CIAT in the 1990s and Beyond:

A Strategic Plan

Supplement

CIAT
Centro Internacional de Agricultura Tropical

CONTENTS

Section 1

ECONOMIC AND AGRICULTURAL TRENDS IN LATIN AMERICA AND THE CARIBBEAN: IMPLICATIONS FOR THE GENERATION OF AGRICULTURAL TECHNOLOGY

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Most of this paper is dedicated to long-term trends because these provide the most useful indicators for the generation of agricultural technology. The paper first deals with past economic and agricultural trends in Latin America and the Caribbean; then with the existing situation and the consequences for possible growth in the near future, leading to a discussion of alternative development paths and long-term trends; and finally closes with a discussion of implications for technology generation and conclusions.

Structural change, 1950-1980

The abrupt changes observed in Latin America since the 1950s in terms of growth, urbanization and modernization were accompanied by a marked trend to diminish the reliance of economic activity on the primary sector, as a result of important developments in industry and services. The strategies of import substitution and self-sufficiency of the 1960s, supplemented by export promotion in the 1970s were based on a model of industrialization at the expense of the agricultural sector (García and Montes, 1989; Krueger et al., 1990).

Agriculture dropped from contributing 21% to the GDP and 54% to employment of the active population in the 1950s, to the present levels of 11% and 32%, respectively (Table S1.1). This reduction was absorbed almost equally by industry and services. Industry now provides 37% of GDP but employs only 26% of the active population. The service sector provides 52% of GDP and employs 42% of the people. Per capita income in the three sectors differs strongly: in agriculture, it is only US$640, whereas in industry and services it is US$2530 and US$2200, respectively.

At first glance, it is easy to conclude that agriculture has lost importance in the Latin American scene. Yet, a closer look reveals that agroindustry has been the main component of growth in manufacture, which in turn is the most dynamic industrial

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Table S1.1. Relative importance of different production sectors in Latin America and the Caribbean.

Production sector	Percentage of GDP (1987)	Annual growth 1980-1987 (%)	Percentage share of employment	Average per capita income (1987) (in US$)
Agriculture	11	2.2	32	640
Industry and mining	37	1.0	26	2530
Services	52	2.1	42	2200
Average		1.7		1790
Total	100		100	

SOURCES: World Bank, 1987 and 1989.

activity (Lynam et al., 1987; Machado, C., 1986; World Bank, 1983). Furthermore, agriculture has expanded its linkages with other industries (e.g., metallurgic, chemical and construction), as well as with the services sector.

The current economic situation

The economic performance of Latin America and the Caribbean in the 1980s was dismal to the point that the decade has been labeled the "lost decade." Structural problems related to the high debt situation, permanent fiscal deficits, hyperinflation, unemployment, and the outburst of parallel and informal economies led to decapitalization and recession in the region.

As shown in Table S1.2, from the early years of the decade, the region's debt burden took on enormous proportions. To overcome this crisis many countries cut their subsidies, curtailed their imports and attempted to stimulate their exports through drastic currency devaluations. The trade balance for the region turned positive toward the middle of the decade and, as most countries made valiant efforts to comply with debt repayment and interest schemes, the capital inflow of the early 1980s was replaced by a capital outflow. Because of worsening terms of trade, growth in the value of exports was less than expected. Also, domestic demand and the need for productive investment made it impossible to limit imports to the level of the mid-1980s. The increase in the trade surplus petered out by the end of the decade.

Table S1.2. Some macroeconomic indicators for Latin America and the Caribbean in the 1980s.

Indicator	1981	1985	1989
1. Outstanding debt (US$ billions)	290	377	415
2. Real effective exchange rate[a]	94	125	151[b]
3. Trade balance (US$ billions)	-12	+29	+22
4. Capital transfer (US$ billions)	+10	-33	-25
5. Inflation (%)	58	275	994

a. Source: de Janvry and Sadoulet, 1990.

b. For year 1987.

SOURCE: CEPAL, 1989.

