Improving the Sustainability of Dryland Farming Systems: A Global Perspective

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I. Introduction

Arid and semiarid regions comprise almost 40% of the world's land area and are inhabited by some 700 million people. Approximately 60% of these drylands are in developing countries. Low rainfall areas constitute from 75–100% of the land area in more than 20 countries in the Near East, Africa, and Asia. Farmers in these regions produce more than 50% of the groundnuts, 80% of the pearl millet, 90% of the chickpeas, and 95% of the pigeon peas. These dryland areas will continue to produce most of the world's food grains for expanding populations in the years ahead. However, yields are extremely low compared with those of the humid and subhumid regions. In some countries of sub-Saharan Africa and the Near East food grain production per capita has declined significantly during the past decade. Although part of this decline can be attributed to high rates of population growth, periodic drought, and unfavorable agricultural production and marketing policies of the national governments, much of it results from the steady and continuing degradation of agricultural lands from soil erosion and nutrient depletion and the subsequent loss of soil productivity (FAO, 1986; Dregne, 1989).

Many of these dryland areas are typified by a highlv fragile natural resource base. Soils are often coarse-textured, sandy, and inherently low in fertility,

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organic matter, and water-holding capacity and easily susceptible to wind and water erosion. Runoff losses during rainfall events commonly exceed 50%. Rainfall patterns are erratic and unpredictable, and crops can suffer from moisture deficits and drought even during normal rainfall periods.

About 75% of the crops produced in the Near East region are grown under dryland or rainfed conditions. It is estimated that more than 70% of the projected food and feed deficit by the year 2000 must come from increased yields on established croplands since very little new arable land is available for agricultural development. The situation is much the same in India, where some 45% of the total crop production now comes from drylands. By the end of this century this amount will have to increase to about 60% if India is to provide adequate food and fiber for a projected population of nearly one billion people by the year 2000 (Indo-U.S. Subcommission Report, 1987; Singh, 1989).

The development of productive, profitable, and environmentally sound farming systems for the U.S. drylands of the Great Plains and Pacific Northwest has become a high priority of U.S. agricultural research. The Agricultural Research Service of the U.S. Department of Agriculture (USDA) has committed major resources for research to improve soil, water, and crop management practices for dryland agriculture in the United States. There is a growing number of scientist-to-scientist linkages between the United States and developing countries which are fostering cooperative research on problems of mutual concern. Such research has become even more important in recent years because of the increased economic and environmental costs associated with irrigated agriculture (Steiner et al., 1988; Singh, 1989; Stewart et al., 1990).

II. The Concept of Sustainability

"Sustainable agriculture" according to Lockeretz (1988) is a loosely defined term that encompasses a range of strategies for addressing many of the problems that afflict U.S. agriculture and agriculture worldwide. Such problems include loss of soil productivity from excessive erosion and associated plant nutrient losses; surface and groundwater pollution from pesticides, fertilizers, and sediment; impending shortages of nonrenewable resources; and low farm income from depressed commodity prices and high production costs. Furthermore, "sustainable" implies a time dimension and the capacity of a farming system to endure indefinitely (Lockeretz, 1988).

Two recent initiatives by the U.S. government to further the concept and understanding of sustainable agriculture are noteworthy. One was the Research and Education Program to promote Low-Input/Sustainable Farming Systems (USDA, 1988) and the other was the widely heralded book on *Alternative Agriculture* which discusses the role of alternative farming methods in modern production agriculture (National Research Council, 1989). This concept is illustrated in Figure 1 which has been adapted from Dr. Neill Schaller, USDA-CSRS (personal communication).

