American Journal of Alternative Agriculture

http://journals.cambridge.org/AJA

The potential for regenerative agriculture in the developing world

Charles A. Francis, Richard R. Harwood and James F. Parr

American Journal of Alternative Agriculture / Volume 1 / Issue 02 / March 1986, pp 65 - 74
DOI: 10.1017/S0889189300000904, Published online: 13 November 2009

Link to this article: http://journals.cambridge.org/abstract_S0889189300000904

How to cite this article:
Charles A. Francis, Richard R. Harwood and James F. Parr (1986). The potential for regenerative agriculture in the developing world. American Journal of Alternative Agriculture, 1, pp 65-74 doi:10.1017/S0889189300000904

The potential for regenerative agriculture in the developing world

Charles A. Francis, Richard R. Harwood, and James F. Parr

Abstract. *Increased food production and greater income for farm families are primary goals of agricultural development in the Third World. Most strategies to achieve these goals are unrealistic in assuming that limited resource farmers can move out of basic food production in multiple cropping systems to high-technology monocropping for export. These strategies are based on petroleum-based inputs that demand scarce foreign exchange. They may include excessive use of chemical fertilizers and pesticides, which adds unnecessary production costs, endangers the farm family, and degrades the rural environment. Dependence on export crops and world markets is economically tenuous, especially for the small farmer. Future agricultural production systems can be designed to take better advantage of production resources found on the farm. Enhanced nitrogen fixation, greater total organic matter production, integrated pest management, genetic tolerance to pests and to stress conditions, and higher levels of biological activity all contribute to resource use efficiency. Appropriate information and management skills substituted for expensive inputs can further improve resource use efficiency. On the whole farm level, appropriate cropping on each field can be integrated with animal enterprises, leading to a highly structured and efficient system. Such systems can serve the needs of national agricultural sector planners, who in many countries are concerned with increased self-reliance in farming inputs and in production of basic food commodities. This includes a realistic focus on training of local development specialists, increased research on food crops under limited resource conditions, and providing information, incentives, and appropriate technologies for operators of both large and small farms. Well-conceived national plans include varied food production strategies and options for farmers with different resource levels.*

Introduction

Strategies to increase food production in the developing world need to include options consistent with the different land and capital resource levels of farmers in each region. Concern for improving the long-term productive capacity of soils, the sustainability of crop and animal production, and the quality of life in the rural environment has generated increased interest in alternative approaches to agricultural development, especially because of the current food crisis in Africa (Francis and Harwood, 1985; Timberlake, 1985).

Many development activities are based on high-technology solutions and on transfer of concepts and technologies from one country or region to another (Harwood, 1979; 1983). These agricultural methods may be difficult to adapt to conditions in a specific country, since they are based on chemical fertilizers and pesticides often not available in a country, or acquired only at a high cost. For example, Maher (1982) and Gonsalves (1982) discuss the complications of using these inputs in Tanzania. As a result, fossil fuel-based technologies have not reached most limited resource farmers of the world (Francis and Harwood, 1985). A growing awareness of the global reality of a declining amount of arable land (Urban and Vollrath, 1984) and finite fossil energy reserves (Brown, 1986) leads to a sobering assessment of how to approach agricultural development. The unique problems of farmers in chronically resource-poor regions, who are faced with limited capital and relatively low production potential (Timberlake, 1985), present a great challenge. They need a range of new solutions; several alternatives were summarized by Francis and Harwood (1985).

Regenerative agriculture was proposed by Gabel (1979) and further articulated by Rodale (1983) as an option that could lead to more sustainable agricultural production systems. This approach emphasizes the use of resources found on the farm instead of expensive imported energy resources, especially chemical fertilizers and pesticides. These contrasting sources of production inputs could be called "internal" and "external" resources (Rodale, 1985). The historical and conceptual bases for productive systems, summarized by Harwood (1983), need to include:

1. The inter-relatedness of all parts of a farming system, including the farmer and farm family,
2. The importance of the innumerable biological balances in the system, and
3. The need to maximize desired biological relationships in the system, and minimize the use of materials and practices which disrupt those relationships.

Harwood's tenets are similar to those cited by Boeringa (1980) and Youngberg (1984) for "alternative agriculture" and by Parr et al. (1983) for "organic farming." There have been several studies of reduced-energy, resource-conserving, sustainable production practices (Harwood, 1984b) and the economic consequences of their adoption (Harwood and Madden, 1982). We integrate these biological and economic components into a diagrammatic explanation of *progressive biological sequencing*, or how the choice of cultural practices can cause a dynamic change in the production environment. This conscious and directed

---

Charles A. Francis is Professor of Agronomy and Extension Crops Specialist, University of Nebraska, Lincoln, NE 68583. Richard R. Harwood is Program Officer and Agronomist, Winrock International Institute for Agricultural Development, Morrilton, AR 72110. James F. Parr is National Program Leader, Dryland Agriculture and Soil Fertility, ARS-USDA, and Coordinator, Dryland Agriculture Project, ARS-USDA/USAID, Beltsville, MD 20705.

manipulation of individual fields by farmers through knowledge of biological interactions among species and the natural environment can lead to improved productivity. The combination over time of crops in several fields with animal enterprises can be called the *integrative structuring of the farming system.* We illustrate these concepts with specific examples of research results and observations from farms. These concepts and practices are ready for incorporation into Third World agricultural development strategies.

Realities of development

Problems that confront limited-resource farmers often involve a complex combination of climatic, biological, economic, cultural, and political factors (Francis, 1981). Limited land, high energy costs, inadequate availability of inputs and credit, distant and insecure markets, and political instability all contribute to the farmer's problems, most of which are beyond the control of the individual or family.

The apparent success of the Green Revolution in regions with a high level of resources has fostered the misleading assumption that science and technology alone can foster similar gains everywhere. One issue that could negate this assumption is the scarcity and long-term trend of increasing cost of fossil fuel energy. Because of the cost and uncertain availability of this external energy source, some development experts conclude that agriculture in many countries in the Third World is unlikely to ever effectively enter the fossil fuel era. Given the scarcity of fossil fuel-based inputs, we need to explore and develop alternatives in soil fertility and pest control both to produce more food and to protect the natural environment, including fish and wildlife (Youngberg et al., 1984). We especially need new approaches for medium and small sized farms in the Third World that are consistent with their limited resource base and the economic, social, and political realities of the farmer's environment (Office of Technology Assessment, 1984).

Macro-economic factors also affect the small farmer through lack of available production credit and high interest rates. Low resource farmers have limited access to capital to expand the farm or substantially change current farming practices. Investment in agriculture is often risky and produces limited return. World-wide concern about Third World indebtedness further reduces the opportunity for outside resources and raises serious questions about the high cost of current agricultural development strategies (Brown, 1985).

Given these realities, and given the growing body of information about biological systems and interactions among components of systems, *progressive biological sequencing* of crops can offer several advantages to farmers:

--Increased productivity, first for the benefit of the farm family, then respectively for the local community, for the region and nation, and for international markets;

--Maintenance or improvement of the productive potential of the soil; and

--Preservation and use of all production materials (nutrients, biocides, residues) within the farm boundary and in the upper layers of the soil profile, away from groundwater.