The region did not develop sufficient repayment capacity to reduce its outstanding debt, the nominal value of which increased throughout the decade.

By the end of the decade, the average deficit in government budgets amounted to 10.2% of GDP (Table S1.3), leading to soaring inflation. This further constrained the functioning of capital markets and stimulated capital flight into foreign exchange, thereby reducing the level of investment.

During the 1980s, per capita income fell by 1% per year; by the end of the decade, on average, people were about 10% poorer than at the beginning. Nevertheless, at US$1780 in 1989, average per capita income in the region remained higher than in Asia, where it was about US$700, and in Africa, where it was only US$470 (World Bank, 1989).

During the 1980s, when the overall economy contracted, agriculture grew more rapidly than the other sectors, but still not as fast as the human population. The cause for agriculture outperforming the rest of the economy in this period was mostly a result of the fixities present in the sector that make it, to a large extent, a recession-proof sector. However, it is also a result of change in the general policy framework that was partly induced by the inability to pursue past policies that were highly demanding in terms of subsidies and fiscal contributions. The model of the 1970s, based on discrimination against agriculture, was severely questioned and a lessening of

Table S1.3. Government spending and deficits in Latin America and the Caribbean, 1987.

Country	Government spending as percentage of GNP (1987)	Deficit as percentage of GNP (1987)
Brazil	26.1	13.3
Mexico	22.7	9.5
Venezuela	22.0	2.1
Colombia	14.7	-0.7
Costa Rica	28.3	4.8
Regional average for		
Latin America	n.a.	10.2
Average OECD members	28.4	4.4

SOURCE: World Bank, 1989.

discriminatory policies with ad hoc compensations directed toward selected commodities has been detected in most countries (Knutsen, 1988).

Population growth in Latin America and the Caribbean averaged 2.4% during the 1980s. This growth was almost entirely concentrated in urban areas, which, by the end of the decade, accounted for 70% of the region's 440 million inhabitants. During the 1990s, population growth is expected to fall to 1.9%, but if this remains concentrated in urban areas, the ratio of urban to rural population will still increase by 2.5% per year.

For both per capita income and population growth, the average figures hide considerable differences, both among and within countries. For example, birth rates in the Southern Cone are lower than in tropical America. Moreover, the average income figure masks the sharp differences between the poor and the rich, characteristic of the region. CEPAL (1990) estimates that 37% of all Latin American and Caribbean households are poor, that is, they have an income less than twice that needed to buy the basic food basket, and 17% of households are destitute, meaning that their income is lower than the cost of the basic food basket.

Table S1.4 shows that the patterns of poverty in the region have been changing. During the 1980s, both types of poverty increased in the urban environment. In the rural areas, destitution increased, whereas the total percentage of poor households remained roughly the same. In all, poverty levels are worse than before, particularly in the urban sectors. In 1970, 37% of the poor were found in that sector, but by the end of the 1980s, 57% were in the cities. Extreme poverty continues to be mostly found in the rural sector, but the proportion in the urban sector grew from 31% in 1970 to 45% in the late 1980s.

In the 1980s, there was a loss in average nutrient intake, as compared with the previous decades. This was particularly notorious in the Andean countries and Southern Cone (Table S1.5). In Central America and the Caribbean, substantial increases in food aid helped to maintain the nutrient intake levels.

FAO (1990b) estimates that, in the mid-1980s, about 55 million of the region's people suffered from malnutrition. The three countries where malnutrition was most prevalent were Haiti, Honduras and Peru, where the daily per capita supply of calories was 1902, 2078, and 2192, respectively, per day (FAO, 1989). Low-income urban dwellers are particularly at risk. Another characteristic of the 1980s was the reduction in health and education expenditures with respect to the levels of the 1970s.

Will the debt crisis continue to influence domestic economies in Latin America and the Caribbean as deeply in the future as it has in the past? Decision makers in financial circles are becoming increasingly aware that the region is unlikely to repay its debts in full, and debt has recently become the subject of negotiation. The price of debt certificates as a percentage of their nominal value halved between 1986 and 1989 (CEPAL, 1989). This suggests that the negative impact of debt repayment on growth will slowly diminish during the 1990s, and that debt will be less and less of a millstone around the necks of Latin American countries. Nevertheless, a revival of international loans to the region should not be expected for many years. Financial institutions have long memories: for the coming decade Latin America will be largely dependent on internal financing.

