intensive but generally unstable cropping systems (Lal 1993a). The main reason for the land use intensification was and still is the increase in food production required to feed the rapidly growing population. For example, the Nigerian population has increased from 115 million in 1991 to 140 million in 2006 (Federal Republic of Nigeria 2007).

The expansion of agriculture into marginal areas, deforestation, the shortening or elimination of fallows, inappropriate farming practices, and low input inevitably have several environmental and economic impacts, especially in sub-Saharan Africa where the resilience ability of the soil is limited (Lal 1995a). This expansion of agriculture causes on-site degradation of natural resources and productivity decline. For example, Mbagwu et al. (1984) observed that soil erosion causes a yield reduction of about 30% to 90% in some root-restrictive shallow lands of southern Nigeria. Off-site problems, such as the siltation of reservoirs, are also common consequences of soil loss. Hence, low agricultural production, food insecurity, low income of the rural population, and poverty are some consequences of soil erosion. Avoidance of soil loss by improved management and the conservation of natural resources is therefore important to maintain the functions of the soil and contribute to food security today and for future generations (Ehui and Pender 2005).

Research on soil conservation has been conducted for many years in Sub-Saharan Africa (e.g., Fournier 1967; Greenland and Lal 1977; Quansah 1990; Kayombo and Mrema 1998; Ehrenstein 2002) and in Nigeria (Lal 1976a, 1990). Initiatives have resulted in various so-called on-farm strategies including agronomic measures, soil management, and mechanical methods, as well as off-farm strategies, including mechanical or biological soil conservation technologies.

This work provides an extensive literature review to obtain information on past and present initiatives focusing on on-farm soil conservation strategies and their application in Nigeria (figure 1). Based on this, the most promising soil conservation technologies for the savanna are identified to improve the management and conservation of soil resources in the country.

MATERIALS AND METHODS

An extensive literature review was conducted in 2006 and 2007. At the beginning, a selection of appropriate scientific, governmental, and nongovernmental institutions working on soil conservation was necessary because of the size of the country and its numerous organizations. First, the resources of the International Institute of Tropical Agriculture, an Africa-based international research-for-development organization, were checked for appropriate records. This institute was established in Ibadan in 1967 and has since then investigated sustainable farming systems to enhance food security and improve livelihoods in Africa. Various international scientific journals were reviewed. In addition,

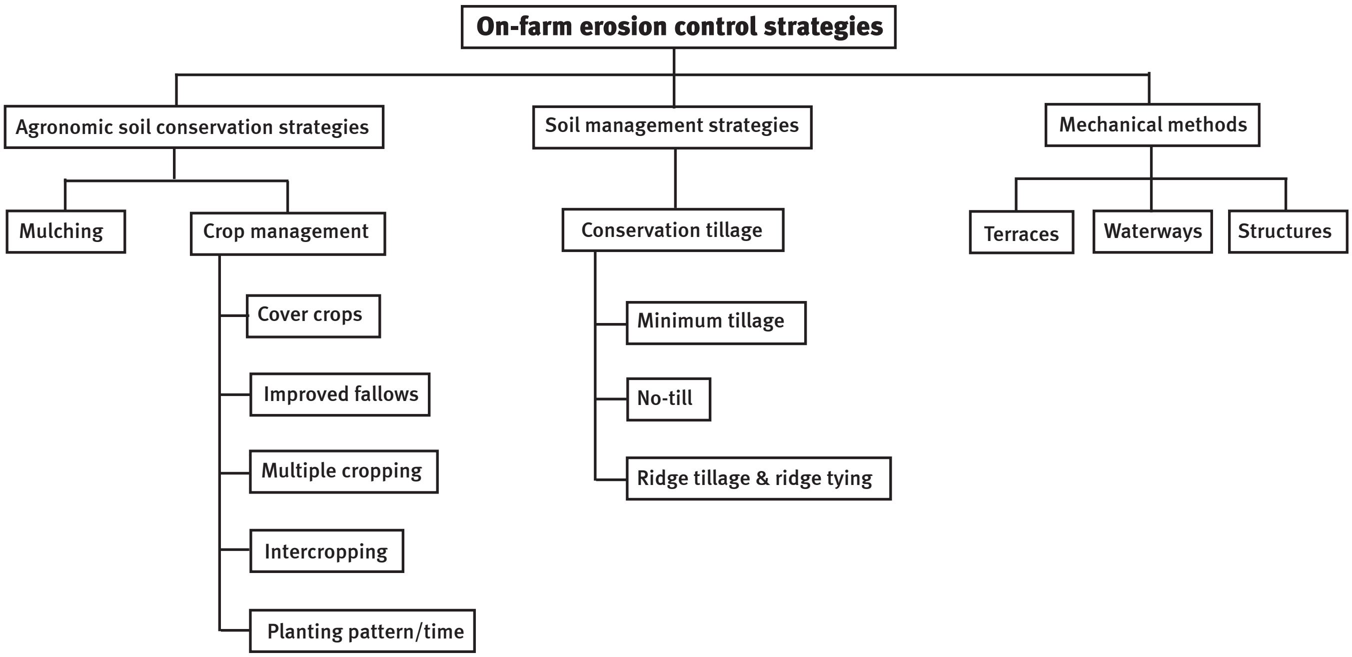

Figure 1
On-farm erosion control strategies (El-Swaify et al. 1982, adapted).

visits were made to the most important national research institutes, the universities at Abeokuta, Ile-Ife, Nsukka, Maiduguri, and Zaria, and the Lake Chad Research Institute, Maiduguri. The Agricultural Development Program in Maiduguri, Federal Environmental Protection Agency in Kaduna and Maiduguri, the Agricultural Land Development Authority in Maiduguri, and the Rural Development Projects in Kaduna and Oshogbo were also contacted to get more information about the work of governmental organizations. Ministries were also visited, such as the Federal Ministry of Environment and Water Resources, Ibadan, the Federal Ministry of Forestry, Kaduna, and the Federal Department of Agriculture, Minna. In addition, the nongovernmental organizations Justice, Development and Peace Commission and the Nigerian Environmental Study/ Action Team in Ibadan were contacted.

Most of the literature on soil conservation was found in research institutions such as the International Institute of Tropical Agriculture, National Agricultural Research Stations, and international scientific journals. Appropriate records were rare in different governmental institutions, even if staff members described the implementation of several initiatives.

It was found that most research projects on soil conservation in Nigeria were performed on station and only a few were on farm and included the participation of farmers.

A database of all collected references was generated, and the literature was reviewed to identify the variety of installed soil conservation measures.

HISTORY OF SOIL CONSERVATION IN NIGERIA

In Sub-Sahara Africa, soil conservation has a long tradition. Indigenous techniques from the pre-colonial era focused on erosion control in combination with water conservation by ridging, mulching, constructing earth bunds and terraces, multiple cropping, fallowing, and the planting of trees (Igbokwe 1996; Scoones et al. 1996).

In colonial times, the British Government worked on natural resource management as interest was high in expanding commercial farming enterprises. Stebbing (1938) wrote the earliest article on soil conservation practiced in northern Nigeria, and Longtau et al. (2002) recorded the implementation of terraces in several areas on the Jos Plateau in former times. Large-scale projects on soil loss control were started, especially in areas of high agricultural potential, but many of them failed as the imported technologies had little relevance in the tropics and were not adopted later by local farmers.

After independence in 1960, more emphasis was put on soil fertility issues. Decreasing funds at the end of the oil boom in the 1980s additionally restricted the performance of soil conservation schemes (Slaymaker and Blench 2002). Today, the seriousness of this environmental problem still exists and is also recognized by the Federal Government of Nigeria that planned to spend about half a million US dollars on soil erosion projects all over the country in 2007 (Federal Government of Nigeria 2007).

AGRONOMIC SOIL CONSERVATION STRATEGIES

Agronomic measures, include mulching and crop management, use the effect of surface covers to reduce erosion by water and wind (Morgan 1995).

Mulching

Mulch is a layer of dissimilar material placed between the soil surface and the atmosphere. Different types of material such as residues from the previous crop, brought-in mulch including grass (figure 2), perennial shrubs, farmyard manure, compost, byproducts of agro-based industries, or inorganic materials and synthetic products can be used for mulching (Lal 1990).

Mulch's impact in reducing the splash effect of the rain, decreasing the velocity of runoff, and hence reducing the amount of soil loss has been demonstrated in many field experiments conducted on several Nigerian research stations (Orimoyegun 1988; Lal 1976a, 1993a; Kirchhof and Salako 2000; Odunze 2002; Adekalu et al. 2006; Salako et al. 2006) (table 1). For example, Lal (1993a) measured soil loss of about 152.9 t ha^{-1} from a plot with bare fallow and 0.2 t ha^{-1} from a plot with maize and mulch. Salako et al. (2006) compared the effect of burned residues with mulched residues from *Mucuna pruriens* and *Pueraria phaseoloides*. They recorded that soil loss from plots with burned residues of *M. pruriens* were significantly higher (6 and 2.8 t ha^{-1}) than from plots with mulched residues of *M. pruriens* and *P. phaseoloides* (1.5 and 1.3 t ha^{-1}) in 1997. M. pruriens was more effective in minimizing the detachment of soil from mounds due to its faster establishment rate, but finally *P. phaseoloides* was more reliable for soil and water conservation as it produces more mulch. Lal (1990, 2000) stated that a mulch rate of at 4 to 6 t ha^{-1} is needed for an effective erosion control, as 70% to 75% of the soil surface should be covered by mulch. This high amount of material might be available in the humid and semi-humid agro-ecological zones but not in the semi-arid regions of Nigeria where climatic conditions restrict the production of sufficient mulching material (Kayombo and Lal 1993). Other reasons that reduce the amount of residues are bush fire (Okigbo 1977) or termites (Maurya 1988a). The complete removal of crop residues from the field for use as animal fodder, firewood, or as construction material is another factor that makes this soil conservation technology less applicable (Kirchhof and Odunze 2003). A possible solution might be mulching with brought-in organic material. In Kaduna and Kano states, household waste was transported from the cities to rural areas and distributed on farmland. This is generally expensive, due to extra costs for purchase and transport of the material as well as the increased labor demand. Hence, this practice can only be economical for some high-value cash crops which make this strategy less appealing for smallholders mostly focusing on subsistence (Lal 1990). Another possibility is to stop frequent burning (Okigbo 1977), to use dead weed and grasses from the field and surrounding areas, and to leave a certain amount of crop residues on the farmland to obtain a protective mulch layer in this environment.