When several fields and their crop sequences are combined with the animal species that are a part of most small farms, the resulting *integrative farm structuring* can help the farmer:

--Make more efficient use of production resources on the farm;

--Integrate production activities on the farm into an efficient biological working system;

--Develop a more profitable and sustainable combination of farm enterprises, consistent with the family's goals and resource constraints; and

--Create a more healthful living and working environment.

Although priorities and practices may be different on certain farms in favored regions, decision makers need to recognize that most limited-resource farmers can work well and become more productive within the above guidelines. Small farm agriculture in most countries is unlikely to use scarce resources efficiently or provide stable food production unless development policies take account of farmers' needs and the constraints under which they must work. This in turn requires the development of a range of options for farms with different resource endowments.

Biological structuring

The complex ways in which all the plants and animals on a farm interact in their growth and development have been called the "biological structuring" of the system (Harwood, 1984b). Unless energy and growth factors are transferred efficiently among niches within a system, high and sustained yields can be achieved only through continuous and high applications of fossil fuel-based inputs, including chemical fertilizers and pesticides. High input systems, such as monoculture of maize, rice, wheat, and other cereal crops, are common in temperate regions and have become the model for the Green Revolution in subtropical and tropical areas where resources are not limiting.

In contrast, organic agriculture or other alternatives take into account more of the complexity of the total farm environment, including the farm family. This is illustrated in the overview in Figure 1. More efficient biological structuring takes advantage of the interactions and interdependencies among the components.

These interactions occur on several levels: among the crops present in the same field at the same time; among the crops present sequentially in the same field; and among the crops and animals in different parts of the farm and at different times. For example, a three-crop relay system used by farmers in Eastern Antioquia in Colombia includes potatoes planted in January, maize in April, and climbing *Phaseolus* beans in July. The potato crop is harvested in June when maize is hilled, and the maize and bean crops are harvested together in December or January. This intensive sequence of overlapping crops effectively captures most of the light energy and rainfall during the entire year. A relay system of maize/sesame, maize/soybean, or maize/maize in the La Maquina area on the Pacific coast of Guatemala takes maximum advantage of the seven-month rainy season there in a way not possible with a single crop. Many and varied multiple cropping systems currently used by low resource farmers in the developing world are based on beneficial interactions among the crop components (Francis, 1986).

The interactions during a single season in one field are only a part of the dynamic interactions among crop components. The production environment changes over time, and the farmer can consciously alter and improve the field for subsequent crops through careful choice of crops and practices. The next section extends the view of what is happening in the field to include the time dimension. After that we discuss integration on the whole farm.

Progressive biological sequencing

A regenerative farming system is characterized by successive cycles of change in the crop and livestock production environment. Each wave of change usually results in an altered environment ideally suited to a different crop. The selection of a crop or combination of crops in each season and the sequence of crops and practices used over time in a field constitute a "rotation". This is both a reaction to those changes in the environment and a conscious influencing of them by the farmer. Environmental changes are both cyclical and linear. Their causal factors and results can be summarized in a diagram that illustrates the *progressive biological sequencing* of a system (Figure 2).

A crop both helps the farm family to meet annual production goals and changes the crop-associated microenvironment for succeeding crops. This is true whether it is grown alone, along with other crops in the same field, or in sequence with other crops. Planned cyclical changes in each field include shifts in weed species if crops are changed from one season to the next, population changes in soil-borne insects, and modifications of the soil nitrogen status. Although the farmer may not understand the basic biology of the system, experience and conventional wisdom have led to development of efficient sequencing. Long-term linear changes in the environment may include an improvement in soil physical properties, a net upward nutrient movement in the soil, a shift toward higher turnover rates of organic matter, increased and altered soil biological activity, and an increase in the labile fraction of soil organic matter.

This sequencing in a single field is illustrated by small farms in Taiwan, where most of the fields are planted to rice during the rainy season, and vegetables are transplanted into the rice straw after harvest. Three or more crop species may be produced in a given year on each small field. The choice of crops and management decisions appears to be influenced by specific goals of the family for the production from each field, as well as by the resources available for

Figure 1. Schematic overview of biological structuring in a regenerative farming system, showing crop/animal/family interdependencies.

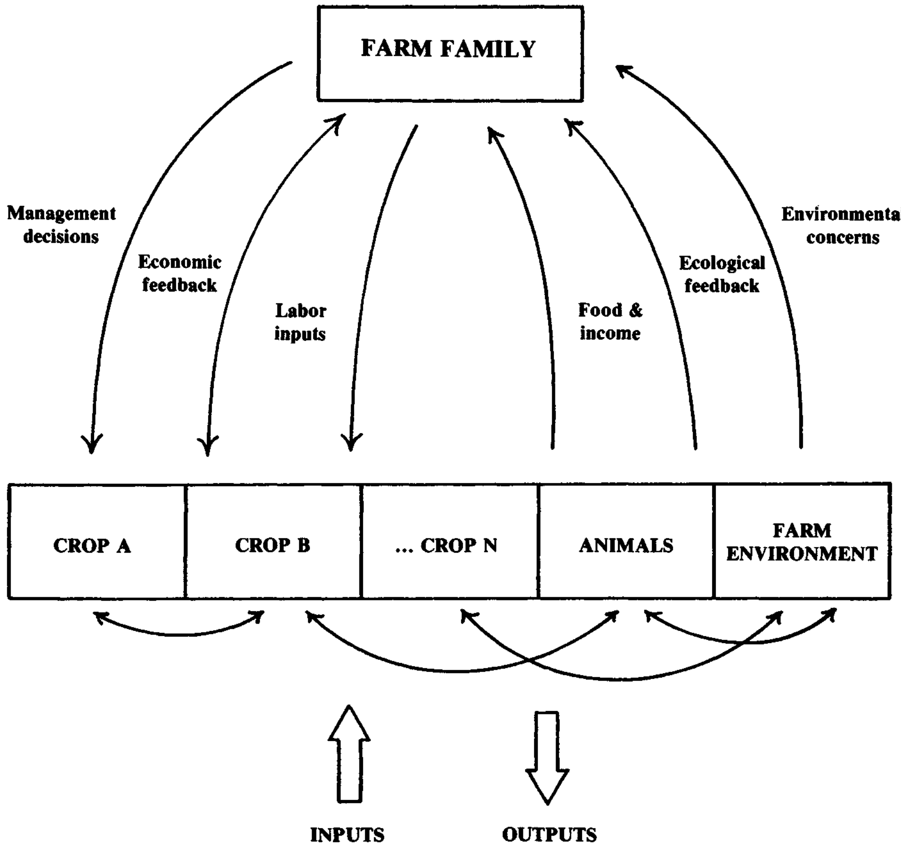
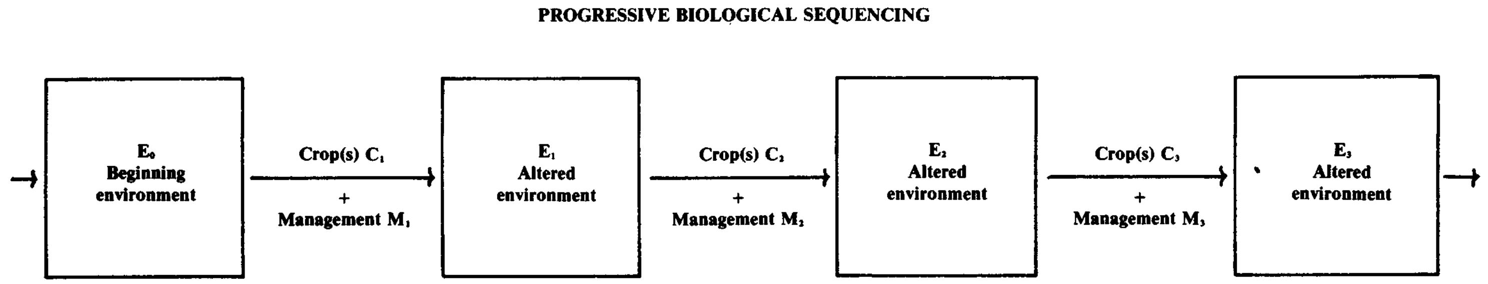


