ISSN 1010-7045

LOW-INPUT, ENVIRONMENTALLY SENSITIVE TECHNOLOGIES FOR AGRICULTURE

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This publication is a published version of the 1984 Grant F. Walton International Lecture that was presented at Rutgers, The State University of New Jersey, New Brunswick, NJ, United States of America.

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Apartado Aéreo 6713
Cali, Colombia

Reprint Series 001
ISSN 1010-7045
Mayo 1987
Press run: 850
Printed in Colombia

Nickel, John L. 1987. Low-input, environmentally sensitive technologies for agriculture. Grant F. Walton International Lecture presented at Rutgers, The State University of New Jersey. 16 October 1984. Centro Internacional de Agricultura Tropical, Cali, Colombia. 22 p.

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Conceptual Context

During the past several decades, through the combined efforts of the developing countries themselves, international financial institutions, and technical assistance agencies, there has been impressive progress in economic development of the third world. Between 1955 and 1980 the developing countries, as a whole, achieved an annual average growth rate of just over 3%. During this period health and nutrition systems were improved, lifting life expectancy and lowering mortality rates, and, in spite of gloomy predictions, food production in the developing countries has kept up with population increases. Between the period 1961 to 1977 food production in the less developed countries increased at an annual rate of 2.7% while population increased at 2.6% per year.

However, some clouds have obscured the brightness of this progress. For one thing, the rate of growth in food production has been slowing down. During the decade of the 1960s, when the impact of the so-called "green revolution" was most apparent, the rate of increase in food production was 2.9%. During the decade of the 1970s this fell to 2.6%. Furthermore, economic development itself created a much more rapid increase in consumer demand, so that the developing countries, which were net exporters of food before the Second World War, registered net imports of food of 5.3 million metric tons per year during the period 1961 to 1965 and 23 million metric tons per year during the period 1973 to 1977. The International Food Policy Research Institute projects these net imports of food staples will increase to 80 million metric tons per year by the year 2000.

Probably the darkest cloud of all on the horizon is that many of the poorest nations and the poorest segments of these and other countries are being left further and further behind in the development process, so that hundreds of millions of people still face appalling deprivation.

There are great differences of opinion on how to define malnutrition, but regardless of which statistics one believes it remains evident that malnutrition is still a pervasive problem in the developing countries. Malnutrition cannot be separated from poverty and, indeed, it is sometimes aggravated by economic development since increased demand for food and growing dependence on imports increases food costs. While for some this is merely an inconvenience, for the poor, who are already living at the very edge of existence and spending a major proportion of their meager incomes on food, increased food prices means eating less food and less nutritious food.

A tremendous challenge still remains to attack both hunger and poverty at the same time. Thus, it is not enough just to produce more food but it is also necessary to produce food at lower unit costs and to increase the incomes of the poor. Since a large proportion of the poorest people are in the rural sector and are small farmers, it is essential that the income of small holders be increased. This will not only help overcome poverty but the increased income for this sector of the population will increase the market for the type of consumer goods more likely to generate employment, since the type of goods they are likely to purchase are the ones which can best be produced by labor-intensive industry. More food at lower unit costs will also provide less expensive wage goods, thus stimulating local industrial development. The key factor in this process is the development of new, land-augmenting technology which will increase productivity.

At the same time as we are trying to meet this difficult and urgent challenge, there is growing concern that increased agricultural production is being achieved at the cost of environmental degradation. This is especially critical as much of the potential increase in production has already been achieved on the best lands and agriculture is being pushed to more marginal conditions. While it is certainly true, as the World Bank President Robert McNamara stated, that "human degradation is the most dangerous pollutant there is", those of us attempting to develop the badly needed new production technology must also try to do so in a manner which is environmentally responsible.

The strategy to develop low-input, environmentally sensitive technology is a key component to meeting this challenge.