Figure 2
Mulching (Owode-Ede, Osun State).

There are various investigations on the beneficial effects of mulch on the physical, chemical, and biological soil properties which influence the soil's erodibility. Hulugalle et al. (1985, 1987) and Lal (2000) found that the bulk density and penetration resistance of the soil are decreased by mulching. Ogban et al. (2001) and Chiroma et al. (2004) investigated on the influence residue mulch on the infiltration capacity and hydraulic conductivity of soils. Ogban et al. (2001) stated that the infiltration was five times higher and the transmissivity four times higher in plots with incorporated mulch compared with the surface or no mulch application. They concluded that incorporating residues may be more beneficial than applying them on the topsoil as the surface roughness is increased and the soil structure

Table 1
Studies on soil conservation by mulching.

Beneficial effect	Author(s)	Location	Kind of mulch
Reduction of splash effect of rain	Lal 1976a	Ibadan	Straw of *Oryza sativa*
Decrease of runoff velocity	Odunze 2002	Zaria	Straw mulch
Reduction of soil loss	Adekalu et al. 2006	SW Nigeria	Leaves of *Phyllostachys bambusoides*
	Salako et al. 2006	Ibadan	Residues of *Zea mays*
Decrease of soil bulk density,	Lal 1978	Ibadan	Straw mulch
penetration resistance	Hulugalle et al. 1987	Onne	*Eupatorium odoratum*
	Lal 2000	Ibadan	Straw of *O. sativa*
Increase of size + stability of soil aggregates	Oyedele et al. 1999	SW Nigeria	?
Increase of infiltration capacity,	Lal 1975	Ibadan	?
hydraulic conductivity	Ogban et al. 2001	Uyo	Grass
	Chiroma et al. 2004	Maiduguri	Wood shavings
Increase of soil moisture	Lal 1978a	Ibadan	Straw mulch
Decrease of soil temperature	Lawson and Lal 1980	Ibadan	Straw of *O. sativa*
	Lal 2000	Ibadan	Straw of *O. sativa*
	Agele et al. 2000	Akure	?
	Chiroma et al. 2005b	Maiduguri	Straw of *Triticum ssp.*
Increase of activity and species	Lal 1975	Ibadan	?
diversity of soil flora and fauna	Salau et al. 1992	Ibadan	Straw of *Pennisetum purpureum*, perforated plastic, wood shavings
	Tian et al. 1997	Ibadan	Prunings of *Dactyladenia barteri*, *Gliricidia sepium*, *Leucaena leucocephala*, stover of *Z. mays*, straw of *O. sativa*
Suppression of weeds	Lal 1975	Ibadan	?
	Lawson and Lal 1980	Ibadan	Straw of *O. sativa*
Increase of organic matter +	Juo and Lal 1977	Ibadan	Stover of *Z. mays*
nutrient content	Maurya 1988	Bakura	Residues of *Z. mays*, *Triticum ssp.*
	Mbagwu 1991	Nsukka	Straw of *P. purpureum*
	Tian et al. 1993	Ibadan	Prunings of *D. barteri*, *G. sepium*, and *L. leucocephala*, stover of *Z. mays*, straw of *O. sativa*
	Vanlauwe et al. 1996	Ibadan	Root + leaf residues of *L. leucocephala*, *D. barteri*, *Flemingia macrophylla*
	Chiroma et al. 2006a	Maiduguri	Wood shavings
Increase of crop yield	Lal 1978	Ibadan	Straw of *O. sativa*
	Okibgo 1979	Nsukka	Plant residues of ?
	Lawson and Lal 1980	Ibadan	Straw of *O. sativa*
	Maurya and Lal 1980b	Ibadan	Straw of *O. sativa*
	Maurya and Lal 1981	Ibadan	Straw of *O. sativa*, polythene
	Maduakor et al. 1984	Onne	Palm fronds
	Hulugalle et al. 1985	Onne	?
	Hulugalle et al. 1987	Onne	*E. odoratum*
	Mbagwu 1991	Nsukka	Straw of *P. purpureum*
	Salau et al. 1992	Ibadan	*P. purpureum*, perforated plastic, wood shavings
	Osiru and Hahn 1994	Ibadan	Polyethylene plastic, straw of *O. sativa*
	Lal 1995b	Ibadan	Residues of *Z. mays*
	Olasantan 1999	Ila-Orangun	Shoots of *E. odoratum*
	Ibewiro et al. 2000	Ibadan	Residues of *M. pruriens var. utilis*, *Lablab purpureus*, leaves + rhizomes of *Imperata cylindrica*
	Lal 2000	Ibadan	Straw of *O. sativa*
	Mbagwu 2000	Nsukka	?
	Kolawole et al. 2004	Ibadan	*P. phaseoloides*
	Chiroma et al. 2006b	Maidugur	Wood shavings
	Anikwe et al. 2007a	Enugu	Plastic-film mulch
Constraints			
Not sufficient mulching material	Kayombo and Lal 1993	N Nigeria	—
Crop residues used as animal fodder, firewood, construction material	Kirchhof and Odunze 2003	N Nigeria	—
Residues reduced by termites and cattle	Maurya 1988	N Nigeria	—
Residues destroyed by burning	Okigbo 1977	Nigeria	—

more open with depth. Crop residues also reduce the soil temperature by some degrees in the upper centimetres of the topsoil and provide better moisture conservation by reducing the intensity of radiation, wind velocity, and evaporation (Lal 1978a; Lawson and Lal 1980, Agele et al. 2000). Oyedele et al. (1999) investigated the size and stability of soil aggregates that are increased on fields with mulch, and Lal (1975), Salau et al. (1992), and Tian et al. (1997) recorded increased activity of earthworms and attributed this to the favorable microclimate under residues. Covering the soil surface also suppresses weeds (Lal 1975; Lawson and Lal 1980). The influence of mulching on the content of organic matter or organic carbon and nutrients of the soils was analyzed by Jou and Lal (1977), Mbagwu (1991), Tian et al. (1993), Vanlauwe et al. (1996), and Chiroma et al. (2006a). For example, Chiroma et al. (2006a) recorded an increase of the organic carbon (11%) content over the initial value after wood-shavings have been applied for three years and recommends this measure for improving the soil in semi-arid areas, even if problems with the high C:N ratio might appear due to the soil amendments rich in lignin.

Studies on the effect of mulching on crop yields are numerous. For example, Maduakor et al. (1984), Hulugalle et al. (1985), Osiru and Hahn (1994), and Olasantan (1999) worked on white yam (*Dioscorea rotundata*), Hulugalle et al. (1987) on cassava (*Manihot esculenta*), Chiroma et al. (2006b) on sorghum (*Sorghum bicolor*), Maurya and Lal (1981), Lal (1995b) on maize (*Zea mays*), and Mbagwu (1991) on maize and cowpea (*Vigna unguiculata*). For example, Mbagwu (2000) recorded 40% increase in maize grain yield when 2 t ha^{-1} mulch were added and of 80% when 4 t ha^{-1} mulch were placed on an Ultisol in Nigeria. He concludes that 2 to 4 t ha^{-1} straw mulch are the optimal rate for increasing yields, as no significant change occurred beyond a mulch rate of 2 t ha^{-1} and no benefits were measured from applying higher quantities. Lal (2000) also recorded the increase of maize grain and stover yields with increasing mulch rates but mentioned the limitations of this soil conservation technology as well. As significant changes in soil properties require long periods of time, this conservation technology might be less attractive for farmers.

In general, mulching is likely to be a useful erosion control technology in most parts of Nigeria as this method both reduces soil loss and enhances soil productivity and crop yields (Lal 1993a, Mbagwu 2000). Soils with shallow surface horizon, a high sand content and soils located in semi-arid areas will benefit from this technology as the water holding capacity will be improved (Lal 1975). Hence, mulching should be integrated into the existing farming systems of smallholders.

Crop Management

Soil loss can also be prevented or reduced by appropriate crop management, which includes cover cropping, multiple cropping, and high density planting.

Cover Crops. Cover crops such as the legumes *P. phaseoloides, M. pruriens, Centrosema pubescens, Stylosanthes guianensis,* and *Phaseolus aconitifolius* or the grasses *Pennisetum purpureum, Brachiaria ruziziensis,* and *Paspalum notatum* are plants that grow rapidly and close (Lal 1995a). Their dense canopy prevents rain drops from detaching soil particles and this keeps soil loss to tolerable limits, so cover crops play an important role in soil conservation (Okigbo and Lal 1977; Lal 1978b, Lal et al. 1979; Ahaneku 1985). Our measurements conducted in Ibadan in 2007 have shown that 3.3 t soil ha^{-1} were eroded from plots cultivated with sole maize and 1.8 t ha^{-1} from plots with the cover crop *P. phaseoloides* (figure 3). The erosion was high on all plots at the beginning of the rainy season due to the small canopy cover and the high rainfall intensity but differed significantly until the end of this period as the coverage of the maize plots was much smaller (max. 40%) than of the plots with *P. phaseoloides* (max. 100%) (figure 4). Comparable results were published by Kirchhof and Salako (2000) and Odunze (2002).