Figure 2. Conceptual pattern of dynamic cyclical and linear changes in one field crop environment as a result of successive crops and management decisions.



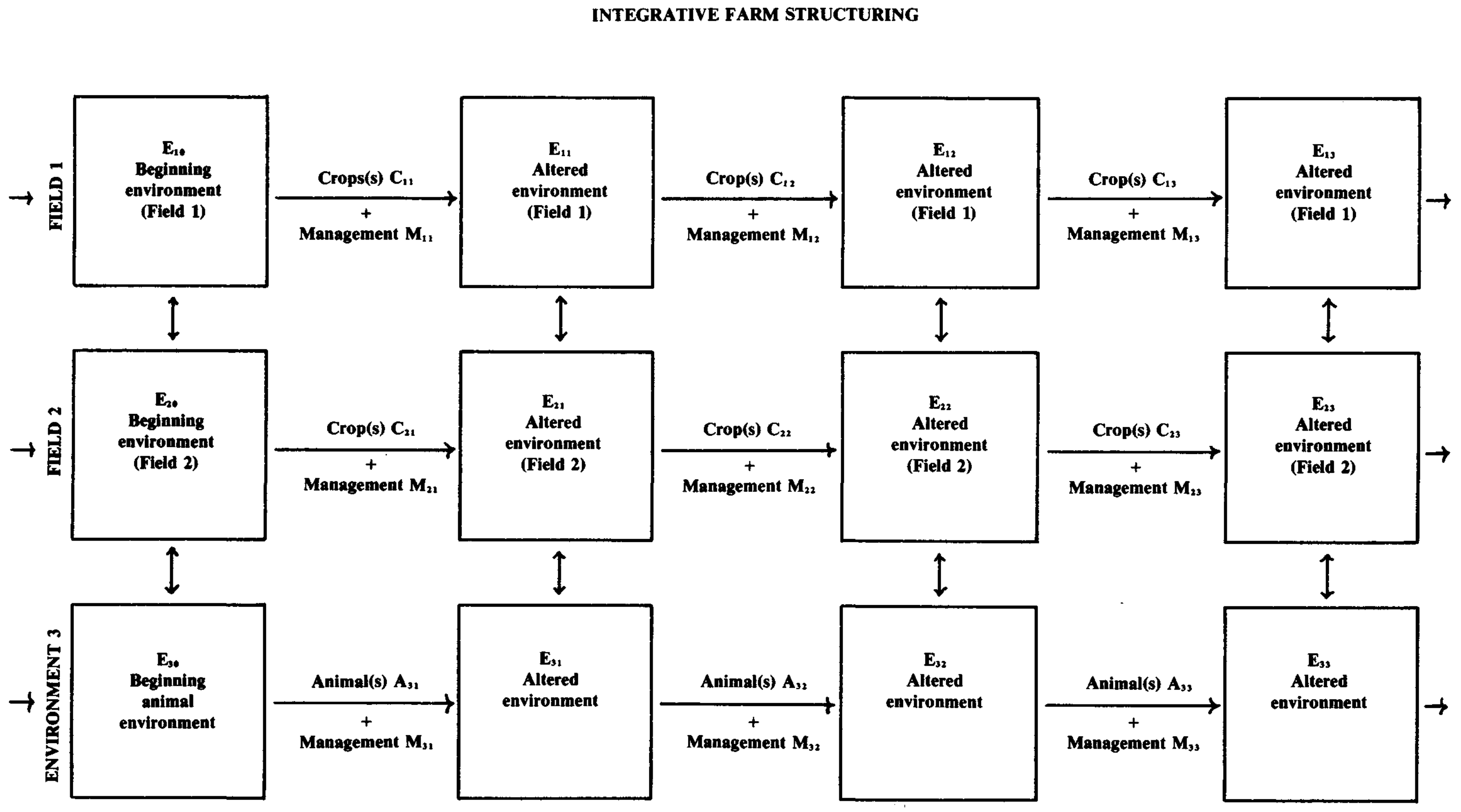
crop production. The field history probably is well-known to the farmer, and past experience will influence management strategy. Central to the decisions on input levels and crops will be the current status of the field environment, which in itself is a product of conscious structuring in this biological sequence. Yet decisions by the farmer may not be based entirely on what is most logical for each field, since a farm has several fields and other enterprises. The total management strategy must take into account the complexity of interactions, which require another dimension in the model.

Integrative farm structuring

When the biological structuring and interactions among the crops in a field are developed into a progressive sequence, cropping becomes efficient in resource use and in meeting the needs of the family. But interactions with the other enterprises on the farm also influence decisions on which crops to plant and how resources are to be distributed among the fields. If there is a conscious and rational combination of these activities on a farm, this could be called the *integrative farm structuring* that ties that farm together in its daily operation as well as in long-term planning (Figure 3). If this structuring is done properly, it will create an efficient distribution and use of total available resources, including family labor. The result will be a sustainable food supply and income for the family and an improvement or regeneration of the soil productivity.

This structuring is illustrated by the

Figure 3. Conceptual pattern of interactions and integrations of primary crop and animal enterprises on a resource efficient farm.



total panorama of activities in the Taiwan situation where cole crops are transplanted into the rice stubble after harvest. They will be followed by at least one more vegetable crop before the next cycle of rice begins. Mushrooms are grown on the rice straw and, as the season closes, the residue from the mushrooms is brought back to the fields and spread for fertilizer on the next rice crop. Straw and other crop residues are fed to small animals kept near the houses, and both human and livestock wastes are brought back to the field as fertilizers.

The integration of activities among enterprises may be more subtle than the moving of residues or the application of manures as fertilizer. The decision to plant rice on most fields to provide a major source of income precludes the planting of other crops that might do equally well in the rainy season. Management of one crop that requires high levels of fertility may reduce the compost or manure available for another crop. Prices of production inputs and value of crops will vary from season to season and year to year, and this may influence management decisions and cropping sequences. Changes in livestock enterprises may require more or less feed for those animals -- thus affecting the decisions made for each field and for the integrated farm operation. Both political and social factors also can influence the management decisions by farmers with limited resources (Francis, 1981).