Will Latin America and the Caribbean succeed in increasing their export earnings to finance those imports that are vital for economic growth? During the 1980s, capitalism has established itself worldwide as the dominant economic system, and the theory of free trade and international division of labor has received strong support. The chances for a period of international peace that would allow the development of international trade look good. The pressure to reduce protectionist policies in the Uruguay round of the GATT has been strong, but has not yet been translated into concrete measures.

Table S1.4. Poverty (percentage of households) in Latin America and the Caribbean.

Household type	1970	1980	1986
Poor households			
Total	40	35	37
Urban	26	25	30
Rural	62	54	53
Households in absolute poverty			
Total	19	15	17
Urban	10	9	11
Rural	34	28	30

SOURCE: CEPAL, 1990.

Table S1.5. Growth rates, by decade, of per capita caloric intake in Latin America (percentage).

Country	1960-70	1970-80	1980-87
Brazil	0.7	0.6	0.1
Mexico	0.6	1.2	0.8
Central America	0.8	0.5	0.6
Caribbean (except Cuba)	0.7	0.5	0.6
Andean countries	0.3	0.8	-0.1
Southern Cone	0.6	-0.2	-0.4
Latin America	0.6	0.6	0.2

SOURCES: FAO, 1987 and 1988.

Although there are some indications that trade will increase, this will often be within economic blocks, such as the European Economic Commission (EEC) or the North American Free Trade Association (NAFTA), instead of in a truly international fashion. In such an environment, the ability to rapidly increase exports depends strongly on negotiating power, and it is difficult to see what are Latin America's advantages, unless practical regional blocks (custom unions) are strengthened. Recent developments like Mercosur and Pacto Andino are certainly steps in the right direction. Moreover, in order to use such increased export earnings for vital imports, it is necessary to ensure that they are not completely absorbed by increased debt payments.

In summary, the Latin American and Caribbean debt crisis is slowly easing but will constrain future international financing; the governments in the region are experiencing severe difficulties in managing this crisis and in maintaining their role in the provision of public services; its export orientation, which initially paid off, has become less effective with diminishing terms of trade, increased import requirements and a weak bargaining position. In consequence, poverty has increased, especially in the cities, and the region now faces more welfare problems than at the beginning of the 1980s.

However, in response to the crisis, macroeconomic policies have been modified. The economic environment of Latin American and Caribbean countries now resembles free market conditions more closely than ever before. If inflation can be controlled and solutions for the remaining debt problems negotiated, the conditions for renewed economic growth in the 1990s will be better than they were in the 1980s.

Economic and agricultural growth in the coming decade

Latin America and the Caribbean in the 1990s will face great challenges. Most of the region's countries will have to pursue economic growth under conditions of foreign capital scarcity and high real interest rates. Monetary policies will have to be conservative in order to restrain growth of inflation. Little money will be available for spending on equity problems, which will have to be addressed, instead, through oriented strategies. At the same time, resource conservation issues will become more important. Governments will thus have little room for maneuver.

Countries will need to look for new export markets to improve their balance of payments. Given the reduced room for the use of policy instruments, countries will have to adhere more and more to the principle of comparative advantage. To develop new markets, cost-reducing technologies that enhance comparative advantage will play a key role.

Where investment capital is constrained and where governments have to reduce their activities, the key to economic development will not lie in a small number of large-scale, national initiatives, but in a large number of small-scale, local initiatives. The small-scale farmer and the informal sector are often seen as subjects of redistributive government policies. In the coming decade there will be no resources available for such policies and the only way to address their poverty will be by linking them to expanding markets (de Janvry and Sadoulet, 1990; Nores, 1990). Such markets can be identified in new export opportunities and in the more dynamic internal commodities. Over the past three decades, rapid urbanization, higher incomes and new technologies contributed to change in the Latin American diet patterns. Perishable, nontransformable or low-value products, such as pulses and roots and tubers, lost their share to easier-to-store, more elaborate and convenient foods. Agroindustry, originally dependent on imported foodstuffs, moved closer to inland production regions, away from the ports, and diversified itself, strengthening the links of industry with agriculture.