Cover crops also positively influence physical soil properties such as the infiltration rate, moisture content, and bulk density (Hulugalle et al. 1986; Lal et al. 1979). They increase the organic matter content, nitrogen (N) levels by the use of N_2-fixing legumes, the cation exchange capacity, and hence crop yields (Obiagwu 1995; Ile et al. 1996; Ibewiro et al. 2000; Salako and Tian 2003a). For example, Tian et al. (1999) estimated an amount of 84 to 202 kg N ha^{-1} fixed by P. phaseoloides within 18 months. This resulted in a higher maize grain yield (2.5 t ha^{-1}) than in the control without a legume (1.3 t ha^{-1}). Another benefit of cover crops is the suppression of weeds, such as speargrass (*Imperata*

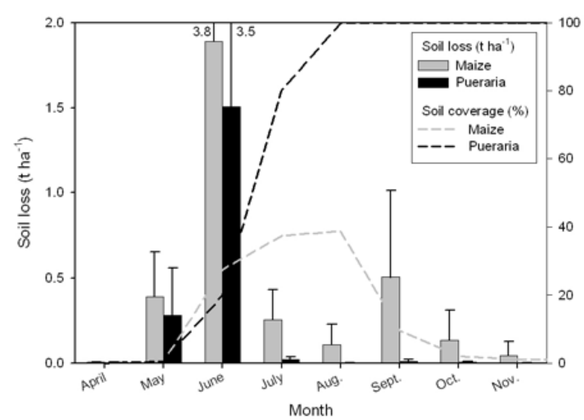

Figure 3
Soil loss from plots with different crops (Ibadan, 2007).

Figure 4
Cover cropping (Ibadan, Oyo State).

cylindrica) or witchweed (*Striga hermonthica*) which are common in Nigeria (Wilson et al. 1982; Chikoye et al. 2002; Ekeleme et al. 2003) (table 2).

Farmers benefit from cultivating cover crops as soil loss is reduced and physicochemical soil properties are improved. However, a problem can be the intensive growth of several cover crop species that might result in competition with food crops for growth factors. Tian et al. (1999) recorded no significant competitive effects from *P. phaseoloides* to maize but reduced yields of cassava. This problem can be combated by choosing compatible crops and by controlling the cover crop by timely cutting.

Improved Fallows. Improved fallows of short periods with selected tree or herbaceous species remain important as the long fallow periods that were part of the traditional shifting cultivation system for encouraging soil regeneration are no longer possible in most Nigerian locations. For example, Juo and Lal (1977) showed that fallows with Guinea grass (*Panicum maximum*) provide much organic matter to the soil. Shrubs of woody plants such as pigeon pea (*Cajanus cajan*) are advantageous in improving the physical soil conditions due to the penetration of their rootlets into deeper soil layers (Juo et al. 1995; Owoeye 1997; Salako 1997; Chianu et al. 2002; Jaiyeoba 2003, Salako and Kirchhof 2003) (table 3). Leguminous fallows with *Leucaena leucocephala, M. pruriens,* or *P. phaseoloides* are known especially for increasing the N content and changing the quantity of available P fractions in the soil (Okeke and Omaliko 1992; Tian et al. 1999, 2001a, 2001b; Okpara and Njoku 2002; Salako and Tian 2003b; Ekeleme et al. 2004; Kolawole et al. 2004). Wick et al. (1998) state the benefits of improved fallows on soil microbiological parameters and Akobundu et al. (1999), Hauser et al. (2006), and Ikuenobe and Anoliefo (2003) on weed control. Tarawali et al. (1999) tested the impact of the forage legume *S. hamata* on livestock productivity in the subhumid zone of Nigeria and showed that cattle grazing on *S. hamata*-based pastures in the dry season produced more milk, lost less weight, and had shorter calving intervals. Hence, improved fallows have a high potential for soil conservation especially in farming systems without fertilizer input.

Multiple Cropping. Multiple cropping involves different kinds of systems depending on the temporal and spatial arrangement of different crops on the same field (Morgan 1995). It has been traditionally practiced and is still very common in Nigeria (Olukosi et al. 1991). The research on mixed cropping was intensified in the late 1960s (Norman 1974) and much has been done on improving the systems since then.

Agroforestry is a collective name for a land use system in which woody perennials are integrated with crops and/or animals on the same land management unit. The integration can be either in a spatial mixture or in a temporal sequence (Rudebjer et al. 2001). Investigations on alley cropping where trees or shrubs such as *L. leucocephala, Gliricidia sepium,* and *Senna siamea* are planted as contour hedges between strips of cropland were part of the research program on many stations (table 4). Studies for evaluating the effectiveness of agroforestry systems on soil erosion control were made by Lal (1989, 1991), Kang and Ghuman (1991), and Nair et al. (1995). For example, Lal (1989) collected 3.64 t ha^{-1} sediment from a plot plowed and cultivated with sole maize 0.07 t ha^{-1} and 0.03 t ha^{-1} from plots with *L. leucocephala* planted at 4-m and 2-m spacing, and 1.40 t ha^{-1} and 0.2 t ha^{-1} from plots with *G. sepium* planted at 4-m and 2-m spacing. The reduction of soil erosion by alley cropping obviously depends on the spacing between the hedges and the species. The 4-m spacing was adequate for erosion control with *L. leucocephala* and 2-m spacing for *G. sepium*. The age of the perennials is also important as most species become effective sediment traps about two to three years after planting (Lal 1990). Young (1989) attributed the potential of agroforestry as an erosion control measure to its capacity to supply and maintain a good soil surface cover by the tree canopy and the pruning material. Another potential is the effect of a runoff barrier when trees are planted across the slope. As the intensive rooting by the woody perennials also improve the structure and infiltration rate of the soil, the amount of runoff and hence soil loss are reduced by alley cropping (Lal 1989; Kang et al. 1995).

Table 2
Studies on soil conservation by crop management: Cover crops.

Beneficial effect	Author(s)	Location	Species
Dense canopy prevents rain drops from detaching soil particles	Ahaneku 1985	Ibadan	*Vigna unguiculata*
	Kirchhof and Salako 2000	Ibadan	*M. pruriens, P. phaseoloides*
	Odunze 2002	Zaria	*M. uniflorum, M. pruriens, Stylosanthes hamata*
	Junge (unpubl.)	Ibadan	*P. phaseoloides*
Increase of size and stability of soil aggregates	Okigbo and Lal 1977		
	Salako et al. 1999	Ibadan	*P. phaseoloides, L. leucocephala*
Decrease of bulk density	Hulugalle et al. 1986	Ibadan	*M. utilis*
Increase of infiltration rate	Lal et al. 1979	Ibadan	*Brachiaria ruziziensis, Paspalum notatum, Cynodon nlemfuensis, P. phaseoloides, Stylosanthes guianensis, Stizolobium deeringianum, Psophocarpus palustris, Centrosema pubescens*
Increase of moisture content	Hulugalle et al. 1986	Ibadan	*M. utilis*
Conservation of soil water	Salako and Tian 2003a	Ibadan	*Aeschynomene histrix, C. brasilianum, C. pascuorum, Chamaecrista rotundifolia, Cajanus cajan, Crotalaria verrucosa, C. ochroleuca, L. purpureus, M. pruriens, Psophocarpus palustris, Pseudovigna argentea, P. phaseoloides, S. hamata*
Increase of content of organic matter + nutrients	Ibewiro et al. 2000	Ibadan	*M. pruriens var. utilis, Lablab purpureus, Imperata cylindrica*
	Lal et al. 1978b	Ibadan	*Panicum maximum, Setaria sphacelata, B. rusisiensis, Melinis minutiflora, C. pubescens, P. phaseoloides, G. wightii, S. guianensis*
	Tian et al. 1999	Ibadan	*P. phaseoloides*
Increase of crop growth + yields	Obiagwu 1995	Benue River Basin	*Sphenostylis stenocarpa, C. cajan,* local + improved, *V. unguiculata*
	Ile et al. 1996	Onne	*M. pruriens var. utilis*
Suppression of weeds	Wilson et al. 1982	Ibadan	*B. ruziziensis, P. notatum, C. nlemfuensis, P. phaseoloides, S. guianensis, S. deeringianum, P. palustris, C. pubescens*
	Udensi et al. 1999	Ibadan	*M. pruriens*
	Chikoye et al. 2002	Ogoja	*M. cochinchinensis, P. phaseoloides*
	Chikoye et al. 2004	Ibadan	*M. cochinchinensis, P. phaseoloides*
	Ekeleme et al. 2003	Ibadan	*M. cochinchinensis, P. phaseoloides*
	Ikuenobe and Anoliefo 2003		*Chromolaena odorata, M. pruriens*
Increase of net benefits	Chianu et al. 2002	Ibadan	*P. phaseoloides*

Much research has been done on alley cropping with leguminous trees or shrubs, especially with focus on improving soil fertility management. For example, Raintree (1980), Kang and Mulongoy (1987), Hauser (1990), Kang (1993ab), Mulongoy et al. (1993), and Kang et al. (1995) investigated nutrient recycling and stated that hedgerows induce a spatial soil chemical micro variability within the alley cropped plots. Research on nitrogen in alley cropping systems were made by Sanginga et al. (1989), Okogun et al. (2000), and Vanlauwe et al. (1996, 2001, 2005a). Sanginga and Mulangoy (1995) found a lack of synchronization between crop nitrogen demand and nitrogen supply of prunings, which can be avoided by the selection of appropriate legume genotypes, the combination of selected tree and crop species, and improved management practices. It was generally assumed that the intensive rooting of the species in different parts of the soil avoids competition for nutrients and water and that trees act as a nutrient pump within the plant and soil system (Young 1989; Schroth and Zech 1995). However, Smucker et al. (1995) found that *L. leucocephala* competed with the first two rows of the alley cropped maize and cowpea. Analyses made by Kang et al. (1985) showed that alley cropping has beneficial effects on the faunal activity and the soil moisture content that is maintained or increased by

Table 3
Studies on soil conservation by crop management: Improved fallows.