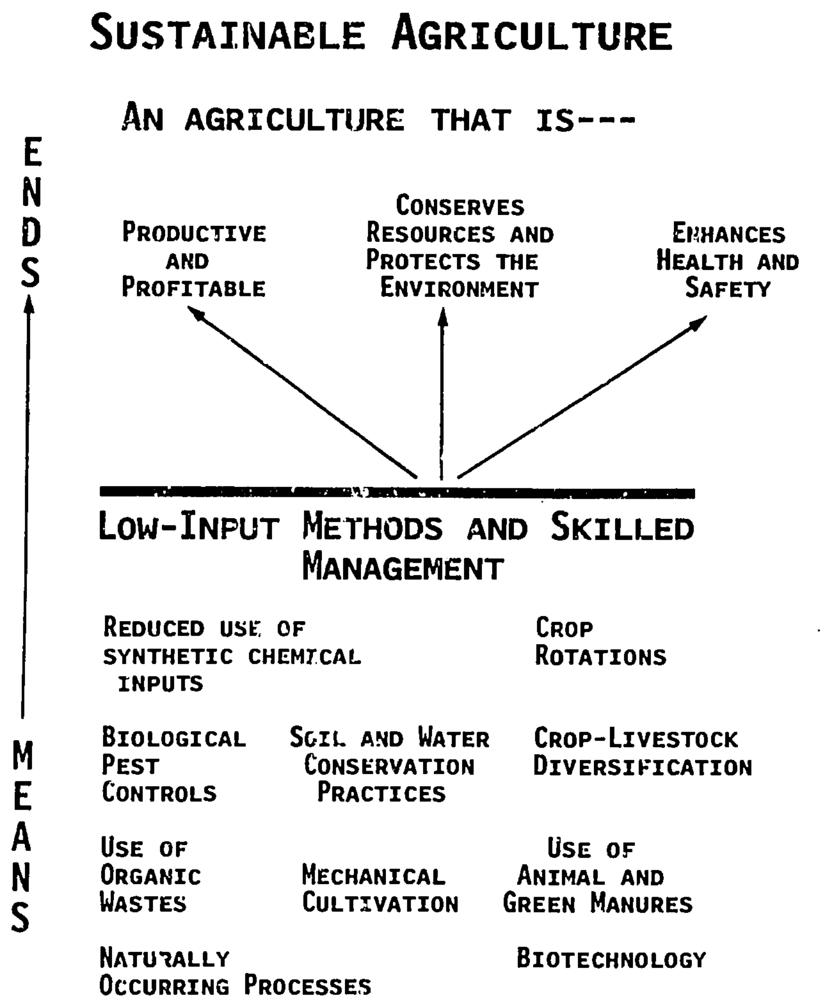

Figure 1. A current concept of sustainable agriculture in the United States showing the ends or objectives and the means of achieving them through low-input methods and skilled management.

The ultimate goal or the ends of sustainable agriculture is to develop farming systems that are productive and profitable, conserve the natural resource base, protect the environment, and enhance health and safety, and to do so over the long-term. The means of achieving this is low-input methods and skilled management, which seek to optimize the management and use of internal production inputs (i.e., on-farm resources) in ways that provide acceptable levels of sustainable crop yields and livestock production and result in economically profitable returns. This approach emphasizes such cultural and management practices as crop rotations, recycling of animal manures, and conservation tillage to control soil erosion and nutrient losses and to maintain or enhance soil productivity. Low-input farming systems seek to minimize the use of external production inputs (i.e., off-farm resources), such as purchased fertilizers and pesticides, wherever and whenever feasible and practicable; to lower production costs; to avoid pollution of surface and groundwater; to reduce pesticide residues in food; to reduce a farmer's overall risk; and to increase both short- and long-term farm profitability (Parr et al., 1989, 1990; Parr and Hornick, 1990).

Another reason for the focus on low-input farming systems is that most high-input systems, sooner or later, would probably fail because they are not either economically or environmentally sustainable over the long-term. Thus, in the U.S., "sustainable agriculture" has settled in as the ultimate goal. How we achieve this goal depends on creative and innovative conservation and production practices that provide farmers with economically viable and environmentally sound alternatives or options in their farming systems.

III. Dynamics of Soil Productivity

The "key" to improving the sustainability of dryland farming systems is soil productivity, which has been defined as "The capability of soil for producing a specified plant or sequence of plants under a defined set of management practices. It is measured in terms of outputs or harvests in relation to the inputs of production factors for a specific kind of soil under a physically defined system of management" (USDA, 1957).