Small-scale farmers and informal sector entrepreneurs are accustomed to earning a living under conditions of capital scarcity. In the financial climate of the region during the 1990s, they may well be better able to contribute to growth than the capital-intensive enterprises that have formed the traditional basis of growth.

The revival of the small farm as a business unit does not imply an end to equity problems. In urban areas, food availability for the poor will remain an important issue. In rural areas, not so much food as access to basic services is likely to become the dominant equity issue.

If this scenario is realized, modest economic growth, of around 1.5% per capita per year, may be expected during the 1990s.

Long-term economic and agricultural trends

Technology generation is a slow process. Considerable lead times are required, both for research and for the dissemination of its results. To select an appropriate agenda for research, long-term forecasts have to be considered. Extrapolating current trends is not reliable for long-term forecasts; the analysis must therefore shift toward understanding the basic mechanisms that underlie the trends.

Relative factor endowments in the region. The key to understanding the international distribution of labor is the principle of comparative advantage. Comparative advantages depend strongly on factor endowments. Table S1.6 compares factor endowments for different regions of the world.

Table S1.6. Assessment of factor endowments of different continents.

Factor	Latin America	Asia	Africa	North America
Land				
Availability	+	-	+	+
Quality	±	±	-	+
Labor				
Availability	±	+	±	-
Quality	±	+	-	+
Capital				
Availability	-	+	-	±
Quality	±	+	-	+

SOURCE: Author's estimates.

Latin America and the Caribbean have ample land, but not as good quality as that of North America. Labor availability is not as high as in Asia, but compares favorably with that of North America. The educational level of the Latin American labor force is below that of both Asia and North America. The capital endowment of Latin America is assessed as rather poor, for two reasons: first, savings rates are low; and second, there will be fewer loans available to Latin America for a long time. The quality of capital, as expressed by the flexibility and the transparency of financial markets, is also inferior to that of both North America and Asia.

This assessment of factor endowments suggests that agriculture is the sector in which Latin America and the Caribbean will have the greatest opportunities for international trade, but that North America, with its ample availability of good land, will be a strong competitor, especially in grains and oil seeds. Export strategies based on industry, which require a plentiful supply of skilled labor and substantial investment, are more feasible for Asian countries. The advantage in international services, which normally require very highly qualified labor, will stay with the developed world for some time.

Expected growth and engines of growth within Latin America. What we have today in this region is a more complex agriculture, intricately related with the rest of the economy. The stronger backward and forward linkages make agriculture a unique sector for reactivating the economic engine and constitute the basis for treating agriculture as a strategic sector for development (Mellor, 1989). Prospects for long-term economic growth in Latin American countries are strongly linked to three aspects. First, political stability: this crucial factor in a country's investment climate influences labor relations, investment risk and the stability of government policies. Second, a steady supply of foreign exchange: as we have seen, the prospects for international borrowing are bad for Latin America and the Caribbean, whose countries will have to rely on other ways of obtaining foreign exchange. Third, the degree of outward orientation a country has: a more open economy helps a country to develop export markets and to remain or become competitive.

In the long term, the agricultural sector in Latin America and the Caribbean will be less disadvantaged than during the 1970s or 1980s. Instead of being sacrificed to industrial growth and being a source of government income, it may well become an engine of economic growth, in which role it will nevertheless be country-specific. Although Latin America as a whole has abundant land, this endowment is heterogeneous: most South American countries have ample land and will be able to develop considerable comparative advantages in agriculture; whereas in other countries, such as Mexico and those of the Caribbean, land is relatively scarce. These countries may be able to develop some specialized agricultural exports, but the potential for agriculture to promote overall economic growth is somewhat limited.