Beneficial effect	Author(s)	Location	Species
Improvement of physical soil properties	Juo et al. 1995	Ibadan	*P. maximum, L. leucocephala, C. cajan*
	Owoeye 1997	Port Harcourt	*Tephrosia candida*
	Salako 1997	Ibadan	?
	Salako and Kirchhof 2003	Ibadan	*L. leucocephala, P. phaseoloides*
Increase of organic matter and nutrient content	Juo and Lal 1977	Ibadan	*P. maximum*
	Okeke and Omaliko 1992	Ozala, Nsukka	*Acioa barteri, C. pubescens, C. odorata*
	Juo et al. 1995	Ibadan	*P. maximum, L. leucocephala, C. cajan*
	Wick et al. 1998	Ibadan	*Senna siamea, L. leucocephala, P. phaseoloides*
	Tian et al. 1999	Ibadan	*P. phaseoloides, C. odorata*
	Tian et al. 2001a	Ibadan	*P. phaseoloides*
	Tian et al. 2001b	Ibadan	*Senna siamea, Acacia leptocarpa, L. eucocephala, C. odorata*
	Okpara and Njoku 2002		*M. pruriens*
	Salako and Tian 2003b	Ibadan	*S. siamea, L. leucocephala, Acacia leptocarpa, A. auriculiformis, P. phaseoloides,*
	Ekeleme et al. 2004		*Lablab purpureus, M. pruriens, C. cajan, C. pascuorum, Crotalaria ochroleuca*
	Kolawole et al. 2004	Ibadan	*P. phaseoloides*
	Tian et al. 2004	Ibadan	*P. phaseoloides, L. leucocephala, C. odorata*
Control of weed	Akobundu et al. 1999	Ibadan	*L. leucocephala, G. sepium*
	Hauser et al. 2006	West + Central Africa	(review)
	Ikuenobe and Anoliefo 2003	Benin City	*M. pruriens, C. odorata*
Increase of livestock productivity	Tarawali et al. 1999		*M. pruriens, S. hamata, S. guianensis*

prunings. Lal (1989) also measured a significant improvement of the available water capacity by *L. leucocephala* (42%) and *G. sepium*-based systems (56%) compared to no-till system. Alley cropping has been regarded as a promising methodology for soil fertility management in the tropics as the regular adding of pruned plant material enhances the organic matter content of the soil (Kwesiga et al. 2003). On-station and on-farm trials conducted by Mulongoy et al. (1993) showed that treatments with *L. leucocephala* maintained the organic carbon in the same level (1.64%) as the bush regrowth (1.63%) in some fields. However, Iwuafor and Kumar (1995) did not find any significant effect of *L. leucocephala* prunings on organic carbon, and Lal (1989) and Diels et al. (2004) observed that soil organic matter in alley cropping systems declined with duration of cultivation. Investigations on the influence of alley cropping on crop yield were made by Lal (1989), Adeola and Ogunwale (1995), Kang et al. (1995), Salami and Oluwole (2003), and Vanlauwe et al. (2005a). The latter recorded results of a long-term (1986 to 2002) alley cropping trial with *L. leucocephala* and *G. sepium* located in Ibadan (figure 5) and stated that maize crop yields declined steadily in all treatments. Hauser et al. (2006) recorded an overestimation of the potential of tree-based cropping systems in West and Central Africa. Their comparison of crop yields from field trials with different combinations of annual crops and perennial trees and shrubs collected from the literature showed that alley cropping had no significant effect on crop yields in most cases. The authors also mentioned doubts about the validity of past research results that might have led to the previous enthusiasm about tree-based cropping systems. In general, alley cropping is regarded as a system with potential to improve the physical, chemical, and biological soil properties and to increase farmers' income through additional products such as fuel wood or timber. However, the crop yield response is uncertain and variable due to the competitive effects of the different cultures for light, water, and nutrients. Yields also can be reduced by a combination of incompatible species, lack of micronutrients, increase of pest and diseases, missing information on planting pattern, or wrong crop management. As the demand for labor

Table 4
Studies on soil conservation by crop management: Alley cropping.

Beneficial effect	Author(s)	Location	Species
Reduction of soil loss	Lal 1989	Ibadan	*L. leucocephala, G. sepium*
	Kang and Ghuman 1991	Ibadan	*L. leucocephala, G. sepium*
	Nair et al. 1995		(review)
Improvement of soil structure,	Lal 1989	Ibadan	*L. leucocephala, G. sepium*
infiltration rate	Kang et al. 1995		
Increase of faunal activity	Kang et al. 1995		
	Hauser 1992	Ibadan	*L. leucocephala*
	Hauser et al. 1998	Ibadan	*L. leucocephala, S. siamea, D. barteri*
	Asawalam 2006	Umudike	*L. leucocephala*
Improvement of nutrient recycling	Raintree 1980		(review)
	Sanginga et al. 1989	Fashola, Ibadan	*L. leucocephala*
	Hauser 1990	Ibadan	*L. leucocephala*
	Atayese et al. 1993	Ibadan	*S. siamea, G. sepium, L. leucocephala*
	Mulongoy et al. 1993	Ibadan, Onne, Ise-Ekiti, Boinu-Banga	*P. maximum, L. leucocephala, G. sepium, D. barteri*
	Vanlauwe et al. 1996	Ibadan	*L. leucocephala, D. barteri, F. macrophylla*
	Kang et al. 1999a	Ibadan	*G. sepium, L. leucocephala*
	Kang et al. 1999b	Ibadan	*G. sepium, L. leucocephala, Alchornea cordifolia, D. barteri*
	Okogun et al. 2000	Ibadan	*Albizia lebbeck, S. corymbosato, S. siamea, L. leucocephala, G. sepium*
	Sanginga and Mulangoy 1995	Ibadan	*S. siamea, L. leucocephala*
	Vanlauwe et al. 2001	Ibadan	*S. siamea, L. leucocephala, G. sepium*
	Vanlauwe et al. 2005a	Ibadan	*S. siamea, L. leucocephala, G. sepium*
	Vanlauwe et al. 2005b	WAfrica	(review)
Maintenance of organic matter	Mulongoy et al. 1993	Ibadan, Onne, Ise-Ekiti, Boinu-Banga	*P. maximum, L. leucocephala, G. sepium, D. barteri*
Increase of crop yield	Siaw et al. 1991	Ibadan	*L. leucocephala, A. barteri*
	Osinubi and Kang 1987a	Ajaawa, Zakibiam	*L. leucocephala*
Control of weed	Osinubi and Kang 1987b	Alabata	*L. leucocephala, G. sepium*
	Yamoah et al. 1986	Ibadan	*Cassia siamea, F. congesta, G. sepium*
Increase of net income	Chianu et al. 2002	Ibadan	*L. leucocephala*
Constraints		Ibadan	
Lack of synchronization between crop N demand and N supply of prunings	Sanginga and Mulangoy 1995	Ibadan	*S. siamea, L. leucocephala, D. barteri, F. macrophylla*
Competition of shrubs, trees with alley crops	Smucker et al. 1995	Ibadan	*L. leucocephala*
No significant effect of prunings on organic carbon	Iwuafor and Kumar 1995	Samaru	*L. leucocephala*
Decline in soil organic matter	Lal 1989	Ibadan	*L. leucocephala, G. sepium*
	Diels et al. 2004	Ibadan	
Decline of crop yield	Vanlauwe et al. 2005a	Ibadan	*L. leucocephala, G. sepium*
	Hauser et al. 2006	W + C Africa	(review)

Figure 5
Alley cropping (Ibadan, Oyo State).

is high in tree-based systems and as the restoration effect on the soil requires many years, alley cropping is not likely to be a suitable soil conservation technology for farmers in Nigeria.

In southeast Nigeria, research on agroforestry was conducted, for example, by Okafor and Fernandes (1987), who investigated the home garden-type of agroforestry systems with multipurpose trees and shrubs in a multistoried association with agricultural crops and small livestock. Larbi et al. (1993) and Ruhigwa (1993) investigated *Alchornea cordifolia*, Oko et al. (2000) researched *Enterolobium cyclocarpum, Dialium guianense,* and *Sesbania macrantha*, and Odurukwe (2004) worked on the timber species *Gmelina arborea*, mango (*Mangifera indica*) and orange (*Citrus sinensis*) (table 5). They are commonly used in periurban cities as border planting on land to demarcate boundaries, to control water and wind erosion, and to supplement the supply of food, fodder, and fuel wood. Oke and Odebiyi (2007) researched on agroforestry systems including cocoa (*Theobroma cacao*), a traditional crop in the southern part of Nigeria. The studies show that the cultivation of several species diversifies production, minimizes the risk of crop failure, improves labor and nutrient use efficiencies, and contributes to soil conservation by controlling erosion and enhancing soil fertility.