In summary, the basic idea is first to understand how the crops in each field alter the specific environment to make it suitable for a different crop or crops. Second, we have discussed how activities can be integrated into a structured model that underlies management of a complex farming system. The next step is to examine research results on specific components of technology, and to determine which of these are useful for the farmer who operates with limited resources. Some results from temperate regions have an application in the developing world. We explore how these fit into regenerative farming systems.

Cover Photo

The color photo on the cover, provided by Charles A. Francis of the University of Nebraska, shows an example of the intensive integrated cropping systems in Taiwan that are discussed in the article he co-authored with Richard R. Harwood and James F. Parr.

Specific technologies and systems

The right sequencing of crops and biological structuring of systems can save production inputs and achieve more sustainable production. For example, yields comparable to those in conventional chemical-intensive agriculture can be achieved at a lower energy cost in organic systems. A review by Pimentel et al. (1983) showed that organic wheat and corn production is 29 to 70% more energy efficient than comparable energy-intensive high technology systems. A number of such comparisons are discussed in the *USDA Report and Recommendations on Organic Farming* (USDA, 1980).

Culik et al. (1983) conducted an in-depth study of production practices, energy use and crop yields for a non-chemical farm in eastern Pennsylvania compared with conventional farms in the same region. Continuous maize production using recommended high technology such as fertilizers, pesticides, machinery and labor required more than twice as much total energy compared with a low-energy, non-chemical, biological-structured system. Thus, energy costs in maize production could be substantially reduced through crop rotations and other alternative practices. To be successful, reduced chemical systems may require a different type of managerial ability which can be gained primarily through knowledge of the biological structuring and interdependency among soils, crops, and animals.

Although fewer comparisons have been made in tropical regions, the reports summarized by Heichel (1973) for maize production in several countries illustrate a wide range of energy conversion efficiencies (units of energy produced per unit of energy invested). Most efficient are the slash and burn systems, where the only input is human labor for burning, planting, weeding, and harvest. These are followed by systems that are entirely based on human energy, where the output/input ratio is between 10 and 19. At the other end of the spectrum are present day systems that depend on heavy investment in fossil fuels, with a ratio of 3 or 4. These latter systems are the most productive per unit of labor and, in some cases, per unit of land area.

Principal integration efficiencies of cropping systems were summarized by Harwood (1984b). The ways in which crop components complement or compete with each other in resource use will influence the success of a specific sequence of crops. Some of the biological processes that promote these efficiencies include nitrogen fixation, nutrient cycling and management, disease suppression, insect population effects, and weed cycling. Because of these structural or integration efficiencies, moderate to high yields can sometimes be maintained without continuous infusion of energy-intensive production inputs.

Nitrogen fixation: In the temperate zone, forage legumes can contribute from 25 to 50% of the nitrogen needed in most cropping systems, but meeting the total N requirement through symbiotic fixation would be difficult with current technology according to Heichel and Barnes (1984). Vogtman (1984), however, presented data indicating that nitrogen self-sufficiency in regenerative or alternative agriculture is achievable. Moreover, Kaffka (1984) in his detailed study of a German dairy farm, substantiates this conclusion. Current methods and techniques for measuring the amount of nitrogen fixed by legumes and available for subsequent crops may underestimate the potential contribution of fixation (La Rue and Patterson, 1981).

Data from the Rodale Research Center (Harwood 1984a) suggest that it is possible to meet the total nitrogen needs of a cereal crop from legumes in rotation. The Kutztown farm, operating with minimal inputs from outside the system for 10 years, has consistently obtained yields of wheat and maize that are substantially above county averages. Wegrzyn (1984) studied nitrogen balance in maize grown for three years following alfalfa and measured no response to added nitrogen during that time. Thus, the current contributions and potential future improvements anticipated in biological fixation are vital to regenerative or alternative agriculture because they can enable farmers to greatly reduce chemical N fertilizers (Alexander, 1984).

Alternative methods are available for maintaining soil fertility in tropical regions as summarized by Liebhardt et al. (1985). Mixed cropping systems including a cereal and a legume were shown to be 38 to 55% more productive than monocultures in Uganda, although the fertility contribution of the legumes could not be singled out because it was confounded by other factors (Osiru and Willey, 1972; Willey and Osiru, 1972). In Trinidad, Dalal (1974) studied maize/pigeonpea (*Cajanus*) intercrops, including detailed measures of total dry matter and nutrient uptake. Total nutrient extraction was consistently greater for the mixture compared to monoculture. More research is needed in the important area of soil fertility, since nitrogen is especially critical for the growth and production of cereal crops. Critical areas for future research were suggested by Barker and Francis (1986).

Nutrient cycling: In a conventional cropping system that uses fertilizer nitrogen and deep inversion tillage (e.g. moldboard plow), the flow of this nutrient is into the crop and down through the soil profile, where it may be totally lost to the crop and become a groundwater pollutant. The long-term effects of this process on groundwater quality in Iowa have been described by Hallberg (1984). In a well-structured system that depends on organic sources of nitrogen and shallow, non-inversion tillage, there may be a net upward movement of nitrogen and some other nutrients.

If roots of several component species exploit different soil strata, total nutrient uptake may be greater (Liebhardt et al., 1985). When deep-rooted and shallow-rooted species are grown together, the deep-rooted plants can capture nutrients that are leached past the roots of the shallow-rooted plants. These nutrients are converted into leaves and other plant material and again deposited on the surface. The difference in nutrient movement in organic compared with conventional systems was suggested by Howard (1947) and has been confirmed by Patten (1982).

The following practices are common to regenerative or alternative farming systems and can promote a net upward movement of nitrogen and other nutrients in the soil profile (Harwood, 1984b):

--The crop rotation must include deep rooted crops;

--Use of highly soluble nutrient sources must be avoided;

--Use of a disk or chisel plow, or minimum tillage, should replace the moldboard plow;

--Nutrients added to a system should be put on sod crops to maximize nutrient uptake;

--Seasonal use of cover crops directly following major cash crops should enhance the uptake and recycling of soluble nutrients; and

--Crop residues should be maintained largely at or near the soil surface to minimize erosion, reduce soil crusting, and decrease evaporative water loss.

Such systems should significantly reduce plant nutrient losses by promoting their cycling through living plant tissue and retention in crop residues and soil organic matter. This would minimize the need for additional nutrient inputs, although more information is needed on these interactions in low-input cropping systems. Cycling in these cropping systems would be similar to what occurs in natural climax forest communities, and there is much to be learned from recent research on agroforestry systems (Keya, 1974; Kock, 1982; MacDonald, 1982; Sanchez, 1976). A long-term goal is to approach the closed nutrient loops defined by Edens and Haynes (1982) for the farming systems of the future.