Perhaps more revealing than the absolute factor endowments, are the recent trends in relative land-to-labor ratios. FAO (1988), for example, found that between 1961-1963 and 1984-1985, countries such as Argentina, Bolivia, Brazil, Chile, Cuba, Dominican Republic, Paraguay, Suriname and Uruguay increased their land-to-labor ratio. Countries such as Ecuador, El Salvador, Guatemala, Honduras, Mexico and Nicaragua reduced their land-to-labor ratio, whereas Colombia, Costa Rica, Haiti, Panama and Venezuela maintained the same ratio at the end as at the beginning of the period of analysis.

Not only differences by country, but also differences by decade could be observed. Frontier expansion was an important source of production growth in the 1960s and 1970s: the factor constraints of the 1980s called for more intensification (higher yields) as the source for output growth (Table S1.7).

Modernization of agriculture has been the logical result of a stagnant, rural, labor force and of the pressures for a more efficient agriculture. FAO statistics show that, in order to maintain food production at constant per capita levels during the 1980s,

Table S1.7. Evolution of yields of selected crops in Latin America.

Crops	Annual growth rates[a]		
	1966-70	1970-80	1980-88
Maize	ns	1.9	ns
Rice	ns	0.9	2.6
Wheat	ns	ns	3.5
Sorghum	ns	3.3	ns
Soybeans	ns	2.1	ns

a. ns = not significant at the 10% level.

SOURCE: Authors' calculations, based on FAO's data.

cereal production grew by 26%, fertilizer use increased by 40% and the number of tractors increased by 82%. This trend should continue as rural population for the year 2000 is projected to remain at 125 million, whereas urban population will grow by 50% (from 275 to 400 million) and the agricultural frontier expansion reaches a halt. Together with the trend to increase use of modern inputs, there is a trend to specialize (as dictated by the fixities of machinery and the need to achieve economies of scale) and to integrate operations both vertically (capturing marketing margins such as in grain-feed-poultry operations) and horizontally (in cooperatives and producers' associations).

As a conclusion, it can be stated that some Latin American countries, such as Mexico and Venezuela, may experience healthy economic growth, with a minor, but strategic, role for agriculture; others, such as the Caribbean countries, will face low growth with, at the most, an intermediate role for agriculture; the countries of Central America are likely to face rather slow growth, but with an important role for agriculture; a few countries, notably Brazil, Paraguay and Colombia, may grow moderately fast, with agriculture playing a vital role. The agricultural technologies developed to address these conditions will need to cover a wide spectrum of options to take into account the differences that will occur in labor costs or input use. Depending on the importance of agriculture, the willingness to invest in agricultural technology will differ strongly among countries.

Alternative agricultural development paths. Industrial labor productivity and migration trends, feasibility of frontier development, and energy prices will strongly influence future agricultural development. We foresee highly heterogeneous agricultural development paths throughout the region, and would like to highlight the following five:

1. Intensive peri-urban farming. This is a labor-using development path which will take place close to urban centers. It responds to the fact that not all rural migrants will be absorbed by urban employment. Their place of residence will give them access to a urban life style while they will still be employed in the rural sector. This development path requires either large urban markets for fruits and vegetables, or an export demand (e.g., flower production in the Sabana de Bogotá, or Chilean fruit for export). A good infrastructure is needed. Environmental problems will typically be those of intensively farmed areas such as pesticide abuse and depletion of water tables. Access to markets will lead to agricultural enterprises with a large number of employers and to individual farmers integrated in cooperatives or vertical marketing channels.

   Major challenges for this development path include the identification of products with a price-elastic demand; the enhancement of mobility of production factors, particularly land; and the management of conflicts between agriculture and other uses of resources, e.g., water for irrigation or urban consumption.

2. Marginal land farming. This development path refers to small to medium-sized farms on less fertile land, more distant from major markets. Frequently their occupants have been pushed out of more fertile regions. These systems present serious sustainability problems, e.g., low incomes, pressure on fragile resources and erosion. Development of these systems should be based on increasing the land-to-labor ratio, by outmigration of part of the population and more extensive land use by the remaining people in order to reduce pressure on resources.