Agroforestry in the semi-arid part of the country focuses on the control of wind erosion (Azeza and Omeje 1985; Okali et al. 1988) and trees are planted to control drought and desertification (Odigie and Obiaga 1990). Species such as *Eucalyptus citriodora, E. camaldulensis,* and neem (*Azadirachta indica*) are common in plantations due to their ability to grow in dry areas. A. indica, a favoured multipurpose tree, is a useful fallow tree because of its easy establishment and rapid growth (Radwanski 1969); it quickly delivers nutrients as the foliage decomposes fast (Uyovbisere and Elemo 2002), and improves crop yields in combination with fertilizer (Thampattii and Padmaja 1995). A. indica also has economic advantages, such as the production of timber and firewood, water-soluble gum, and oil; it provides fodder for nomadic herds. Extracts are used for medicine and to control fungi (Steinhauer 1999). Studies on the influence of *E. camaldulensis* and of *A. indica* on soil properties and crop yields were carried out by Verinumbe (1985, 1992), Igboanugo et al. (1990), and Adderley et al. (1997), and on teak (*Tectona grandis*) by Verinumbe and Okali (1985). The large canopy of this species caused reduced yields of interplanted maize, but it also protected the soil surface from the impact of raindrops.

Intercropping. Intercropping systems including different kinds of annual crops planted in alternating rows also reduce soil erosion risk by providing better canopy cover than sole crops (Morgan 1995). Erosion measurements on soil loss from mono- and intercropping systems conducted by Aina et al. (1979) showed an average soil loss of 110 t ha^{-1} from cassava plots and 69 t ha^{-1} from maize and cassava plots. The high amount of eroded sediment from the plots with the sole root and tuber crop is caused by its slow growth and small canopy cover at the beginning of the rainy season. Growing maize between the cassava ridges increases the soil coverage and hence reduces the impact of rain (Lal 1990).

In Nigeria, numerous investigations have been conducted on intercropping of cereals such as maize (*Zea mays*), sorghum (*Sorghum bicolor*) or millet (*Pennisetum glaucum*) with herbaceous grain legumes (figure 6) or root and tuber

Table 5
Studies on soil conservation by crop management: Agroforestry (home garden-type, tree plantation).

Beneficial effect	Author(s)	Location	Species
Reduction of water + wind erosion	Jaiyeoba 1996	Zaria	*Acacia albida, P. bigloboza, Eucalyptus camaldulensis*
	Oko et al. 2000	Calabar	*Enterolobium cyclocarpum, Dialium guianense, Sesbania macrantha*
	Odurukwe 2004	Uzuakoli, Obehie, Isikwuato	*G. arborea, Mangifera indica, Citrus sinensis*
Reduction of wind erosion	Azeza and Omeje 1985	Sahel	(review)
	Okali et al. 1988	Nigeria	(review)
	Larbi et al. 1993	SE Nigeria	*A. cordifolia, Diallum guineense, Ficus capensis, Baphia nitida, Manniophytum fulvum, Homalium aylmeri, Glyphaea brevis, Rauwolfia vomitoria, L. leucocephala, G. sepium*
	Ruhigwa 1993	Onne	*D. barteri, A. cordifolia, S. siamea, Gmelina arborea*
Control of drought + desertification	Odigie and Obiaga 1990	Sundan, Sahel zone	(review)
	Radwanski 1969	Sokoto	*Azadirachta indica*
Increase of nutrient content	Jaiyeoba 1996	Zaria	*Acacia albida, P. bigloboza, Eucalyptus camaldulensis*
Delivery of nutrients by foliage	Uyovbisere and Elemo 2002	Zaria	*A. indica, Parkia biglobasa*
Increase of crop yields	Thampattii and Padmaja 1995		*A. indica*
Influence on soil properties + crop yields	Verinumbe and Okali 1985	Ibadan	*Tectona grandis*
	Verinumbe 1985	Maiduguri	*E. camaldulensis, A. indica*
	Verinumbe 1992	NE Nigeria	(review)
	Adegbehin and Omijeh 1991	Niger State	(review)
	Igboanugo et al. 1990	Kabama, Samaru, Guga	*E. citridodora, E. camaldulensis,*
	Adderley et al. 1997		*E. camaldulensis, A. indica*

crops with other annual crops to improve soil productivity and crop yields (table 6). For example, Odunze et al. (2004) determined the effect of grain legumes in legume/cereal treatments on soil properties in the arid ecosystem of northern Nigeria. The results showed that sole groundnut improved the soils' bulk density at the 0 to 10 cm depth (1.26 g cm^{-3}) better than sole maize (1.34 g cm^{-3}). The cultivation of legumes also resulted in better stability of soil aggregates in the topsoil, which generally reduces the erodibility of the soil. The highest mean weight diameter of peds developed was 0.63 mm obtained under soybean (*Glycine max*), followed by cowpea (0.58 mm), and sole maize (0.48 mm). Sole legumes and legume/maize treatments improved the soil nitrogen content (range between 65.6 and 84.8%) compared to sole maize treatments (5.9%). Investigations on the effect of intercropped root and tuber crops with cereals on soil properties were conducted by Ghuman and Lal (1991). They measured a moisture content of 14.5% to 14.7% in the top 20 cm of plots with maize, melon, and yam and from 12.7% to 14.2% on monocropped maize plots. The maximum soil temperature in the topsoil was also affected by intercropping as it was reduced by about 2°C to 9°C compared with temperature under sole maize. The increased moisture and reduced temperature in the topsoil of the intercropping system was attributed to the shading effect of the different crop species, which reduced water evaporation from the soil surface. Hulugalle and Ezumah (1991) and Olasantan et al. (1996) analyzed the effects of cassava-based cropping systems on earthworms and stated that these macro organisms were more active in intercropping than in monocropping systems. Field trials concerning the influence of intercropping systems on crop yields were made, for example, by Bbuyemusoke et al. (1985) (cereal + cotton (*Gossypium hirsutum*), Ifenkwe et al. (1989) (cereal + potato (*Solanum tuberosum*)), Kalabare and Momoh (1989) (cassava + maize + plantain (*Musa paradisiaca*), Unamma et al. (1991) (cassava + maize), Adeleye (1994) (cereal + soybean), and Singh and Tarawali (1997) (cereal + cowpea). Carsky et al. (2001) also worked on cowpea-cereal rotation systems in northern Nigeria. The grain yields of the leguminous crop planted in the early season was relatively high (400 to 700 kg ha^{-1}) since insect pressure and pest damages were reduced. The grain yields of maize planted in the second part of the same season was higher after the cultivation of legumes than after a grass fallow due to the additional nitrogen supply. They concluded that intercropping of early maturing cowpea varieties with maize can be a relatively productive low input system for the Guinea savanna.

Research on the herbaceous legumes *Aeschynomene histrix, Centrosema pascuorum, Lablab purpureus, Macrotyloma uniflorum,* or *Stylosanthes hamata* cultivated as live mulch in intercropping systems with cereals was conducted by Vanlauwe et al. (1998) and Odunze et al. (2002). The latter evaluated the soil erosion control potential of different treatments and collected 0.08 t ha^{-1} sediment from a plot with straw mulch, 0.17 t ha^{-1} from a plot with *M. uniflorum*, 0.24 t ha^{-1} from a plot with S. hamata, and 0.29 t ha^{-1} from a sole maize plot. Hence, the use of straw and *M. uniflorum* live mulch was recommended for enhanced soil conservation in the semi-arid northern zones of Nigeria.

The studies on intercropping systems indicate that multiple cropping generally contributes to erosion control. The increased coverage of the soil surface and the enhanced stability of soil aggregate reduce the erosivity of the rain and the erodibility of the soil. As the productivity of soils cultivated with different crop species is also increased, this measure is likely to be adopted as a soil conservation technology in the tropics.

Planting Pattern/Time. Planting pattern, plant density, and time of planting also play an important role in soil conservation (figure 3). Crops planted at close spacing or at a certain time provide a higher canopy during periods with high rainfall intensities and hence protect the soil from erosion. Literature on cropping pattern and planting schedules with regard to erosion control is rare, but records focusing on crop performance are numerous. Appropriate investigations on cereals, grain legumes, and root and tuber crops were made, for example, by Abolaji and Olsen (1988), Olasanta (1988), Prameela and Nair (1991), Craufurd (2000), Yusuf et al. (2004), and Udealor and Aseigbu (2005) (table 7). Observations made by Abolaji and Olsen (1988) showed that intercropped cereals were shorter and legumes taller than the monocropped controls. However, the risk of lodging of cereals and the percentage of barren crops increased when a certain density was exceeded. Yusuf et al. (2004) investigated the time of seeding and found that simultaneously seeding of sorghum and soybean led to optimum resource utilization and yield by both crops and that planting at different times might intensify the competition for the growth resources light, water, and nutrients. These examples show that plant densities also affect soil loss by influencing the height of crops and extend of surface coverage.

Figure 6
Intercropping (Ibadan, Oyo State).

It can be concluded that diverse crop management practices have various beneficial effects as erosion is reduced, the physical, chemical, and biological soil properties are improved, and crop production is increased. Additional advantages are a decreased risk of total crop failure and the suppression of weeds. As product diversification and higher crop yields help to ensure both subsistence and disposable income, polyculture is of huge economic value for the farmers (Kang 1993a). Carsky et al. (2001) recommended the cowpea-maize intercropping system as it can be a relatively productive low-input system for the savanna zone. Special knowledge on the selection of species and good crop management is needed when annual crops are planted between hedgerows of woody perennials and this makes alley cropping less attractive for farmers (Hauser et al. 2006).