Integrated nutrient management: The low-resource farmer needs alternative ways to restore and maintain soil fertility with a minimum of external inputs and costs. One such alternative is proper utilization of on-farm sources of crop residues and manures (FAO, 1975; USDA, 1980). Proper crop sequences and well-designed intercrops of cereals and legumes can improve soil physical structure, fertility, and total productivity, which in turn could lead to increased crop yields and greater net return. Deep-rooted crops can recover some plant nutrients from lower soil depths, where they might otherwise be totally lost from the system, and make them available for current or succeeding crops. Overseeding legumes into a growing crop, or providing a legume cover during a fallow period, can produce up to 100 kg/ha of nitrogen in a few months (Heichel and Barnes, 1984; Liebhardt, 1983). Maintaining substantial amounts of nitrogen and other nutrients in organic form during periods when crops are not grown can help reduce nutrient losses through leaching and erosion.

Integration of animals into the total system is another option. Use of manure converts a waste product into a resource that can improve soil fertility, as illustrated by two reports from Tanzania (Ngaiza, 1983; Samoka et al., 1983). Obviously, the animals also are a source of food and income for the family. The incorporation of woody legumes into cropping patterns such as alley cropping (planting of annual crops between rows of leguminous trees spaced two to five meters apart) could provide substantial amounts of fixed nitrogen for a non-leguminous crop, a canopy for protecting the crop and minimizing soil erosion, and a source of fuel and fodder (Office of Technology Assessment, 1984).

Disease suppression: Crop rotations often reduce soil-borne diseases (Harwood, 1984a). The mechanisms are not well understood but appear to be related to the soil's high organic matter content and high level of microbiological activity and to the diversity of crop species grown in sequence. Some of the steps that might promote disease suppression include:

--No one crop species should be grown in the same field more frequently than every five years;

--Processed compost or manure should be incorporated into the soil each year to maintain soil physical properties and fertility; and

--Residues from crops that may contain harmful pathogens should be buried after each harvest.

A better understanding of disease suppression could make integrated management and non-chemical control of soil-borne diseases more practical. Gliessman (1980) and Altieri and Liebman (1986) review examples of reduced diseases in multiple cropping systems and speculate on some of the mechanisms that might be involved.

Insect population effects: Organic systems sometimes have lower levels of damaging insects. This may be due to higher levels of predatory insects, parasites, and antagonistic microorganisms compared with conventional chemical systems (Karel et al., 1983). Among the practices used on non-chemical farms to reduce damaging insect populations are crop rotations, diversity both within the field and in border strips, different forms of multiple cropping, and border strips between fields. Motyka and Edens (1984) compared an organic onion farm with two conventional onion farms and found a higher insect species diversity in the former. There were also fewer onion flies reported on the organic farm than on conventional farms using chemical control. The benefits of multiple cropping systems to reduce insect populations were summarized by Altieri and Liebman (1986), who found that most reports supported this hypothesis. Diabrotica beetles in (*Phaseolus*) beans and fall army worms (*Spodoptera*) in maize were both significantly reduced in bean/maize intercrops in Colombia, compared to nearby monoculture plots (Altieri et al., 1978). Cultural control of insects could significantly lower production costs and minimize a farmer's dependence on chemical pesticides. It can also reduce exposure of people to chemicals and contamination of food chain crops.

Weed cycling: Cropping cycles can significantly control weeds without chemicals by inhibiting the growth and development of individual weed species. Alternating field conditions such as flooded crop/dryland crop or cereal crop/legume crop in the tropics and winter species/summer species or annual crop/perennial hay crop in the temperate zone can all provide a contrasting series of environments that prevents the build-up of weeds that are better adapted to single crop systems. A summer annual cereal followed by a hay crop is an example of a sequence where different weed species prevail in each crop. Because this crop sequence is counter-cyclical to the weed species development, it often can provide satisfactory control without expensive chemicals. Suppressive crops such as buckwheat, sorghum-sudan hybrids, or oats can be used in rotations when weeds are severe in temperate cropping systems.

Multiple cropping systems have also been shown to compete successfully with weeds. This has special relevance in the developing world because farmers cannot always depend on herbicides (Akobundo, 1980; Walker and Buchanan, 1982; Altieri and Liebman, 1986). In Tanzania, many of the most noxious weeds can be controlled by a combination of cultural methods and chemical control (Minjas and Jana, 1983). Preventive measures include use of clean crop seed, well-decomposed manure, and clean equipment (Minjas, 1978). To design effective weed management strategies, more information is needed about weed growth and cycling in tropical climates, particularly as affected by soil conditions and crop/weed interactions.

Yields and yield stability: Crop yields depend very much on the management skills of the farmer in both conventional and alternative or regenerative systems. On the average, yields in highly-structured, non-chemical farming systems range from higher to as much as 10% lower than in conventional systems in temperate zones (Parr et al., 1983). Production costs and energy inputs may be up to 40% lower in the non-chemical systems, although labor and management costs may be higher (USDA, 1980). A livestock farm in Pennsylvania (Culik et al., 1983) and a prairie wheat farm in Washington (Patten, 1982) (the latter having used regenerative or alternative agricultural practices for 70 years) offer examples of stable yields without chemical inputs to maintain soil fertility or control pests.

Examples of biologically structured systems in the tropics include the potato/maize/bean system in Antioquia, Colombia, and the maize/sesame or maize/soybean system used on the Pacific coast of Guatemala. Greater stability of yield in bean/maize intercrop systems in Colombia (Francis and Sanders, 1978) and in sorghum/pigeonpea intercrop systems in India (Rao and Willey, 1980) further illustrates the advantages of multiple species systems that are well structured. Both sequencing of crops within a field and the combinations of crop and animal enterprises on the whole farm illustrate the application of the principles of progressive biological structuring and integrative farm structuring.

Contributions of conventional research

There is a substantial store of research on conventional systems that can be directly applied to regenerative agriculture. Crop yield responses to fertility, to density, and to pest losses will be relevant under a wide range of management systems. Likewise, the crop varieties and hybrids that are well adapted to a given environment likely will perform well in another management system in that same region, although there may be interactions of genotype with cropping system when management is changed drastically (Smith and Francis, 1986). The contribution of conventional research to these structured systems is illustrated with three examples: use of organic wastes, integrated pest management, and genetic improvement of crops.

Utilization of organic wastes: Developing countries have traditionally used organic materials, such as animal manures, crop residues, and green manures and composts, to maintain or improve the productivity, physical structure, and fertility of their agricultural soils. With the publicity and promise of the Green Revolution in the 1960s, organic recycling practices on some farms were largely replaced with chemical fertilizers. At that time, these chemical products were relatively inexpensive and easily obtainable, and they often produced dramatic yield increases. Consequently, proper use of organic matter in maintaining soil productivity was neglected. As a result, the agricultural soils in some areas have undergone extensive degradation because of excessive soil erosion, nutrient runoff losses, and depletion of soil fertility.