3. Commercial farming on fertile land. These systems can be found in large areas of the continent which, at present, produce the basic grains for the urban population. We envisage a factor-neutral development path which will respond to the overall limits to area expansion and increasing transport

costs. At the same time, demand growth, outmigration and an aging population will cause a need to increase labor productivity.

This implies increased mechanization and a trend toward less diversified systems. The challenge will be to increase efficiency in a sustainable manner, avoiding the present problems of specialized agricultural systems such as excessive use of agrochemicals, weeds and erosion.

4. Intensification of environmentally low-value land with agricultural potential. This development path, e.g., the intensification of the acid-soil savannas, offers scope for a substantial intensification from present low levels of productivity. This implies increases in both land and labor productivities. Area expansion would play a key role in the process.

   The critical issue for this development path is whether, in a scenario of increasing energy prices that affect transport and input costs, the savannas can compete with areas closer to the market.

5. Intensification of environmentally valuable land with low agricultural potential. This refers to the exploitation of the humid forest for cropping and livestock. In the past, humid forest exploitation had a markedly land-using nature, associated with free access to this resource. The severe environmental problems resulting from such land use have led governments to question its soundness. There is growing consensus on the need to better understand this ecosystem and on the trade-off implied in the design of more appropriate technology. It is clear that, if at all, the appropriate development path should be labor using. This implies the need to establish precisely targeted sets of policies and incentives to induce such a labor-using development path.

Energy and agricultural development. The previously described development paths would be sensitive to energy costs. The expected increase in oil prices may negatively affect the development of marginal areas in oil-importing countries even further than already anticipated, as transportation subsidies become unmanageable. The reverse may be true for oil exporters such as Mexico, Venezuela, Ecuador, Colombia and Bolivia. Among the oil importers, resurgence of agricultural energy sources (such as PROALCOL) will regain credibility, shifting resources away from food production. Chemical inputs will become more expensive, thus imposing more efficient input use within the context of an integrated crop management approach, and substituting chemical use for more sound management.

Agricultural development and natural resource conservation. Increasing population densities and poverty constitute a powerful mix for resource overexploitation, degradation and depletion. A basic economic force to increase concern for sustainability is to place higher value on future incomes than is currently done. In other words, to be in a condition of applying low discount rates that do not excessively tax future incomes over present ones. But this will not happen under conditions of poverty; poor people value current income very highly and rightly view immediate resource use as the only alternative for improving their status. Likewise, most countries with short-term democratic regimes will value immediate incomes highly, particularly if the debt burden and fiscal deficits run high at a time when terms of trade are deteriorating and market access is reduced.

The share of agriculture in a country's growth will also affect attitudes toward sustainability issues in agriculture. Countries experiencing rapid growth with a substantial role for agriculture will probably recognize the importance of sustainability issues; they will emphasize the role of technology in contributing to growth, but, at the same time, will seek to enhance the sustainable use of their natural resources. Where growth is rapid but the role of agriculture is small, countries may be able to afford a conservationist attitude toward sustainable agriculture, because their future does not depend on it. They may choose to set natural resources apart in nature reserves, or to adopt legislation which restricts unsustainable practices. Countries experiencing slow growth but with an important role for agriculture, will tend to mine the natural resource base until growth has accelerated. In countries where growth is slow, with a small role for agriculture, sustainability will probably be a non-issue. All four attitudes either are or will be found in Latin America and the Caribbean, where the role of agriculture in development varies considerably from country to country. This means that the requests for agricultural technology that will be made to institutions, such as CIAT, will become more diverse.

Agricultural exports. What kind of agricultural exports should the continent aim for? Two issues affect the answer to this question. The first is that of food self-sufficiency versus food self-reliance. The concept of food self-reliance has recently gained considerable support in development circles, but the willingness of countries to rely on international markets for their basic food supplies remains to be seen.