An important relationship that is often overlooked is that for most agricultural soils, degradative processes such as soil erosion, nutrient runoff losses, and organic matter depletion are going on simultaneously with the beneficial effects of conservation practices such as crop rotations, conservation tillage, and recycling of animal manures and crop residues. Hornick and Parr (1987) first illustrated this relationship, shown in Figure 2, which was modified by Stewart et al. (1990) to include the last two processes and practices shown here. As soil degradative processes proceed and intensify, soil productivity decreases concomitantly. Conversely, soil conservation practices tend to slow these degradative processes and increase soil productivity. Thus, the potential productivity of a particular soil at any point in time is the result of ongoing degradative processes and applied conservation practices. Generally, in arid and semiarid environments the most serious degradative processes are soil erosion and associated nutrient losses, and organic matter depletion.

On our best agricultural soils—that is, gently sloping, medium-textured, well-structured, and with a deep, well-drained profile—a high level of productivity can be maintained by relatively few, but essential conservation practices that readily offset most degradative processes. However, on marginal soils of limited capability, such as steeply sloping, coarse-textured, poorly structured soils depleted of nutrients and with a shallow, poorly drained profile, soil conservation practices must be maximized to counteract further degradation. Thus, a truly sus-

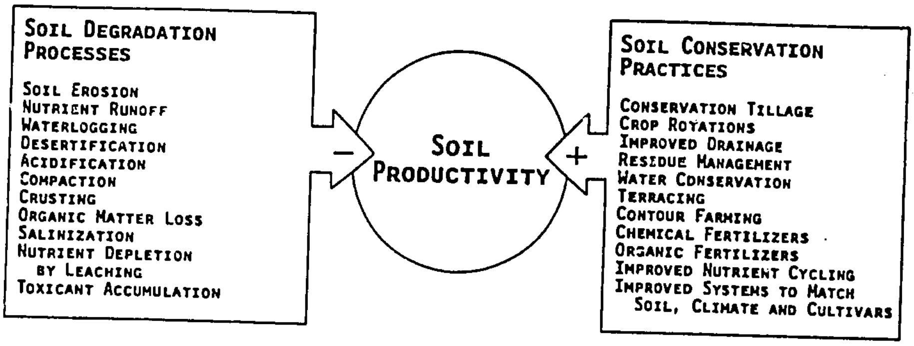

Figure 2. Relationship of soil degradative processes and soil conservation practices.

tainable farming system is one in which the beneficial effects of various conservation practices are equal to or exceed the adverse effects of degradative processes. Organic wastes and residues offer the best possible means of restoring the productivity of severely eroded agricultural soils or of reclaiming marginal soils (Hornick and Parr, 1987).

The vital component in this dynamic equilibrium (see Figure 2) is soil organic matter, which must be maintained and replenished through regular additions of organic materials such as animal manures and crop residues (Parr and Colacicco, 1987) and composted municipal wastes (Hornick et al., 1984). The proper use of organic amendments is of utmost importance in maintaining the tilth, fertility, and productivity of agricultural soils and in minimizing wind and water erosion and preventing nutrient losses through runoff and leaching.

IV. Opportunities and Limitations

Climate and soil are the two most critical factors that will determine the ultimate sustainability of agricultural systems. Figure 3 shows how varying the temperature and soil moisture regimes affects the difficulty of attaining sustainability of an agricultural system (Stewart et al., 1990). As temperature increases and precipitation decreases, the development of sustainable farming systems becomes more difficult. This happens because, under these conditions, soil erosion and organic matter depletion generally become the dominant soil degradative processes. Soil organic matter levels generally decrease as temperatures increase because of increased microbial activity. Intensive tillage also accelerates the loss of soil organic matter through oxidative processes.