The world energy crisis that began in the early 1970s and global food shortages around the same time resulted in the sharply increased cost and uncertain availability of chemical fertilizers in many developing countries. Not surprisingly, the 1974 World Food Conference in Rome passed a strong resolution calling on the Food and Agriculture Organization (FAO) of the United Nations to initiate programs and workshops that would emphasize the value and importance of organic wastes as fertilizers and soil amendments, and to reintroduce both established techniques and new practices for their effective utilization on agricultural land (FAO, 1975; Parr and Papendick, 1983). As a result, many countries have requested information and appropriate technology for recycling organic wastes, both from on-farm and off-farm sources. There has been strong and renewed interest in composting technology for two principal reasons. First, the process resolves many of the problems associated with various organic wastes (including animal manures, nightsoil, sewage, and sludge), such as odors, human pathogens, and storage and handling constraints. Second, composting produces a stabilized form of organic matter that has a greater residual effectiveness for improving the physical structure and productivity of soils (Parr and Papendick, 1983; USDA, 1978). The U. S. Department of Agriculture has developed a highly successful aerated pile method for rapid composting of sewage sludge, animal manures, municipal refuse, and pit latrine wastes (Willson et al., 1980). Several developing countries have adapted this technology, which is simple, relatively inexpensive yet effective, and flexible in allowing considerable trade-offs between labor and capital.

Developing countries generate substantial amounts of various organic wastes that could be composted and made available at a nominal fee to farmers who need off-farm sources of organic matter to improve the soil structure and productivity of their lands. National governments should conduct surveys of the types, amounts, and availability of different organic wastes that could be used for this purpose (Parr and Papendick, 1983; USDA, 1978).

Integrated pest management: Appropriate strategies using integrated pest management (IPM) build on the efficiencies of a well-structured biological system to provide internal control of most pests. In contrast to the expense, danger, and long-term consequences that may accompany the use of conventional chemicals, IPM uses knowledge about the crops and pests to design strategies to manage and reduce the impact of weeds, insects, and pathogens, rather than to eradicate them. Combining resistant or tolerant crop varieties, rotations of crops that are dissimilar in growth habit and resource use, effective management of crop residues, and encouragement of natural predators and parasites can all lead to adequate control of pests without the costs and risks of heavy chemical applications (Luckmann and Metcalf, 1975).

Exploiting genetic potentials of crops: An important research challenge is to develop plant species that can make maximum use of limited levels of water and nutrients. Combined with new approaches to provide fertility, it will be invaluable if plants have the genetic ability to efficiently use whatever nutrients are either supplied externally or are present in the soil profile. Insect and disease resistance or tolerance and an ability to compete successfully with weeds early in the crop cycle are also important.

The genetic code carried in the seed is especially valuable to the farmer with limited resources, since this is potentially one of the least expensive inputs that can be purchased for a large area. In crops like beans, potatoes, soybeans or wheat the farmer can carefully select and save seed for the next season. This can also be done if new maize or sorghum varieties are the result of a cross between two variable parent lines, and if the new variety can be grown in sufficient isolation to maintain its genetic identity.

A recent paper by Jain (1985) points out that grain yield increases for wheat in the United States, United Kingdom, and India have resulted from a reduced plant height and increased harvest index (i.e., ratio of grain to total dry weight). For the last 75 years, grain yield increases have often been associated not with any significant increase in the biological yield (ie. total dry matter production), but rather with a higher proportion of grain. There is some doubt that the harvest index can be increased much more, and maximum levels may already have been reached for some crops. The key to further increasing the yield of most cereal crops, as well as grain legumes, depends on increasing the biological yield. This in turn could be partitioned to divert more photosynthate into the grain. A high priority for biotechnology is to genetically induce these plants to fix more carbon.

Improved crop quality is an additional priority when breeding crop varieties for home consumption or sale. Genetic engineering may provide the increased efficiencies outlined above, as well as enhanced grain quality and better insect and pathogen resistance. Yet manipulation of the genome is only a first step in a long series of activities. Selection and testing in the field are also required before release of a new variety, and genetic engineering provides no quick-fix panacea for solving all the complexities and time needed in plant breeding. Preservation of genetic resources for future generations, as well as providing access for all countries to the materials developed in national and international programs, is important to improving production. A favorable environment for exchange of ideas and germplasm needs to be fostered in the international community.

Conclusion -- farmer self reliance

When specific technologies applied in a well-structured cropping sequence reduce the farmer's dependence on external inputs, management is less determined by externalities over which the farm family has little control. Given what is known about the biological efficiencies of alternative cropping sequences and management, the farmer can adopt regenerative technologies that produce yields similar to those of conventional systems, but with substantially lower production costs. The farmer can implement these practices partly by substituting knowledge or new information for what was previously purchased to grow the crop, as we have illustrated in the earlier examples. When family labor is available, there is an advantage to intensive crop management, and in some cases there is a comparative advantage in these systems for the operator of a small or medium sized farm. The self reliance that can be developed by the limited resource farmer can lead to greater food and income security.

Governments and bilateral/international assistance agencies can help farmers achieve this self reliance by developing a broader range of regenerative, organic, or other alternative resource-efficient technologies. Strategies can be designed at the national level that encourage local autonomy and self reliance, although these are quite a departure from most development approaches in vogue today. An improved understanding of traditional farming systems and their complex biological components opens up different approaches for limited resource farmers through efficient farm structuring.

Food production for local and national consumption needs to have priority in a total development strategy. Governments can encourage production of basic food commodities through import and export policies, realistic price supports, and by incentives for farmers to increase production. International and bilateral programs also need to support this decision. Thus, the government's policies can promote a degree of self reliance at the national level, and can foster the same objective at the local level.

Technology that improves soil fertility and pest control using internal resources needs to be developed and tested on the farm. This could build toward increased local stability of production and eventually greater national security in the basic food supply. The use of internal inputs for agricultural production reduces costs for transportation, eases complications of a poorly developed infrastructure, and increases self-reliance in each region.

Regenerative farming systems provide one approach that could improve both the production potential of the soil and the environment in which the farm operates. By reducing or eliminating use of chemical pesticides and external sources of fertilizer, non-chemical methods could help increase the biological potential of the soil environment. Implementation of some practices described above could help countries to become more self-reliant in food supply through a rational use of natural resources. Tomorrow's development strategies will be characterized by a range of options for farmers, and by a more efficient use of scarce production resources in agriculture.

Acknowledgment: The authors wish to sincerely thank Dr. W. Lockeretz, Technical Editor, for his insight and substantial contributions to this article. It is published as Paper No. 8075, Journal Series, Nebraska Agric. Exp. Stn.

