Chapter 8

Tillage systems and agricultural sustainability

Agricultural sustainability implies increasing *per caput* productivity to meet present needs without jeopardizing future potential. The strategy is to use natural resources to enhance progressively the productive capacity and life support processes of an ecosystem without adverse effects on the environment. With this perspective, an important issue relevant to tropical ecosystems concerns achieving sustainability on the basis of minimum inputs. Input is a relative term. At present, tropical agriculture is mostly based on little or no commercial input. In contrast, agriculture in North America and Western Europe is heavily dependent on them. Ecologically, no-input agriculture can be as harmful to the economy and tropical environment as are excessive inputs and intensive agriculture. Whilst farmers in North America must take steps to reduce inputs, subsistence farmers in the tropics can achieve substantial yield improvements by marginal increases in added inputs.

Sustainable agriculture aims to optimize the use of energy-related inputs. High crop yields are, however, possible if non-industrial inputs are increased. These include improved cultivars, new crops, efficient cropping systems, improved tools, increased fertilizer-use efficiency and systems of integrated pest management. Such inputs accord with the principles of good farming and land stewardship. Good farming, by this definition, is that which is ecologically, economically and culturally compatible.

TILLAGE AND SUSTAINABILITY

Tillage plays a major role in agricultural sustainability through its effects on soil processes, soil properties, and crop growth (Figure 57). Tillage may enhance or curtail these processes depending on initial conditions and the type of tillage tools used. Tillage affects agricultural sustainability through its long-term effects on the life-support processes of the soil, including soil structure, soil organic matter content, rate and capacity for supplying water and nutrients to crops, soil productivity and economic profitability. An important effect of tillage on sustainability is through its impact on the environment, for example on soil degradation, and pollution of surface and groundwaters. While conservation tillage can reduce soil erosion, it may increase risks of water pollution through increased use of pesticides, fertilizer and other agricultural chemicals. In contrast, plough-till systems may enhance risks of soil erosion, increase rates of mineralization of soil organic matter, and accentuate emission of “greenhouse” active gases from soil-related processes.

There is now a greater need to attain agricultural sustainability than ever, especially in the fragile ecosystems and marginal lands of the topics and subtropics. These are found mainly on the semi-arid, arid and humid tropics, and

FIGURE 57
Tillage effects on agricultural sustainability (Lal, 1991b)

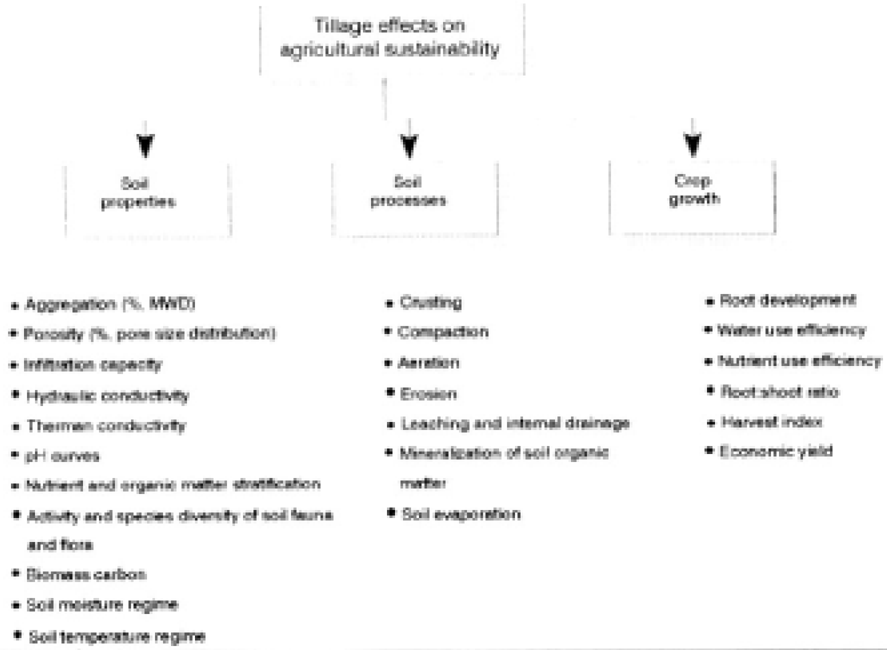


TABLE 144
Issues of agricultural sustainability in fragile lands of marginal ecoregions (Lal, 1991b)

Region	Issues
Humid tropics	• High subsistence agricultural usage of the land • Reduction in fallow period • Soils of low fertility and low yields due to resource-based and no-input agriculture • Soil degradation due to fertility, depletion, accelerated erosion, structural deterioration and reduction in soil organic matter
Arid and semi-arid tropics	• Risks of desertification due to degradation and aridization of soil and environment • Perpetual drought stress • High risks of crop failure • Nutrient deficiency and soils of low fertility • Soil compaction • Low carrying capacity of land
Irrigated agriculture in dryland tropics	• Water shortage • Salt imbalance and salinization • Poor quality irrigation water • Deterioration of soil structure
Steeplands	• Accelerated soil erosion, mass movement and land slides • Shallow soils of low fertility • Difficulties of mechanizing farm operations • Energy shortage • Low carrying capacity and low yields