The potential for erosion by water and, particularly, wind also tends to increase with increasing temperatures. Both of these degradative processes progressively accelerate with increasing aridity because of the associated decline in soil organic matter, and because there is less natural vegetation to control erosion. The rate

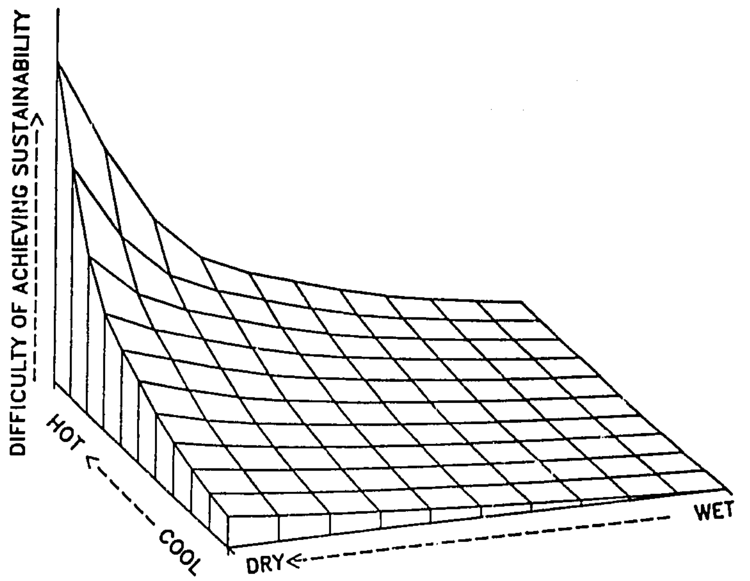

Figure 3. Generalized representation of the effects of temperature and precipitation on the difficulty of developing sustainable agricultural systems.

and extent of these degradative processes are greater for hot and dry climatic regimes. Moreover, the cost and level of inputs needed to restore the productivity of degraded lands in such a harsh environment are much greater, and the benefits to be derived from soil conservation practices are considerably lower than in the cooler and wetter areas.

The key to improving the sustainability of rainfed/dryland farming systems is to halt any further deterioration of the natural resource base, that is, agricultural land, and the associated loss of soil productivity. This can be achieved largely by implementing sound soil and water management practices. In many cases, improvements can be achieved by the application of established principles of soil and water management to crop and livestock production. In other situations, new concepts and methodologies appropriate to the unique aspects of dryland areas will be required. It should be recognized that in some cases soil and climatic factors will seriously limit the feasibility and practicability of reclaiming degraded lands for agricultural use. Obviously, government policies, land tenure arrangements, and social, cultural, and economic factors influence the way in which dryland resources are used. Achieving long-term sustained growth in the productive capacity of low-rainfall areas will require sound decisions and cooperative efforts by national governments and donor organizations based on accurate assessments of problems and potentials of the natural resources, as well as on careful analysis of alternative policies, programs, and projects (Steiner et al., 1988).

V. Perspectives and Strategies

In view of the urgent need to improve the productivity, stability, and sustainability of dryland farming systems for an expanding world population, the editors felt that a book was needed not only to address the current state of the art, including research needs and priorities, but also to present new perspectives and strategies to minimize the risks of dryland farming. The volume, *Dryland Agriculture: Strategies for Sustainability*, comprises 17 chapters written by widely recognized authorities on the most vital aspects of dryland farming.

Two chapters deal with the agroclimatic resource base and address the relationships of precipitation, temperature, and crop growth. Six chapters focus on different aspects of tillage including conservation tillage systems, crop residue management and soil organic matter dynamics, mechanization and equipment, soil fertility and nutrient cycling, control of soilborne plant diseases, and management of crop residues for water conservation and for use by livestock, especially small ruminant animals.

One chapter emphasizes ways in which water-use efficiency by crops can be enhanced while two others discuss the mechanics, prediction, and control of water erosion and wind erosion. Two rather innovative chapters deal with ways of overcoming spatial variability of soils in dryland field research trials and the role of soil biodiversity in improving the sustainability of dryland farming systems.

In assessing the sustainability of these systems the economic aspects are often neglected. Thus, a chapter has been included on an economic analysis of farm management practices and improved technologies for sub-Saharan Africa. There is also a chapter on the use of crop simulation models in dryland agriculture to provide researchers with greater capability for predicting and evaluating crop response to various management practices and technological inputs. Finally, the volume concludes with a chapter which provides examples of some successful approaches and strategies for increasing the productivity and stability of dryland farming systems in a number of developing countries.