The green revolution: a dynamic process

The high-yielding rice and wheat varieties which made possible the recent dramatic surge in production, popularly known as the "green revolution", were greatly superior to traditional varieties, although only under conditions of high-input use, particularly of nitrogen fertilizer and irrigation. Any talk advocating low-input technologies may therefore be assumed as implying criticism of the research strategy which led to the green revolution. This is certainly not my intent. The dramatic beneficial impact of the early generation, high-yielding varieties cannot be ignored. The world is a better place because of those developments. By helping overcome the very urgent shortages of grain in some of the most critically deficient countries these achievements have improved nutrition and real income of millions of farmers and urban poor. At the same time they have purchased valuable time to grapple with the more complex problems of food production under less optimal conditions.

By advocating a low-input strategy, I am not suggesting that we turn the clock back to antiquated, unrealistic crop improvement methodologies. Those of us who visited agricultural research stations and agricultural development projects in the 1950s and 1960s, frequently witnessed two phenomena: on the one hand, at research stations, plant breeders working with a very narrow germplasm base were making their selections in fields without the use of any fertilizers or pesticides with the rationale that farmers could not afford such inputs; and, on the other hand, extension agencies were conducting large numbers of fertilizer demonstrations with the assumption that by using fertilizers alone farmers could greatly increase their productivity. It was clear that neither of these strategies were working very well. The real breakthrough came when Norman Borlaug and his colleagues, at what later became CIMMYT[1], and the scientists at IRRI[2], recognized why cereals were not responding to fertilizers and changed the basic plant types to those which would. While it is true that one of the reasons for this success was that they selected materials under favorable conditions in order to identify those with high-yielding potential, there was much more to the research philosophy which ushered in the green revolution than this.

Other important components in the crop improvement strategies of the Rockefeller Foundation, and IRRI and CIMMYT programs which contributed to their success included:

A quantum jump in the size of the genetic base available to breeders and the number of crosses made;

An interdisciplinary crop improvement effort, involving genetics, agronomy, plant physiology, entomology, and plant pathology;

Use of extensive, collaborative networks to test adaptation to different ecological conditions and disseminate promising materials;

Combining high-yield characteristics with resistance to pests, diseases, and adverse environmental conditions; and

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[1] CIMMYT: Centro Internacional de Mejoramiento de Maíz y Trigo, El Batán, Mexico.

[2] IRRI: International Rice Research Institute, Los Baños, Philippines.

International mobility of materials, people, and ideas.

And we have come a long way since then.

While it was logical to give initial priority to those crops and conditions which would give quick payoff to research investments in terms of increased agricultural production, the system of International Agricultural Research Centers (IARCs), which began with work on wheat and rice, has gradually expanded to cover many other food commodities and cropping systems, including those in areas with marginal conditions for agriculture.

For many of these crops and systems the major production constraints are not inadequate response to fertilizers, but various other factors such as: susceptibility to pests and diseases, soil toxicity problems, and drought. Many of these factors are amenable to genetic solutions. In such cases improvement of yield levels and yield stability is feasible through new technology that is relatively independent of the amounts of purchased inputs.

The use of fertilizers, pesticides, and irrigation will continue to play an important, and probably an increasing, role in the future for at least two reasons. One is the urgent need to close the increasing gap between production and demand for agricultural products. All the tools at our disposal, including increased use of inputs, will be necessary to meet the challenge to reverse these trends and solve the tremendous problems of individual human misery that they imply.

Inputs are especially important to improve the lot of small farmers. By definition small farmers have limited land resources. In order to maximize their return on this scarce resource, and on their own labor, small farmers of all people are those who should be using more inputs whenever it is possible for them to do so. Thus, advocating the development of technologies which are not dependent on high levels of inputs is not so much recommending against farmers using inputs as a recognition of what is possible and likely.