Table 6
Studies on soil conservation by crop management: Intercropping.

Beneficial effect	Author(s)	Location	Species
Reduction of water erosion	Aina et al. 1979	Ibadan	*Z. mays* + *Manihot esculenta*
	Lal 1990	Ibadan	*Z. mays* + *M. esculenta*
Reduction of bulk density	Odunze et al. 2004	Zaria	*Z. mays* + *Arachis hypogaea*
Increase of aggregate stability	Odunze et al. 2004	Zaria	*Z. mays* + *Arachis hypogaea*
Increase of soil moisture	Ghuman and Lal 1991	Benin City	*Z. mays* + *Dioscorea rotundata* + *Citrullus lanatus*
Reduction of soil temperature	Ghuman and Lal 1991	Benin City	*Z. mays* + *Dioscorea rotundata* + *Citrullus lanatus*
Increase of earthworm activity	Hulugalle and Ezumah 1991	Ibadan	*M. esculenta* + *Z. mays*
	Olasantan et al. 1996	Ibadan	*M. esculenta* + *Z. mays*
Increase of crop yields	Bbuyemusoke et al. 1985	Ibadan	Cereal + *Gossypium hirsutum*
	Ifenkwe et al. 1989	Umuahia	Cereal + *Solanum tuberosum*
	Kalabare and Momoh 1989	Agbaaho	*M. esculenta* + *Z. mays* + *Musa paradisiaca*
	Unamma et al. 1991	Olokoro, Awka, Igbariam, Bori, Ogbakiri, Elimgbu	*D. rotundata, Z. mays* + *M. esculenta*
	Adeleye 1994	Ibadan	Cereal + *Glycine max*
	Singh and Tarawali 1997	Kano	Cereal + *Vigna unguiculata*

SOIL MANAGEMENT STRATEGIES

Conservation Tillage

Conservation tillage describes the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as key criteria (Lal 1990). The practices therefore range from reduced or no-till to more intensive tillage depending on several factors, such as climate, soil properties, crop characteristics, and socio-economic factors (Lal 1983).

Minimum Tillage. Minimum tillage describes a practice where soil preparation is reduced to the minimum necessary for crop production and where 15% to 25% of residues remain on the soil surface (Morgan 1995).

No-Till. No-till or zero-tillage is characterized by the elimination of all mechanical seed bed preparation except for the opening of a narrow strip or hole in the ground for seed placement. The surface of the soil is covered by crop residue mulch or killed sod (Lal 1983).

Ridge Tillage and Ridge Tying. Ridge tillage is the practice of planting or seeding crops in rows on the top, along both sides or in the furrows between the ridges which are prepared at the beginning of every cropping season. Tied ridging or furrow diking includes the construction of additional cross-ties in the furrows between neighboring contour ridges (Lal 1990).

Most smallholders in Nigeria still perform soil preparation manually by using hoes. Larger farms use plows and harrows pulled by tractors, which results in the complete inversion of the top 20 to 30 cm of the soil. Hence, ridging is very common all over Nigeria (figure 7), whereas tied ridging is primarily conducted in the semi-arid northern part of the country to conserve both soil and water in individual basins (Chiroma et al. 2006c).

Research on quantifying the effects of different tillage operations on runoff and erosion were conducted by Lal (1984). He recorded that soil loss was 42 times higher from the plowed watershed (5.5 t ha^{-1}) than from the no-till watershed (0.1 t ha^{-1}). Other erosion measurements on soil loss were made by Couper et al. (1979), Armon (1980), Olaniyan (1988), and Kirchhof and Salako (2000) (table 8). The latter collected 2.8 t ha^{-1} of sediment from plots with bare fallow, 1.8 t ha^{-1} from conventionally tilled plots, and 1.3 t ha^{-1} from plots without tillage. These results clearly show the suitability of conservation tillage as an effective soil erosion control measure through the protective effect of residue mulch.

Table 7
Studies on soil conservation by crop management: Planting pattern/time.

Beneficial effect	Author(s)	Location	Species
Improvement of crop performance	Abolaji and Olsen 1988	?	Z. mays + G. max
	Olasanta 1988	?	M. esculenta + Z. mays, V. unguiculata
	Prameela and Nair 1991	?	M. esculenta + V. unguiculata
	Craufurd 2000	Minjibir	Sorghum bicolour, Pennisetum glaucum + V. unguiculata
	Yusuf et al. 2004	Badeggi	S. bicolour + V. unguiculata
	Udealor and Aseigbu 2005	Umudike	M. esculenta + V. unguiculata

Investigations focusing on the influence of different tillage methodologies performed manually or mechanically on soil properties and crop yields are numerous in Nigeria. In particular, Lal carried out many field experiments in Ibadan and stated that soil surface management is the key for solving problems associated with the transition from traditional farming to more productive land use systems in the tropics (Lal 1982, 1983). He developed a tillage guide based on factors, such as soil moisture regime and texture, to assess the applicability of tillage and no-till practices for different tropical soils (Lal 1982) and specified tillage-based technological packages for sustainable soil management on small-scale and medium-sized farms in the tropics (Lal 1991). According to these studies, no-till and mulch farming are sustainable management technologies for the humid and sub-humid tropics, whereas rough plowing, tied ridging, and mulching are appropriate techniques for the semi-arid area.

Several studies showed that reduced and zero-tillage systems contribute to long-term maintenance of the soil structure as pores from root growth and the activity of the soil fauna and the soil aggregates from the previous years are less or not at all disturbed (Lal 1993b; Franzen et al. 1994). Onwualu and Anazodo (1989) mentioned a higher porosity of soils under conventional treatments (52.9%) than under no-till (40.3%) as tillage loosens the soil. But the larger pore volume of tilled soils is only temporary and collapses rapidly under the impact of rainfall and runoff during the rainy season. Soils with reduced tillage are characterized by less total pore space but have more stable fine pores and fewer air-filled pores than tilled farmland soils (Osunbitan et al. 2005). Analyses on soil aggregates under different tillage operations were made by Nurudeen (1992) and Adesodun et al. (2007), who showed that cultivation significantly reduced the macroaggregate fractions to smaller diameters. Armon (1980) recorded that aggregates from no-till plots were characterized by a higher stability (mean weight diameter method 3.60 mm, calculated after Van Bavel's (1949) method) than those from tilled plots (mean weight diameter 2.61 mm). Agele et al. (2005) published comparable results which show the contribution of reduced tollage to the maintenance of the soil structure.

Studies on the bulk density of surface soil layers showed differences according to the tillage methods. Armon (1980) found out that bulk density of the surface (0 to 5 cm) was significantly higher in conventionally tilled plots (1.35 g cm^{-3}) than in no-till plots (1.16 g cm^{-3}) before plowing and planting. Bulk density was reduced due to the loosening effect of tillage and increased again later as a result of the gradual compaction of soil particles resettling after soil preparation (Onwualu and Anazodo 1989). Changes in the bulk density of no-till treatments with mulch during the year were negligible, according to Ogunremi and Lal (1986). Tillage operations also affect the infiltration capacity and hydraulic conductivity of soils which has an impact on the amount of runoff and, hence, of soil loss. Lal (1997) observed the highest infiltration rate for no-till treatments (32 to 40 cm h^{-1}) and lower rates for plowing (22 cm h^{-1}). Comparable results were observed by Aina et al. (1991) and Kayombo and Lal (1993). The saturated hydraulic conductivity of the 0 to 5 cm layers in the no-till plots was also higher than in the conventionally treated plots (Maurya and Lal 1980a; Ogunremi et al. 1986). Studies on the influence of different tillage methodologies on the soil moisture content were made by Lal (1976b, 1986b), Ojeniyi (1986), Opara-Nadi and Lal (1987), and Amezquita et al. (1993). They all recorded that the moisture content was higher in the surface soil of no-till plots than in treatments prepared with tillage machines. For example, Lal (1986b) measured soil moisture content of 15.4% to 17.5% in the top 10 cm of the soil on plots with no-tillage and 10.9% to 15.5% on tilled plots 58 days after the seeding of maize. Studies on the influence of different kinds of tillage operations on the soil temperature showed contrasting results. Obi and Nnabude (1988) stated that soil temperatures did not differ significantly on plots with different treatments, whereas Lal (1995a) found reduced soil temperatures on the field with conservation tillage as

Figure 7
Ridging (Badume, Kano State).

the surface was covered with mulch. The more favorable moisture and temperature conditions in plots with reduced or no tillage also have beneficial effects on the activity of the soil fauna, such as earthworms. These soil organisms reduce compaction and crust formation, construct macropores, and contribute to an improved soil structure by the formation of stable aggregates. These processes improve the infiltration rate for rainwater and reduce the erodibility and, hence, the erosion of the soil (Lal 1982, Aina et al. 1991).

In addition, the content of organic carbon and nitrogen was maintained at significant higher levels in the surface soil of untilled systems than in tilled systems. For example, Armon (1980) measured an organic carbon content of 1.7% in no-till and 1.1% in conventionally tilled treatments and attributed this to the slower decomposition rate of the mulch left on the soil surface compared to the crop residues incorporated by tillage operations. The maintenance or increase of the organic matter by conservation tillage is a basic ingredient in maintaining soil productivity and the stability of systems according to Lal (1982). Investigations on the impact of different tillage operations on crop yields are numerous and were conducted by Hulugalle et al. (1985), Maurya (1986, 1988b), Oni and Adeoti (1988), Lal (1978c, 1995b, 1997), Olaoye (2002), and Anikwe et al. (2007b). The results are different. For example, Lal (1986b) observed increased maize grain yields on plots with no-till treatment (2.5 t ha^{-1}) compared with the plow-till treatment (2.0 t ha^{-1}) in southwest Nigeria. Maurya (1988b) conducted comparable field trials in northern Nigeria. He stated higher crop yields in the residue plots (4.4 t ha^{-1}) than in the conventionally treated plots (3.9 t ha^{-1}) from Kadawa site but contrary results from Bakura site where the grain yield were generally lower in no-till than in conventional tillage systems. Ogunremi et al. (1986) affirm that a continuous no-till system is applicable in lowlands and feasible for the intensive use of tropical wetlands, so it might be of interest in increasing rice production.