TABLE 145
Tillage and soil surface management effects on indices of agricultural sustainability (Lal, 1992)

Level of sustainability	Index of sustainability influences by soil tillage
Plant/crop	Agronomic yield
Cropping system	Productivity
Farming system	Profit, income, resource and environment quality
Region/community	Supply, off-farm income, comparative advantage, environmental quality
Nation	Gross national product (GNP), resource sustainability, trade status
International	*Per caput* calorie intake

on steepland in all regions (Table 143). The productivity and land carrying capacity of such areas are low, but demographic pressures and demands on the limited resources are high. As a consequence, resources are used to the limit, and the risks of soil and environmental degradation are great. Issues of agricultural sustainability in these areas, especially those relevant to soil tillage, are shown in Table 144. High risks of soil degradation (due to erosion, compaction, deterioration of soil structure, and decline in soil organic matter content), low soil productivity, and low carrying capacity of land are widespread problems. The risks of soil and environmental degradation are accentuated by the resource-based and low-input agriculture widely practised.

Adoption of proper tillage systems and techniques of soil management can help attain agricultural sustainability by reversing the degradative trends and restoring the productive capacity of the soils. Soil tillage and conservation-effective technologies influence sustainability at different levels (Table 145). Soil tillage influences sustainability at crop level through its effect on agronomic yield, at cropping system level by influencing productivity, and at farming system level by enhancing profitability. Specific tillage-based technologies for sustainable management of soil and water resources are outlined in Table 146. These are based on the principles of conserving soil and water resources, preventing or minimizing degradation of soil and environments, restoring degraded lands and reducing dependence on off-farm purchased inputs while enhancing productivity and increasing profitability. The overall objective is to increase yields, generate income and transform subsistence farming into commercial agriculture.

Soil tillage is a basic part of agricultural production technology. In addition to preparing the desired seedbed, tillage is needed to manage crop residue, eradicate weeds and reduce pest incidence, mix fertilizer with the soil, improve aeration, alleviate compaction, and optimize soil temperature and moisture regimes. The exact nature of appropriate tillage operations depends on soil and crops (Lal, 1985b). Examples of suitable tillage methods for agricultural sustainability on small and medium sized farms in the tropics are listed in Tables 147 and 148. Specific components or sub-systems of tillage-based technologies in relation to sustainability are described in the section below.

SYSTEMS APPROACH TO TILLAGE METHODS

The effectiveness of conservation tillage on soil and water conservation and resource management is greatly enhanced by adopting a systems approach. There are strong interactions between various aspects of agricultural technology. A holistic approach views tillage as an integral part of a whole system. Conservation tillage requires a

TABLE 146

Specific technologies for sustainable management of soil and resources for tropical ecological regions (Lal, 1983)

Humid	Sub-humid	Semi-arid	Arid
Soil management systems for improving water use efficiency			
• Mulch farming • No-till • Manual clearing • Drainage and water management • Erosion control • Water harvesting	• No-till • Mulch farming • Contour ridges • Agroforestry • Drainage and water management	• Rough ploughing • Tied ridges • Mulch • Micro-catchments • Diggets • Contour bunds • Grass hedges • Vetiver • Fallowing • Early planting • Salinity control • Irrigation • Water harvesting	• Water harvesting • Fallowing • Early planting • Grass hedges • Vetiver • Salinity • Irrigation • Water conservation
Soil/crop management systems for increasing nutrient use efficiency			
• Perennial crops • Root crops • Agroforestry • Mulch farming • Fertilizers • *In situ* burning • Drainage and water management	• Cover crops • Mulch farming • Agroforestry • Mixed cropping • Crop rotations • *In situ* burning • N and P fertilizers • Drainage and water management	• Manure/kralling • Mulch farming • Cover crops • Relay-mixed cropping • N and P fertilizers • Irrigation • Leaching and salinity control	• Manure/kralling • Irrigation • Water harvesting • N and P fertilizers • Salinity and sodicity control

special set of cultural practices that may be different than those needed for a plough-till system. Some crops and varieties are more suited to conservation tillage than others. The rate, time, mode and type of application of fertilizers and other amendments are likely to be different, as are measures for pest control. Conservation tillage also requires different seeding equipment and farm machinery to manage the uneven and trashy soil surface. Some crop rotations and farming systems are better suited to conservation tillage than others. Mulching is a key technique in conservation tillage, so cultural practices that ensure the availability of large quantities of residue mulch are most compatible. Vehicular traffic must be so used to reduce the risks of soil compaction. At harvest time method, time and type of equipment may affect soil compaction. Conservation tillage, therefore, is a package of cultural practices that are specifically developed and adopted to conserve soil and water resources, sustain high and satisfactory returns, minimize degradation of soil and environment, and preserve the soil resource. The interrelationship between conservation tillage and supportive cultural practices is shown in Figure 58. Some of the cultural practices specifically developed to enhance the effectiveness of conservation tillage are described below.