Rationale for a Low-Input Philosophy

While recognizing that the continued, rational use of inputs will be required in world agriculture, I strongly believe that those responsible for developing new production technology, particularly for the marginal lands and small farmers characterizing much of the production of the tropical developing countries, must generate technology which will increase productivity with the minimum use of inputs. This is true on a global basis but is particularly true for the tropical developing countries. I will first develop the reasons for the general, worldwide applicability of this philosophy and then indicate why there is a particularly critical need for such technology in the lesser developing countries.

The title of this paper is *Low-Input, Environmentally Sensitive Technologies for Agriculture*. In this section I wish to point out why in many cases the terms "low-input" and "environmentally sensitive" are nearly synonymous. Increasing evidence shows the adverse effects of excessive fertilization and pesticide applications on the soil and subsurface water. Furthermore, pesticide residues on foods, particularly in countries where there is little control of such residues, represent a public health hazard which would be reduced if this use could be minimized. The literature also abounds with examples of induced pest outbreaks resulting from the destruction of natural enemies by imprudent use of pesticides.

The use of purchased inputs can reduce unit costs of production when the costs of such inputs are more than offset by the increased productivity. Nevertheless, to the extent that new technology can be developed which will produce the same amount at lower input levels, production costs and prices to consumers can be reduced.

Many agricultural production inputs are based on fossil fuels; others are dependent on the use of mineral deposits. Reducing the levels of input required per unit of increased productivity will reduce the rate at which these finite resources are depleted.

These considerations are of even greater importance in tropical developing countries. Much of the food production in the third world is on marginal, nonirrigated lands which are in the hands of small farmers with limited resources and poor access to credit and input markets. Also, most of the poorest and hungriest people in the world live in the tropics. Here, the ecological conditions impose additional reasons for minimizing input use. In the case of pest control, problems created through destruction of natural enemies are to a large extent annually erased in lands with harsh winters. Farmers in the tropics have to live with their mistakes for a longer time.

Fertilizer efficiency is also less in the tropics because of the higher degree of leaching of nitrogen and the greater degree of fixation of phosphorus. Thus, the cost of fertilizer used per unit of increased productivity is often higher in the tropics, placing a greater premium on finding ways of minimizing the amount of fertilizer required to achieve increased productivity.

The hot, humid conditions of the tropics, as well as the limited resources of the farmers, make the use of protective masks and clothing practically impossible. This and the fact that many farmers are poorly educated means that printed warnings on pesticide containers, if indeed they are present, are often ignored. Thus the use of pesticides is more hazardous to applicators under tropical developing conditions.

For these reasons the goal of agricultural research, particularly in the tropical developing countries, should be to develop technology which will make possible higher yield potentials with high-input levels when such use is economically and ecologically feasible but which will at the same time also significantly increase productivity at low-input levels, so that those who cannot or should not use high levels of inputs will still have access to the benefits of such technology.

Research Strategy

Pursuit of the goals described above requires a considerable modification in research strategy.

Genetic versus chemical solutions

Using the tremendous amount of genetic variability now at our disposal in the vastly expanded pool of genetic resources available in large germplasm banks it is possible to solve many of the production constraints through the "seed" rather than the "bag".

The chief application of the "seed" versus "bag" concept is in the field of plant protection. There is increasing evidence that many pests and diseases can be controlled by incorporation of genetic resistance rather than by excessive reliance on pesticides. While genetic resistance will certainly not solve all pest problems, it is an important component of integrated pest management practices. In many cases the type of resistance encountered is that of tolerance, that is, a plant will be less adversely affected by modest levels of pests and diseases. This fits neatly into integrated control concepts since moderate levels of pests numbers are often required to maintain natural enemy populations.

Genetic tolerance to adverse conditions, such as soil acidity or soil salinity, can greatly minimize the need for the application of soil amendments. Thus, it is possible to change the plant instead of changing the soil environment.

The extent to which plants, either because of physiological mechanisms or greater earliness, are able to maintain reasonable productivity levels under low levels of soil moisture availability or to escape moisture stress, the amount of irrigation water and energy required can be reduced. The risk of short-term drought for those farmers who do not have access to irrigation is therefore minimized.