However, as mentioned above, different tillage operations are necessary in locations with unfavorable climatic conditions or problematic soils (table 9). Water harvesting is important in arid and semi-arid areas with erratic and small rainfalls. The construction of ridges or tied ridges with a series of small basins is a useful technology for the collection and storage of rainwater in dry areas (Lal, 1991, Chiroma et al. 2006c) (table 10). Alhassan et al. (1998) and Chiroma et al. (2005a) conducted field trials on improving rainwater harvesting by in northern Nigeria and recorded that no-tilled flat beds with mulch appeared to be a viable alternative to the farmers' practice of planting crops on either ridge-tilled or flat bed without residue mulch. But as mulching material is generally rare in semi-arid areas, the applicability of this technology is limited. Destroying surface crusts or compactions that prevent rainwater from infiltrating into the soil and plant roots from penetrating different layers by plowing is of great importance (Lal 1991). Takken et al. (2001) recorded that the use of tillage implements was more effective than no-till for each level of compaction. According to him, the germination and yield of cotton were higher on compacted plots treated by disk harrowing or plowing than on plots without any tillage. Hence, arable land

Table 8
Studies on soil conservation by soil management: Minimum tillage and no-till.

Beneficial effect	Author(s)	Location	Equipment for comparing tillage operations
Reduction of water erosion	Lal 1984	Ibadan	Mouldboard plow + disc harrow
	Couper et al. 1979	Ibadan	Plow
	Armon 1980	Ibadan	Plow + harrow
	Olaniyan 1988	Mokwa	Plow + harrow
	Kirchhof and Salako 2000	Ibadan	Rotovator + disc plow + harrow
Long-term maintenance of the soil structure	Lal 1993b	Ibadan	(overview)
	Franzen et al. 1994	Ibadan	Disc plow
	Onwualu and Anazodo 1989	Nsukka	Disc plow + disc harrow; rotary tiller, chisel plow
Increased stability of fine pores	Osunbitan et al. 2005	Ile-Ife	Hoe, disc plow, plow + harrow
Increased aggregate stability	Armon 1980	Ibadan	Plow + harrow
	Nurudeen 1992	Ile-Ife	Plow
	Agele et al. 2005	Akure	Plow + harrow
	Adesodun et al. 2007	Abeokuta	?
Reduction of bulk density	Armon 1980	Ibadan	Plow + harrow
Improvement of infiltration rate + hydraulic conductivity	Lal 1997	Ibadan	Disc plow, chisel plow, rotovator, harrow
	Aina et al. 1991	W Africa	(review)
	Kayombo and Lal 1993	Africa	(review)
Improvement of saturated hydraulic conductivity	Maurya and Lal 1980a	Onne	Disc plow + harrow
	Ogunremi et al. 1986	Ibadan	Plow, rotovator
Increase of soil moisture content	Lal 1976b	Ibadan	Disc plow + harrow
	Lal 1986b	Ibadan	Mouldboard plow + harrow, disc plow + rotovator
	Ojeniyi 1986	Ila-Orangun	Disc plow
	Opara-Nadi and Lal 1987	Onne	Disc plow
	Hulugalle 1994	Ibadan	Disc plow
	Amezquita et al. 1993	Ibadan	Disc plow + harrow
	Anikwe et al. 2007b	Enugu	Hoe
Increase of soil temperature	Obi and Nnabude 1988	Nsukka	Hoe
	Lal 1995a	Tropics	(review)
Increase of activity of soil fauna	Lal 1982	Tropics	(review)
	Aina et al. 1991	W Africa	(review)
Increase of root density	Maurya and Lal 1979	Ibadan	Disc plow + harrow
Maintenance/increase of content of organic	Lal 1974	Ibadan	Disc plow + harrow
carbon + N	Armon 1980	Ibadan	Plow + harrow
	Aiyelari et al. 2002	Ibadan	Hoe, disc ridger
Increase of crop yields	Hulugalle et al. 1985	Onne	Disc plow
	Maurya 1986	Kadawa	Disc plow + harrow
	Ogunremi et al. 1986	Onne	Plow
	Oni and Adeoti 1988	Zaria	Disc harrow, mouldboard plow + disc harrow, disc plow
	Lal 1986a	Ibadan	Rotovator
	Lal 1986b	Ibadan	Mouldboard plow + harrow, disc plow + rotovator
	Lal 1997	Ibadan	Disc plow, chisel plow, rotovator, harrow
	Olaoye 2002	Ilorin	Disc harrow, mouldboard plow + disc harrow, disc plow + disc harrow
	Agbede 2006	Owo	Hoe
	Anikwe et al. 2007a	Enugu	Hoe
Constraints			
Not sufficient mulching material	Kayombo and Lal 1993	N Nigeria	–
Reduction of crop yields due to weed problems	Maurya 1988b	Bakura	–

compacted—for example, by repeated tractor passes—needs to be loosened periodically by mechanical tillage (Lal 1982, 1985). Aeration of clayey soils with poor drainage conditions or during wet periods is also improved by ridging and especially supports the production of root and tuber crops (Kowal and Stockinger 1973). Eziakor (1990) recommends ridge tillage also for shallow soils, where hardpan seriously restricts root development and crop production. The accumulation of soil material increases the rooting zone and the mixture of the topsoil with nutrients and moisture from the subsoil facilitates the growth of crops in addition. Ojeniyi and Adekayode (1999) tested several mechanical and manual tillage techniques to analyse their influence on crop production. They got the highest grain yield from cowpea (0.9 t ha^{-1}) and maize (1.5 t ha^{-1}) on plowed fields with ridges followed by no-till, manual heaping, and manual ridging. Braide (1986), Akinyemi et al. (2003), and Agbede (2006) also state that a ridge tillage system gave higher outputs in yield and economic benefit than the no-till system.

Attention has to be paid when ridge tillage is conducted on hillsites. Lal (unpublished) measured a soil loss of 8.0 t ha^{-1} from plots with cassava planted on ridges leading downslope, and 4.4 t ha^{-1} from flat plots with maize. This obviously shows the possible negative impact of this kind of tillage on soil loss. Contour ridging, the preparation and cultivation across the slope, is a simple approach to erosion control in areas with small slope gradient but its effectiveness decreases with an increase in slope gradient, slope length, and increasing rain intensity. As contour ridges are easily destroyed by concentrated overflow, this technology is not sufficient to control runoff and soil loss on steep slopes or in areas with high rainfall erosivity (Lal 1995a). Soils with high erodibility factor that are characterized by a high percentage of fine sand and silt tend to be problematic soils for ridge tillage as they are more susceptible to water erosion if not covered with residues or crops (Lal 1993).

The numerous studies on conservation tillage emphasize reduced tillage and no-till as feasible erosion control measures since structural soil properties are maintained or enhanced and soil water transmission improved to reduce runoff and soil loss. Additional effects are enhanced soil fertility as the contents of organic matter and nitrogen are raised and an increase in the activity of soil organisms due to a favorable soil climate. Tillage remains important when the surface crusts or when compacted layers or poor drainage reduce infiltration. Hence, a site-specific soil treatment ought to be chosen, depending on the objectives to alleviate specific constraints and to be fitted into the local farming systems by being adapted to the different soils, crops and agro-ecological regions (Lal 1982).

MECHANICAL METHODS

Mechanical methods, including bunds, terraces, waterways, and structures such as vegetative barriers or stone lines installed on farm also can break the force of winds or decrease the velocity of runoff to reduce soil erosion (Morgan 1995).

Terraces

Contour bunds made of earth or stones or terraces that consist of an excavated channel and a bank or ridge on the downhill side for cultivating crops are permanent erosion control technologies (Morgan 1995, Lal 1995a). The first are installed across slopes of low gradients (figure 8), the latter at right angles to the steepest slope in hilly areas. Research on contour banks was conducted by Couper (1995), who considered these measures to be useful to prevent gully erosion, the most spectacular type of erosion. He also prepared an implementation guide for farmers including the description of the design and construction of graded contour banks. Field trials on terraces made by Lal (1995a) in Ibadan showed that the mean soil loss from a catchment without any erosion control measures was 2.3 t ha^{-1} and from a terraced catchment, 0.7 t ha^{-1}. Terraces were also built in Mokwa (Palmer 1958), in the Pankshin area on the Jos Plateau (Longtau et al. 2002), and at Maku near Udi-Nsukka (Igbokwe 1996) (table 11). The records state that permanent structures of these kinds are effective soil conservation technologies as excessive soil loss and silting up of the fields are reduced. However, high labor intensity, time-consuming regular inspections, high consumption of scarce farmland, and the large amounts of construction material required are factors that stop farmers from installing or maintaining terraces (Igbokwe 1996).

Waterways

Waterways such as cut-off drainage (figure 9) are permanent structures that aim to collect and guide excess runoff to suitable disposal points. They are constructed along the slope, often covered with grass to prevent destruction, and primarily installed in areas with high rainfall rates (Morgan 1995). Literature on investigations into drainage systems is rare in Nigeria. The implementation probably needs special knowledge of the water regime of the area and the construction of waterways (Lal 1995a).