References

1. Akobundo, I. O. (ed.) 1980. Weed control strategies for multiple cropping systems of the humid and subhumid tropics. In: Weeds and The Control in the Humid and Subhumid Tropics. International Inst. Tropical Agriculture, Ibadan, Nigeria.
2. Alexander, M. 1984. Nitrogen fixation. Report on Technology Application through the Year 2000. Office of Technology Assessment, U.S. Congress, Washington, DC.
3. Altieri, M. A., C. A. Francis, A. Van Schoonhaven, and J. D. Doll. 1978. A review of insect prevalence in maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) cropping systems. Field Crops Res. 1:33-50.
4. Altieri, M. A. and M. Liebman. 1986. Insect, weed, and plant disease management in multiple cropping systems. In: Multiple Cropping Systems, C. A. Francis (ed.), Macmillan Publ. Co., New York, NY. Chapter 9.
5. Barker, T. C. and C. A. Francis. 1986. Agronomic aspects of multiple cropping. In: Multiple Cropping Systems, C. A. Francis (ed.), Macmillan Publ. Co., New York, NY.
6. Boeringa, R. 1980. Alternative methods of agriculture: Description, evaluation and recommendations for research. Agric. Environm. 5:1-199.
7. Brown, L. R. 1986. State of the world, 1986. Worldwatch Institute, W. W. Norton & Co., New York, NY. 263 pp.
8. Culik, M., J. C. McAllister, M. C. Palada, and S. Rieger. 1983. The Kutztown Farm Report. Rodale Research Center, Emmaus, PA. 55 pp.
9. Dalal, R. C. 1974. Effects of intercropping maize with pigeon pea on grain yield and nutrient uptake. Exp. Agr. 10:219-224.
10. Edens, T. C. and D. C. Haynes. 1982. Closed system agriculture: Resource constraints, management options, and design alternatives. Ann. Rev. Phytopath. 20:363-385.
11. Food and Agriculture Organization. 1975. Organic materials as fertilizers. Soils Bulletin No. 27. FAO, United Nations, Rome.
12. Francis, C. A. 1981. Rationality of decisions by small farmers. Farming Systems Research Conference, Kansas State Univ., Manhattan, KS.
13. Francis, C. A. (ed.) 1986. Multiple Cropping Systems. Macmillan Publishing Co., New York, NY.
14. Francis, C. A. and R. R. Harwood. 1985. Enough Food. Special Publ., Rodale Press and Regenerative Agriculture Association, Emmaus, PA.
15. Francis, C. A. and J. H. Sanders. 1978. Economic analysis of bean and maize systems: Monoculture versus associated cropping. Field Crops Res. 1:319-335.
16. Gabel, M. 1979. Ho-Ping: A world scenario for food production. World Game Institute, Philadelphia, PA.
17. Gliessman, S. R. 1980. Multiple cropping systems: A basis for developing an alternative agriculture. In: Workshop on Innovative Biological Technologies for Lesser Developed Countries, Office of Technology Assessment, U.S. Congress, Washington, DC.
18. Gonsalves, J. F. 1982. Trainer's guide to small-scale biointensive food production: The French intensive biodynamic method. Dept. of Agricultural Education and Extension, Univ. Dar-es-Salaam, Morogoro, Tanzania.
19. Hallberg, G. 1984. Agricultural chemicals and groundwater quality in Iowa. Bulletin No. CE-2081j. Coop. Extension Serv., Iowa State Univ., Ames IA.
20. Harwood, R. R. 1979. Small farm development: Understanding and improving farming systems in the humid tropics. Westview Press, Boulder, CO.
21. Harwood, R. R. 1983. International overview of regenerative agriculture. In: Resource-Efficient Farming Methods for Tanzania. Rodale Press, Emmaus, PA.
22. Harwood, R. R. 1984a. Organic farming research at the Rodale Research Center. In: Organic Farming: Current Technology and Its Role in Sustainable Agriculture. D. F. Bezdicek (ed.) Spec. Publ. No. 46, American Society of Agronomy, Madison, WI.
23. Harwood, R. R. 1984b. The integration efficiences of cropping systems. In: Sustainable Agriculture and Integrated Farming Systems. Michigan State Univ. Press, E. Lansing, MI.
24. Harwood, R. R. and J. P. Madden. 1982. Research agenda for the transition to a regenerative food system: Food production. Cornucopia Project, Regenerative Agriculture Assoc., Emmaus, PA.
25. Heichel, G. H. 1973. Comparative efficiency of energy use in crop production. Connecticut Agr. Exper. Station Bulletin No. 739, 26 pp.
26. Heichel, G. H. and D. K. Barnes. 1984. Opportunities for meeting crop nitrogen needs from symbiotic nitrogen fixation. In: Organic Farming: Current Technology and Its Role in Sustainable Agriculture. D. F. Bezdicek (ed.) Spec. Publ. No. 46, American Society of Agronomy, Madison, WI.
27. Howard, A. 1947. The soil and health: A study of organic agriculture. Devin-Adair, New York, NY. 196 pp.
28. Jain, H. K. 1985. Agriculture of tomorrow -- greater productivity, efficiency, and diversity. pp. 327-337. In: Biotechnology in International Agricultural Research, International Rice Research Institute, Los Baños, Philippines.
29. Kaffka, S. 1984. Dairy farm management and energy use efficiency. A case study with comparisons. Ph.D. Dissertation, Cornell Univ., Ithaca, NY. 113 pp.
30. Karel, A. K., M. E. Quentin, and D. L. Matthews. 1983. Alternatives to the conventional use of chemical pesticides. In: Workshop on Resource-efficient Farming Methods for Tanzania, Morogoro, Tanzania. Rodale Press, Emmaus, PA.
31. Keya, N. C. O. 1974. Grass/legume pastures in western Kenya. Legume Performance at Kitale, Kisii, and Kakamega. E. Afr. Agric. For. J. 39:247-257.
32. Kock, W. 1982. Principles and technologies of sustainable agriculture in tropical areas: A preliminary assessment. World Bank Report, Washington, DC.
33. La Rue, T. A. and T. G. Patterson. 1981. How much nitrogen do legumes fix? Adv. in Agron. 34:15-38.
34. Liebhardt, W. C. 1983. Nitrogen self-sufficiency. In: Workshop on Resource-efficient Farming Methods for Tanzania, Morogoro, Tanzania. Rodale Press, Emmaus, PA.
35. Liebhardt, W. C., C. A. Francis, and M. Sands. 1985. Research needs for the development of resource efficient technologies. In: Workshop on Regenerative Farming Systems. Rodale Institute, presented to USAID, Washington, DC.
36. Luckmann, W. H. and R. L. Metcalf. 1975. Introduction to insect pest management. John Wiley and Sons, New York, NY.
37. MacDonald, L. H. 1982. Agro-forestry in the African humid tropics. In: Proceedings Workshop at Ibadan, Nigeria, May, 1981. United Nations Univ., NRTS-17-UNUP-364.
38. Maher, D. 1982. The applicability of organic agriculture to the immediate and long-term needs of the Arusha region, Tanzania. Development Alternatives Inc. Report, Washington, DC.
39. Minjas, A. N. 1978. Weed problems and control practices in Tanzania. International Weed Sci. Soc. Conf. IITA, Ibadan, Nigeria.
40. Minjas, A. N. and R. K. Jana. 1983. Weed control. In: Workshop on Resource-efficient Farming Methods for Tanzania, Morogoro, Tanzania. Rodale Press, Emmaus, PA.
41. Motyka, G. and T. Edens. 1984. A comparison of heterogeneity and abundance of pests and beneficials across a spectrum of chemical and cultural controls. Pest Mgt. Tech. Rept. #41, Dept. of Entomology, Michigan State Univ., E. Lansing, MI.
42. Ngaiza, E. M. 1983. Manure and compost handling in Tanzania. In: Workshop on Resource-efficient Farming Methods for Tanzania, Morogoro, Tanzania. Rodale Press, Emmaus, PA.
43. Office of Technology Assessment (OTA). 1984. Africa Tomorrow: Issues in technology, agriculture, and U.S. foreign aid -- a technical memorandum. U.S. Congress, OTA-TM-F-31. U.S. Government Printing Office, Washington, DC.
44. Osiru, D. S. O. and R. W. Willey. 1972. Studies on mixtures of dwarf sorghum and beans (*Phaseolus vulgaris*) with particular reference to plant population. J. Agric. Sci. Camb. 70:531-540.
45. Parr, J. F. and R. I. Papendick. 1983. Strategies for improving soil productivity in developing countries with organic wastes. pp. 131-143. In: Environmentally Sound Agriculture. W. Lockeretz (ed.) Praeger Scientific Inc., New York, NY.
46. Parr, J. F., R. I. Papendick, and I. G. Youngberg. 1983. Organic farming in the United States: Principles and perspectives. Agroecosystems 8:183-201.
47. Patten, A. G. W. 1982. Comparison of nitrogen and phosphorus flows on an organic and conventional farm. M.S. Thesis, Washington State Univ., Pullman, WA.
48. Pimental, D., G. Berardi, and S. Fast. 1983. Energy efficiency of farming systems: Organic and conventional agriculture. Agric. Ecosystems, and Environ. 9:359-372.
49. Rao, M. R. and R. W. Willey. 1980. Evaluation of yield stability in intercropping: Studies with sorghum/pigeonpea. Expl. Agric. 16:105-116.
50. Rodale, R. 1983. Breaking new ground. The search for sustainable agriculture. The Futurist 17(1):15-20.
51. Rodale, R. 1985. Internal resources and external inputs -- the two sources of all production needs. In:

Maine study identifies soil-improving wastes

The Maine Department of Agriculture has published a report on waste products in the state that have value as agricultural soil amendments. The 13 waste products inventoried and described range from paper mill sludge to cheese whey.

In addition to providing the volume and location of each waste product, the 170-page report includes information on physical and chemical characteristics, suitability as a soil amendment, best handling methods, and farm use constraints. Copies of *Usable Waste Products for the Farm* are available on request from the Division of Resource Management, Maine Department of Agriculture, State House Station 28, Augusta, ME 04333.

Oil-related agriculture problems predicted

A report described as the first detailed comprehensive effort to predict U.S. oil-related agriculture problems well beyond the year 2000 has been published. Projections based on computer analyses indicate producers may face such high energy costs early in the next century that the United States will be unable to continue as a net exporter of agricultural products.

The 304-page volume is based on a 3-year study sponsored by Carrying Capacity and carried out by the Complex Systems Research Center at the University of New Hampshire. Copies of *Beyond Oil: The Threat to Food and Fuel in the Coming Decades* is available for $14.95 postpaid from Carrying Capacity, 1325 G St., N.W., Washington, DC 20005.

Organic directory is published in California

A directory listing more than 200 organic food wholesalers and distributors and more than 100 suppliers of biological pest controls and other organic farming inputs has been published by the California Agrarian Action Project.

The directory has listings from 32 states and Canada and is designed to help make connections between organic farmers, wholesalers, and suppliers. *1986 CAAP Directory: Wholesalers of Organic Produce and Products* is available to non-members for $26.75 postpaid from CAAP, P.O. Box 464, Davis, CA 95617.

OTA issues major farm technology report

The Congressional Office of Technology Assessment (OTA) has issued a major report that analyzes the likely impacts of biotechnology and information technology on agriculture between now and the year 2000. It focuses on the relationship of technology to production, farm structure, rural communities, resource conservation, credit, research and extension, and public policy.

The 374-page report identifies and describes 150 production technologies likely to become available commercially to shape and define agriculture over the next 15 years. Copies of *Technology, Public Policy, and the Changing Structure of American Agriculture* are available for $13 from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Environmental education guide is available

A guide to environmental programs offered by 95 colleges and universities in New England has been published. In addition to listing a faculty contact and describing the environmental curricula offered, the guide covers internship opportunities, research and fieldwork facilities, and associated environmental organizations.

Single copies of *A Guide to Environmental Programs in New England Colleges & Universities* are available on request from the New England Environmental Network, Lincoln Filene Center, Tufts University, Medford, MA 02155.

Workshop on Regenerative Farming Systems. Rodale Institute, presented to USAID, Washington, DC.

52. Sanchez, P. A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, Inc., New York, NY.
53. Samoka, J. M. R., B. J. Ndunguru, and W. C. Liebhardt. 1983. Agronomic aspects of manure and compost use. In: Workshop on Resource-efficient Farming Methods for Tanzania, Morogoro, Tanzania. Rodale Press, Emmaus, PA.
54. Smith, M. E. and C. A. Francis. 1986. Breeding for multiple cropping systems. pp. 219-249. In: Multiple Cropping Systems. C. A. Francis (ed.) Macmillan Publ. Co., New York, NY.
55. Timberlake, L. 1985. Africa in crisis: The causes, the cures of environmental bankruptcy. Earthscan, International Institute for Environment and Development, Washington, DC. Russell Press, London, UK.
56. Urban, F. and T. Vollrath. 1984. Patterns and trends in world agricultural land use. U.S. Government Printing Office, Washington, DC.
57. U.S. Department of Agriculture. 1980. Improving soils with organic wastes. U.S. Government Printing Office, Washington, DC. 157 pp.
58. U.S. Department of Agriculture. 1980. Report and recommendations on organic farming. U.S. Government Printing Office, Washington, DC. 94 pp.
59. Vogtmann. H. 1984. Making nitrogen with organic cropping systems. pp. 16-18. New Farmer and Grower (Spring).
60. Walker, R. H. and G. A. Buchanan. 1982. Crop manipulation in integrated weed management systems. Weed Sci. supplement 30:17-24.
61. Wegrzyn, V. A. 1984. Nitrogen fertility management in corn -- a case study on a mixed crop livestock farm in Pennsylvania. Ph.D. Dissertation, Pennsylvania State Univ., University Park, PA. 158 pp.
62. Willey, R. W. and D. S. O. Osiru. 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. J. Agric. Sci. Camb. 79:517-529.
63. Willson, G. B., J. F. Parr, E. Epstein, P. B. Marsh, R. L. Chaney, D. Colacicco, W. D. Burge, L. J. Sikora, C. F. Tester, and S. B. Hornick. 1980. Manual for composting sewage sludge by the Beltsville aerated pile method. EPA-600/8-80-22. U.S. Government Printing Office, Washington, DC. 65 pp.
64. Wortman, S. and Cummings, R. G. 1978. To Feed this World: The Challenge and the Strategy. Johns Hopkins Univ. Press, Baltimore, MD.
65. Youngberg, I. G. 1984. Alternative agriculture in the United States: Ideology, politics and prospects. In: Alternatives in Food Production. D. W. Knorr and T. R. Watkins (eds.) Van Nostrand Rheinhold Co., New York, NY.
66. Youngberg, I. G., J. F. Parr, and R. I. Papendick. 1984. Potential benefits of organic farming practices for wildlife and natural resources. Trans. North Amer. Wildlife and Natural Res. Conf. 49:141-153.