I now come to fertilizer use, which I have purposely mentioned last, because it is usually first in people's minds when a minimum-input strategy is discussed. Indeed fertilizers, particularly nitrogen fertilizers, are required for reasonable production levels of cereals. However, when considering a broader range of crops, other production constraints, such as pests, diseases, adverse soil conditions, and drought, are often more important than soil fertility in reducing production. While fertilizers will, in many cases, be required, genetic improvement can, in some cases, even reduce the use of this important input. One way, which is restricted mostly to the legumes, is that of nitrogen fixation. Whenever it is possible to improve the efficiency of nitrogen fixation through genetic improvement so to more effectively fix nitrogen with native, added, or selected rhizobium strains, the amount of nitrogen fertilizer required can be reduced. Also, the uptake of nutrients naturally occurring in the soil or added as fertilizers can be enhanced through improved mycorrhizal plant associations. In the case of nutrients applied as fertilizers, their efficiency can be increased through improved fertilizer formulation. However, taking up nutrients more efficiently in unfertilized soils may result in depletion of soil nutrient resources. Therefore, the genetic approach to finding plants with lower intrinsic nutritional requirements represents a longer range solution to reducing fertilizer requirements.

Agronomic practices

Minimum or zero tillage techniques are increasingly being developed by research institutions. These reduce soil erosion and may also lessen the amount of fossil fuel consumed in land preparation.

Associated cropping, for example, simultaneous or relay planting of several species on the same piece of land, is commonly practiced by farmers in tropical developing countries. Many experiments have shown that this is a very sound practice—not only does it frequently increase the total net income per unit of area for the farmer, but there is growing evidence that insect and disease problems are less severe in mixed cropping as opposed to monoculture. Furthermore, intercropping often reduces the severity of weed problems, minimizing the need for hand weeding or herbicide applications.

Research Methodology

Having outlined a general research strategy to develop low-input, environmentally sensitive technology, I now wish to turn to some specific methodology implications for the implementation of such a strategy.

Input levels in varietal improvement

The level of input to use in selection nurseries is a matter of considerable controversy and probably one on which it is not possible to generalize but in which specific methodology will need to be used for different species or crop types. Our colleagues working with maize and wheat report evidence that if selections are all made at low-input levels the resulting varieties will lack the potential for higher yields at high-input levels. On the other hand, methodological experiments with beans have demonstrated that advanced lines selected in early generations without protection from insects and diseases perform well under both protected and unprotected conditions, whereas lines developed through selection in early generations under protected conditions perform well when protected but poorly when unprotected. Also, early in our cassava breeding efforts we found that selection of higher yielding plant types under optimal conditions resulted in materials which performed very badly in more stressful environments. Initial selection under the conditions of high pest, disease, and soil stress followed by a selection for high yields appears to be a better approach.

It will probably be necessary, for most crops, to develop a methodology which involves evaluation and/or selection under a range of conditions in order to achieve the goal of developing technology which will perform better than the current technology at low-input levels and at the same time have the potential for high levels of productivity at high-input levels.

Interdisciplinary team approach

The application of the research strategy described cannot be done effectively by researchers, such as breeders, plant pathologists, entomologists, soil scientists, economists, working in isolation or even under some form of loose coordination. The best approach appears to be the development of well integrated, interdisciplinary teams of scientists organized along commodity lines.

Decentralized crop improvement

In order to develop technology for high- and low-input systems as well as different ecological conditions, it has become even more apparent that selection of segregating materials and development of agronomic practices cannot be done at a single location. For each commodity distinct ecologies—each with its particular complex of edaphic, climatic, and biotic conditions and cultural practices—must be defined and research conducted in sites representative of the major systems to develop the appropriate technology for each one. To accomplish this we need to generate a better inventory of the ecologies in which the respective commodities are currently grown or will potentially be cultivated.