We believe this volume fulfills a long-recognized need that will assist researchers, educators, extension workers, and administrators of national governments and donor organizations to develop practical and workable strategies for improving the sustainability of dryland farming systems worldwide. Meeting this challenge in the years ahead will require more sustainable production per unit area, conservation and rational use of natural resources, preservation and protection of the environment, development of improved management practices and appropriate/affordable technologies, and favorable government policies and incentives for farmers to increase their productivity.

References

Dregne, H.E. 1989. Desertification of Drylands. *In* Proc. Intl. Conf. on Dryland Farming, August 11-15, 1988, Amarillo/Bushland, Texas. Texas Agric. Exp. Sta., College Station.

Food and Agriculture Organization (FAO). 1986. African Agriculture: The Next 25 Years. Main Report. FAO, Rome.

Hornick, S.B. and J.F. Parr. 1987. Restoring the productivity of marginal soils with organic amendments. Am. J. Alternative Agric. 2:64–68.

Hornick, S.B., L.J. Sikora, S.B. Sterrett, J.J. Murray, P.D. Millner, W.D. Burge, D. Colacicco, J.F. Parr, R.L. Chaney, and G.B. Willson. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. U.S. Department of Agriculture Information Bulletin No. 464.

Indo-U.S. Subcommission on Agriculture. 1987. Report of the U.S. Dryland Farming Team and the Economics Team Visits to India, March/April and June 1987. Published by USDA-OICD-FERRO, December 1987, New Delhi.

Lockeretz, W. 1988. Open questions in sustainable agriculture. Am. J. Alternative Agric. 3:174–181.

National Research Council. 1989. Alternative Agriculture. Committee on the Role of Alternative Farming Methods in Modern Production Agriculture. Board on Agriculture, National Academy Press, Washington, D.C.

Parr, J.F. and D. Colacicco. 1987. Organic materials as alternative nutrient sources. Chapter 4, pp. 81–89. *In* Z.R. Helsel (ed). Energy in Plant Nutrition and Pest Control. Elsevier Science Publishers, Amsterdam, The Netherlands.

Parr, J.F. and S.B. Hornick. 1990. Recent developments in alternative agriculture in the United States. *In* Proc. of Intl. Conf. on Kyusei Nature Farming, October 17–21, 1989, Khon Kaen University, Khon Kaen, Thailand (in press).

Parr, J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer. 1990. Strategies for developing low-input sustainable farming systems for rainfed agriculture. *In* Proc. Intl. Symposium for Managing Sandy Soils, February 6–11, 1989, Jodhpur, India. Indian Council of Agricultural Research, New Delhi (in press).

Parr, J.F., R.I. Papendick, I.G. Youngberg, and R.E. Meyer. 1989. Sustainable agriculture in the United States. Chap. 4, pp. 50–67. *In* Proc. Intl. Symposium on Sustainable Agricultural Systems. Soil and Water Conservation Society, Ankeny, Iowa.

Singh, R.P. 1989. Dryland/rainfed agriculture and water resources management research and development in India. *In* Proc. Intl. Colloquium on Sharing Innovation: Global Perspectives on Food, Agriculture and Rural Development, October 17–18, 1989, Washington, D.C. Smithsonian Institution (in press).

Steiner, J.L., J.C. Day, R.I. Papendick, R.E. Meyer, and A.R. Bertrand. 1988. Improving and sustaining productivity in dryland regions of developing countries. Adv. Soil Science. 8:79–122. Springer-Verlag, New York.

Stewart, B.A., R. Lal, and S.A. El-Swaify. 1990. Sustaining the resource base of an expanding world agriculture. *In* Proc. Workshop on Mechanisms for a Productive and Sustainable Resource Base, July 29–30, 1989, Edmonton, Canada. Soil and Water Conservation Society, Ankeny, Iowa (in press).

U.S. Department of Agriculture. 1957. Soil–Yearbook of Agriculture. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Agriculture. 1988. Low-Input/Sustainable Agriculture: Research and Education Program. U.S. Government Printing Office, Washington, D.C.