Table 9
Studies on soil conservation by soil management: Ridging.

Beneficial effect	Author(s)	Location	Equipment for comparing tillage operations
Reduction of water erosion in areas with low slope gradient	Lal 1995a	Ibadan	(review)
	Malgwi 1992	Borno State	Hoe
Reduction of compaction	Lal 1982	Tropics	(review)
	Lal 1985	Tropics	(review)
Increase of nutrient content by deep ploughing	Eziakor 1990	Kurmin Biri reserve	Hoe, disc harrow
	Ojeniyi and Adekayode 1999	Akure	Hoe, plow + harrow
	Braide 1986	Nigeria	(review)
	Akinyemi et al. 2003	Ago-Iwoye	Plow
Increase of crop yields	Okigbo 1979	Nsukka	Hoe
	Ogban and Babalola 2002	SW Nigeria	Hoe
	Agbede 2006	Owo	Hoe
Increase of aeration of roots during wet periods	Kowal and Stockinger 1973	Nigeria	(review)
Constraints			
Increase of water erosion on steep slopes, area with high rain erosivity, erodibility of the soil	Lal 1993	Nigeria	—
	Lal 1995a	Nigeria	—

Table 10
Studies on soil conservation by soil management: Ridge tying.

Beneficial effect	Author(s)	Location	Equipment for comparing tillage operations
Reduction of water erosion	Chiroma et al. 2006c	N Nigeria	(review)
Improvement of rainwater harvest	Alhassan et al. 1998	Maiduguri	Hoe, harrow
	Chiroma et al. 2005a	Maiduguri	Hoe
Increase of crop yields	Chiroma et al. 2005b	Maiduguri	Harrow

Structures

Structural barriers made of stones or vegetation installed along contour lines are another mechanical erosion control measure (Morgan 1995). As they operate as filters, they may not reduce the runoff amount but retard its velocity and hence encourage sedimentation, increase infiltration, and facilitate the formation of natural terraces (Lal 1990). Vegetative barriers are usually constructed as single lines or in the form of strips of several meters wide. Malgwi (1992, 1995) investigated the effectiveness of vetiver (*Vetiver zizanioides*), a perennial grass with a deep and fibrous root system, in northern Nigeria. He recommends this grass as an appropriate soil conservation technology for semi-arid zones as it also withstands denudation, fire, drought, and flood. Records on on-farm trials with vetiver in the derived savanna were also made by Kolade (2006) who emphasised the beneficial effects on soil conservation and economic advantages. Lal (1995) published a list of grass species commonly used for establishing vegetative hedges in the humid tropics and stated the thick root systems prevent rilling, gullying, and tunnelling. References on the use of stone lines installed as barriers on the field were not found in this study. In general, mechanical measures are effective soil conservation technologies as they reduce soil loss. But as the installation and maintenance is usually labor-intensive, these structures are not likely to be adopted by farmers.

Figure 8
Contour bunds (Ibadan, Oyo State).

OTHER APPROACHES

Studies on simulation models, remote sensing, and geographic information systems (GIS) are modern technologies that focus on better land use planning and proper soil management, and improve the knowledge on soil conservation in Nigeria (table 12). For example, Igwe (1999a) used the Soil Loss Estimation Model for Southern Africa (SLEMSA) to quantify erosion and produced a soil erosion hazard map of Anambra/Enugu states based on the results. He also estimated the erodibility of soils in Southeast Nigeria (Igwe 1999b, 2003), defined different categories of areas with potential erosion hazards, and developed suitable land use options including arable farming, agroforestry and intensive aforestation. The Sediment Off-loading Model (SOM), Tectonic Origin Model (TOM), and Soil Erosion Model (SEM) were tested by Egboka and Orajaka (1987) to improve the understanding and application of these models

Table 11
Studies on soil conservation by mechanical methods.

Technology	Beneficial effect	Author(s)	Location	Measure
Contour bunds	Interception of water running downslope	Couper 1995	Nigeria	(guide for installation)
Terraces	Prevention of runoff, erosion	Palmer 1958	Mokwa	Earth bunds (50 yd wide, 1,500 ft long)
		Lal 1995a		
		Longtau et al. 2002	Pankshin + Kanko area	Stone walls
		Igbokwe 1996	Maku near Udi-Nsukka	Wtone walls (up to 35 cm thick)
Waterways				
Structural barriers	Vegetative barriers	Malgwi 1993	Borno State	*Vetiver ssp.*
		Malgwi 1995	Borno State	*Vetiver ssp.*
		Lal 1995		
		Kolade 2006	Oshogbo	*Vetiver ssp.*

Figure 9
Waterways (Esa Oke, Osun State),.

to find solutions to problems posed by widespread soil and gully erosion. Ehui et al. (1990) conducted an economic analysis of erosion to suggest appropriate measures for land management.

The interpretation of remote sensing data, such as aerial photographs and satellite images, is another useful tool that has been used to compile an inventory of land use and soil degradation and to monitor changes of land use and erosion within time at different scales. For example, Gobin et al. (2002) combined the analyses of aerial photograph with participatory rural appraisal and logistic modelling to elicit spatial determinants and to model agricultural land use. The results could be incorporated into a land use framework for planning purposes, scenario analysis or impact assessment at the local government level according to the authors. Ologe (1978) produced a map on the distribution of gullies in the area of Zaria, northern Nigeria, by interpreting aerial pictures. Studies based on the satellite images LANDSAT TM and NIGERIASAT-1 were made by Ayeni et al. (2004). He compared the images made in 1986 and 2003 and detected erosion of the Lagos coast line. Igbokwe (2004) also worked on the interpretation of NIGERIASAT-1 and recorded its feasibility for mapping and monitoring gully erosion in southeastern Nigeria.

The studies show that the modern technologies all improve the understanding of land use, soil degradation, and its consequences and may provide solutions to the problems. Widespread implementation in governmental institutions is still a problem as the equipment and trained staff are often lacking.

SUMMARY AND CONCLUSIONS

This review shows that past and present soil conservation measures in Nigeria have resulted in various technologies implemented on farm and off farm. Indigenous measures focused on soil and water conservation by ridging, constructing earth bunds and terraces, mulching, multiple cropping, fallowing, and tree planting.

According to the literature, soil conservation measures should be site-specific depending on the local factors such as topography, soil texture, water regime, and farming system.

Mulching, crop management, and conservation tillage are appropriate technologies for conserving sandy soils of high erosivity and low water-holding capacity. Leguminous cover crops and residue management reduce the impact of rain, which is especially high in the tropics, and trap and store soil moisture. These measures also enhance the levels of soil organic matter and nutrients, especially nitrogen, which is generally limited in tropical soils.

Intercropping of compatible species is recorded as a promising cropping system, as cultures with different rooting patterns and growth cycles can promote nutrient cycling and suppress weeds. Economic benefits also result from polyculture due to product diversification and reduced risks of crop failure.

Alley cropping is regarded as an effective erosion control measure but is not practiced on farm in Nigeria as this technology is very labor intensive and the benefits on soil fertility did not materialize as expected.

Research on reduced tillage has shown its beneficial effect on physical, chemical, and biological soil properties. However, the application of reduced tillage is problematic on soils with poor drainage, surface crusts, or compacted layers that still require periodic soil preparation to enhance infiltration. Conservation tillage operations that use the effect of surface covers or increased roughness to reduce erosion risks ought to be chosen according to factors such as rainfall, crop, texture, depth, and drainage conditions of the soil. Minimum tillage and no-till are effective erosion control measures on coarse- and medium-textured soil with good drainage, whereas ridge tillage is advantageous in areas with low or variable rainfall, shallow soils and where root and tuber crops are cultivated.

Tree plantations in gardens or on boundaries are common and show benefits for soil conservation and economic issues. Permanent mechanical methods for conserving the soil are rare, as implementation and maintenance are time, labor, and cost intensive and success is visible only after long periods.

Table 12
Studies on soil conservation by other approaches.

Technology	Beneficial effect	Author(s)	Location	Approach
Simulation models	Increase of knowledge on soil erosion hazards	Igwe 1999a	Anambra + Enugu State	Soil Loss Estimation Model for Southern Africa (SLEMSA)
				Universal Soil Loss Equation (USLE)
				Map of erosion hazard
		Igwe 1999b	Anambra + Enugu State	Estimation of soil erodibility
				Map of potential erosion hazards, suitable land use options
		Igwe 2003	SE Nigeria	Estimation of soil erodibility
		Egboka and Orajaka 1987	Agulu-Nanka gully system	Sediment Off-loading Model (SOM)
				Tectonic Origin Model (TOM)
				Soil Erosion Model (SEM)
		Ehui et al. 1990	Ibadan	Economic analysis of erosion
Remote sensing	Increase of knowledge on environmental changes and its results	Ologe 1978	Zaria area	Analyses of aerial photograph
				Map on gully distribution
		Gobin et al. 2002	SE Nigeria	Analyses of aerial photograph, rural appraisal, modelling of agricultural land use
		Ayeni et al. 2004	Lagos coast line	Analyses of LANDSAT TM, NIGERIASAT-1
		Igbokwe 2004	SE Nigeria	Analyses of NIGERIASAT-1 to map, monitor gully erosion
		Rotimi 2004	Kano State	Analyses of NIGERIASAT-1 to map environment
		Junge (unpubl.)	Badume, Kayawa, Gadza	Analyses of aerial photographs, IKONOS, QuickBird to map, monitor land use intensification and soil erosion

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