Onfarm research

In order to ensure that the new technology being developed is appropriate to real farming systems under less-favored environmental conditions, onfarm evaluation must be incorporated at an early stage of the technology generation process. Conditions on experiment stations generally tend to be more nearly like those of farms at high levels of management. Therefore, technology which is developed and evaluated only on experiment stations is less likely to be useful for the conditions of the average farmer, in particular, small-scale farmers. Consequently, an important component of a low-input research strategy is onfarm testing, not only to evaluate the technology which has been developed, but to provide an important feedback into the earlier phases of technology generation.

Some Examples of Progress

The type of research strategy described above is not an untried philosophy. Increasing evidence from a number of research institutions, including many of the international agricultural research centers, demonstrates that this strategy works. What follows are some examples of progress in the application of this strategy taken from CIAT's programs.

Beans

The common bean, *Phaseolus vulgaris,* is susceptible to a wide range of viral, fungal, and bacterial diseases, as well as to several insect pests, but it is usually grown with little or no chemical protection. Insects and diseases represent the most important production constraints for this crop. The CIAT Bean Program has concentrated most of its breeding efforts on developing resistance to pests and diseases in order to improve yield stability as well as increase yield levels and reduce the need for chemical pesticides. Much of the selection in the breeding program is conducted in fields with little or no chemical protection.

The most destructive bean disease in several Central American and Caribbean countries is bean golden mosaic virus. CIAT scientists collaborating with Guatemalan scientists have developed new hybrids that are tolerant to this disease. Several of these were recently released to farmers by the national research agency of Guatemala. Sister lines have been selected and a new variety released in Mexico. Results on farmers' fields in both countries, under conditions of heavy disease pressure, have demonstrated an important principle of the low-input technology philosophy: that technology developed for low-input conditions can also increase potential for higher yields for those farmers who can afford the use of purchased inputs. In these trials the new, tolerant varieties yielded more without use of pesticides than the traditional local variety using insecticide seed treatment and five insecticidal sprays. With insecticide applications they yielded even more. The fact that the selections were made in the presence of the disease rather than at CIAT headquarters where it does not exist also illustrates the important principle of decentralized crop improvement.

The leafhopper, *Empoasca,* is the most important insect pest of beans in Latin America. With current varieties it is impossible in some areas to obtain a bean crop without repeated insecticidal sprays. No single genes for resistance to this pest have been found in the germplasm collection. However, some moderate tolerance was found in a few plants. This tolerance was found to be additive and multigenic. After many generations of crossing the tolerant lines, the level of tolerance in some of the lines presently coming out of this breeding program has increased remarkably, reducing the amount of insecticide required to produce a good crop.

Most soils in which beans are grown, especially in Latin America, are highly deficient in phosphorus. Therefore, some phosphorus fertilizer application is usually essential to obtain a reasonable bean yield. In many cases, the best yield is obtained at very high levels of phosphorus fertilizer application (300 kg or more of P_2O_5). CIAT's bean breeding program is screening breeding lines at lower levels (for example, 50 kg of P_2O_5 per ha) in soils with less than 2 ppm of P (Bray II extraction method) and has found considerable genetic variability in the ability to produce reasonably well at these modest fertility levels. Although only preliminary results are available, there is reason to believe that the higher yielding genotypes actually have a lower intrinsic phosphorus requirement (a higher efficiency of use) rather than merely the ability to extract phosphorus more efficiently from the soil.

One reason bean farmers traditionally use few inputs is the high degree of riskiness of this crop. If the risk can be reduced by greater disease and insect resistance and/or drought tolerance, farmers are more likely to use improved agronomic practices, including needed inputs. Data from Costa Rica, where 37% of the farmers who are utilizing new, improved bean varieties have also increased their planting density, support this hypothesis.