Agroforestry and alley cropping

Agroforestry is a technique of growing food crop annuals in association with woody perennials to optimize the use of natural resources, minimize the need for inputs from nonrenewable resources and reduce the risks of environmental

TABLE 147
Some examples of tillage-based technological packages for sustainable management of soil and water resources on small farms (less than 5 ha) in the tropics (Lal, 1991b)

Structurally active soils	Structurally inert soils
Grain crop/cover crop rotation	
• Conservation tillage mulch farming • Strip cropping • Chemical fertilizers (supplementary) • Water management • Irrigation	Conservation tillage and water management options will differ as follows: • Contour ridges • Tied ridges • Periodic subsoiling or chiselling
Grain crop/alley cropping systems • Conservation tillage • Chemical fertilizers (supplementary) • Water management • Irrigation	
Ley/mixed farming • Conservation tillage grain crop-pasture rotation • Growing woody perennials to supplement food • Reservoirs for runoff storage • Organic manures • Chemical fertilizers (supplementary) • Drainage and irrigation • Water harvesting	
Agroforestry systems Same as crop-pasture rotation but pasture replaced by shrubs and woody perennials Smallholder plantations Cover crops (kudzu, Centro, etc.) Tangya system Chemical fertilizers Supplementary irrigation	

degradation. A range of woody plants and numerous agricultural crops are grown in one or another form of agroforestry in the tropics (King, 1968). The most common tree species used are *Nauclea diderrichii, Lovoa trichilioides, Khaya ivorensis, Acacia, Erythrina, and Tectona grandis*; woody perennials include *Leucaena, Gliricidia, Flemingia* and *Caliandra*.

Alley cropping is a form of agroforestry in which annual food crops are grown between adjacent hedgerows of leguminous shrubs and woody perennials (Kang *et al*., 1981; 1985). The woody perennials are regularly pruned to limit shading and to provide nitrogen-rich mulch for the food crop annuals. Satisfactory crop yields are obtained provided that compatible species are chosen, and that the plant available reserves of soil-water are sufficient to meet the evapotranspiration needs of both species. The system is best suited to humid and sub-humid regions in which precipitation exceeds evapotranspiration during the growing season. At present, the system is labour-intensive and is suited more for resource poor farmers than for large-scale commercial farming. Maize-*Leucaena* alley cropping can be economic if hired labour is available at low cost (Guy *et al*., 1984).

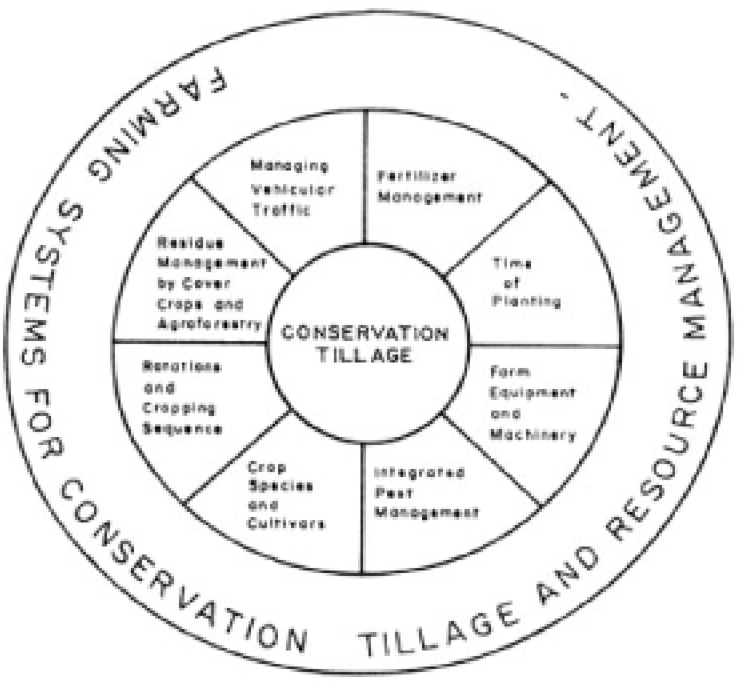
TABLE 148

Some examples of tillage-based technological packages for sustainable management of soil and water resources on medium-sized farms (5-25 ha) in the tropics (Lal, 1991b)

Structurally active soils	Structurally inert soils
Grain crop/cover crop rotation	
• Conservation tillage with herbicides and periodic loosening to alleviate compaction • Chemical fertilizers • Planting trees or woody perennials at 1 m intervals • Water management	• Contour ridges • Terraces and waterways • Engineering structure • Water management • Supplementary irrigation
Grain crop/pasture rotation	
• Water harvesting and reservoirs • Conservation tillage with herbicides • Tree hedges at 1 m intervals • Chemical fertilizers • Drainage and irrigation	• Water reservoirs and engineering structures • Supplementary irrigation • Tied-ridge or basin tillage • Water management
Plantation and cover crops	
• Erosion control • Fertilizer management • Drainage and irrigation	• Erosion control on access roads • Fertilizer management • Water harvesting • Supplementary irrigation

FIGURE 58

System approach to conservation tillage



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