Cassava

The root crop cassava (*Manihot esculenta*) is an important part of the diet and a relatively inexpensive source of calories for hundreds of millions of people in the tropical developing countries. This crop is also an example of one in which the goal of maximum yields under optimal conditions may not be totally compatible with stable, improved productivity at low input-levels. Therefore, distinct breeding strategies are required for different ecologies. Like beans, cassava is grown mostly by small farmers. However, because it has a long growth cycle (usually about 12 months versus 4 months for beans), is vegetatively propagated, and is normally grown under marginal conditions, a considerably different strategy is required to develop a low-input technology for improved productivity of this crop than with beans.

Short-term insect or disease damage to the aerial portions of the cassava plant can be sustained without causing as great a yield loss to the harvested portions as would result with shorter duration crops. A large germplasm collection has been assembled and sources for genetic resistance to important diseases such as cassava bacterial blight and superelongation disease, as well as to important insect pests such as thrips, have been identified. The breeding program combines these resistance factors with high-yield ability in improved hybrids. However, no genetic resistance has been found to the hornworm, a defoliation pest. Biological control methods have been identified, but these depend on permitting moderate levels of infestation and defoliation. Thus, a leaf area index (LAI) of 3 (that is, the total area of the leaves of the plant is 3 times the surface area of the soil on which the plant is grown), which is considered ideal for maximum root production under optimal conditions, does not allow a safety margin for adverse circumstances, such as a hornworm attack. Varieties with a higher LAI (surplus leaf production) have been shown to sustain massive defoliation from hornworm attacks with little loss in root yields, while less leafy clones, considered to have a more optimal LAI, suffered greater yield loss from hornworm infestations. This demonstrates that, in the case of cassava, a breeding strategy to produce a plant which requires little or no chemical protection is different from that which develops a plant for maximum production under ideal conditions.

Drought stress experiments have shown that long periods without rain greatly reduce the yields of some clones, but not others. The most affected ones were precisely those which yield best under optimal conditions. These findings demonstrate that the achievement of stable performance under different water availability patterns may be achieved only by sacrificing some yield potential under less stressful conditions.

The combination of cassava's fibrous root system and mycorrhizal fungi (which usually occur naturally in the soil) enables this plant to grow in soils with very low phosphorus content. Current studies at CIAT have demonstrated that inoculation with selected mycorrhizal fungi will enhance P uptake, especially on degraded soils which lack natural inoculum.

Rice

Rice crosses at CIAT are made to produce a more vigorous plant that tolerates soil and disease stresses, with the hope that such a plant will be competitive with weeds and produce high yields at reduced levels of nitrogen fertilization. These crosses have resulted in a new variety, which the Instituto Colombiano Agropecuario (ICA) has released in Colombia as CICA 8, and which is now grown widely throughout Latin America. This variety is sufficiently more vigorous and better adapted to a range of environments than previous varieties that farmers have responded by reducing seeding rates and lowering levels of nitrogen fertilizer. In Colombia, irrigated-rice growers have reduced their seed rates and nitrogen fertilization by 50 to 100 kg/ha and still obtain higher yields than with previous varieties.

Because of high energy costs of irrigation and greatly increased land cost in traditional irrigated production areas, more and more growers are cultivating rice under favored upland conditions. "Upland" is defined as direct seeded rice production without water control through bunding or irrigation. Thus, it can be applied in areas of cheaper land where there is adequate rainfall to produce a rice crop and where no irrigation is used. Here CICA 8 has also performed well under more difficult soil and moisture conditions. CICA 8, being somewhat more vigorous and competitive than earlier HYVs, has been adopted very rapidly for favored upland conditions in many Latin American countries.

CICA 8 is also resistant to the plant hopper, *Sogatodes oryzicola*, a severe pest in tropical Latin America, enabling farmers to eliminate insecticide applications.

The application of a low-input strategy to rice in Latin America is also shown in a search for stability of resistance to the rice blast disease (*Pyricularia oryzae*), the most damaging disease in that region. All improved rice varieties initially display resistance to rice blast but eventually develop susceptibility to it, because of the constantly changing race structure of the fungus. Although this disease can be controlled by chemical fungicides, special attempts have been made to obtain more stable resistance.

The CIAT rice breeding program has implemented a series of genetic strategies to combine genes for resistance to rice blast from various parents of different geographical origins. The varieties CICA 7 and CICA 8, products of this program, have remained relatively resistant for nine and seven years, respectively. Other lines from this crossing program, incorporating an even broader range of sources of genetic resistance, have now been tested for several years throughout Latin America. One was recently released by ICA as Oryzica 1. Consequently, fungicide use has decreased.

Pastures

CIAT's Tropical Pastures Program concentrates its efforts on the acid, infertile savannas of Latin America. The soils of this region are characterized by a low pH (between 4.0 and 4.5) and very high aluminum saturation of the exchange capacity. The traditional approach in the selection and development of improved pastures for such soils is to apply large amounts of lime to reduce soil acidity and overcome aluminum toxicity. Instead, the Tropical Pastures Program is selecting plants adapted to such soil conditions. The Program has accumulated a germplasm bank representing some 10,000 tropical grasses and legumes. Many of these legumes were obtained through collection expeditions in areas of Latin America where such species have evolved on acid soils. Other leguminous plants have been collected under similar conditions in Asia and a number of grasses have been obtained from Africa. Out of this collection, several species and cultivars have been identified that prosper under acid infertile savanna conditions and require only low levels of fertilizer for establishment and pasture maintenance.

Selecting plants which do well under acid soil conditions has two important benefits. First, in contrast to nonadapted species—which require lime application to neutralize soil acidity and which, therefore, have their root zone restricted to the top few inches of the soil where the lime has been applied—adapted species send their roots deeply into the soil. Thus, they are better able to survive and to provide forage during the dry season. Second, since the soils remain acid, rock phosphate applied to these soils becomes soluble over time, reducing the necessity to use the more costly and energy-consuming, soluble phosphate sources.

Similarly, the Tropical Pastures Program is developing pastures based on grass/legume associations so that the pasture grasses, which usually require a great deal of added N for high productivity, will not require any nitrogen fertilizer. Development of legume-based pastures, in addition to providing N for the grass, also results in higher quality forage, particularly during the dry season. One added advantage of legumes is greater pasture persistence and therefore sustained animal productivity over time.

Other technological improvements include the development of more efficient methods of fertilizer application and cultural systems utilizing reduced tillage. Good progress has been made in developing pasture establishment methods which involve minimum disturbance of the soil. This not only reduces costs and energy requirements but avoids soil erosion.

Good progress has been made in the application of this strategy. Long-term experiments in savanna regions have demonstrated a twofold increase in individual animal gains and a fifteenfold increase in productivity per area of land relative to native pastures.

Conclusions

The preceding examples have shown that a research strategy aimed at producing technology which is less dependent on high levels of purchased inputs can indeed produce technology which is equity sensitive and environmentally friendly.

The application of this research strategy can make a major contribution to solving the problems described at the beginning of this paper. Insect and disease-resistant materials will reduce the riskiness of farming and thereby improve the livelihood of thosse farmers who are so poor that they have little margin for error. Reducing production costs and increasing productivity by small holders will increase their net income, improving not only their welfare but making them important customers for consumer products and so stimulating industrial production in the urban sector. The larger quantity of lower cost products will be essential to provide the food required for the increased demand which greater employment generated by industrial development will create.

Thus, the new low-input production technology will represent an important tool to overcoming both hunger and poverty which work together to rob hundreds of millions of impoverished people of the most essential elements of a decent, dignified existence. They will also permit expansion of agricultural production into marginal areas in a manner consistent with the protection of the environment.

While these applications are particularly important to the developing world, elements of this research strategy also need to be applied in industrialized countries where current technology depending on high energy use must be modified in a manner so as not to rob future generations of their heritage of nonrenewable resources.

A CIAT Publication

Communication and Information Support Unit

Editing:	Elizabeth L. de Páez
Cover design:	María Claudia Ortíz H.
Production:	CIAT, Graphic Arts