The second issue is international transport costs. At present one ton of wheat can be shipped from the Mexican Gulf to Egypt for only US$30 (FAO, 1990a). Although international oil prices and, therefore, transport costs, are volatile, the expectation is that they will tend to increase in the medium to long term, because of reduction in reserves of non-OPEC oil suppliers (IMF, 1990). This would suggest that it is best to concentrate on products with a low ratio of transport costs to value of produce. For the purposes of Latin American exports, this would point to high-value crops. These high-value crops need to be in considerable demand in order to contribute to domestic growth. Fruits, flowers and off-season vegetables should be considered, as well as coffee, cocoa, sugar, bananas, and even meats (especially chicken and beef), and possibly oil seeds and pulses.

Investment in agriculture and in the generation of agricultural technology appear good bets for Latin America and the Caribbean. The focus should be on enhancing the labor cost advantage that the continent has in producing high-value products, and on increasing the productive capacity of the region's plentiful but relatively infertile land. The resulting boost to agricultural development may well trigger agroindustrial growth in both the input and processing sectors.

Employment. Agriculture still provides considerable employment in Latin America and the Caribbean, but it is no longer the sector that absorbs most labor as it still does in Asia and Africa. Average incomes in the agricultural sector are less than one third of those in other sectors. In Asia, agriculture is seen as the employment buffer of society, but this is no longer so in Latin America and the Caribbean, where the service sector has become the principal source of employment.

If the employment buffer has shifted from the agricultural to the service sector, then the principal challenge for agriculture in the coming decades will be to raise per capita income. Increased labor productivity will therefore be a key objective for agricultural development. Seed-based and other yield-increasing technologies will contribute to increased labor productivity, but will need to be complemented with appropriate mechanization to remove labor peaks in small and medium-sized farm operations. For many of these farms, these would be the first steps on the mechanization track, and therefore the expected return to investments would be high.

The opportunities for increasing labor productivity are not equal across the different ecosystems of the region. For example, in many hilly areas the potential for higher labor productivity is very limited. To avoid further outmigration from these regions, it will be necessary to create new income-generating opportunities. This will require the design of employment policies for rural industries and services, as well as for agriculture.

Sectorial linkages. As shown by Pineiro (1988) and Mandler (1987), the agricultural sector of Latin America and the Caribbean is becoming increasingly integrated with the rest of the economy. The intermediate consumption of the agricultural sector amounts to 29% of the gross value of its output, and 34% of the gross agricultural output is input to another productive process. CIAT (see Section 2, this volume) suggests that technical change in agricultural production causes substantial welfare gains both within the agricultural sector and in the rest of the economy. For rice and beans, the income effects triggered in the rest of the economy are estimated at 78% and 41%, respectively, of the direct gains to producers and consumers.

Thus, even though the role of agriculture in the region's total economy is relatively small, agricultural development will trigger substantial growth in other sectors. The ability of the sector to induce agroindustrial growth and rural development should be taken into account in national planning. An important issue is how to link the small-farm sector to expanding markets.

Implications for agricultural technology generation

As we have seen, the economic circumstances of Latin American countries will vary substantially toward and beyond the year 2000. This will influence their attitudes to agricultural technology generation. For some countries, technologies oriented toward sustainable land use will be the key to growth; for others, short-term productivity increases will be the most urgent consideration.

The role of the public sector in technology generation and diffusion will probably be reduced, because of budgetary problems. Nongovernmental organizations may step in to fill the vacuum. Such organizations have good local knowledge, but little access to policy makers.

The fiscal and financial constraints faced by governments will force them to select, with great care, their interventions to achieve growth. Price supports or credit subsidies will be difficult to afford. Instead, technology generation and diffusion, which enhance rather than obfuscate comparative advantages, will be emphasized as the main source of growth.

We now find an agriculture where there is intense pressure to increase labor and capital productivity, as the model of frontier expansion will be limited by financial constraints. Modernization and more commercially oriented farmers will demand germplasm responsive to inputs, which, ideally, should also produce acceptable yields at low-input levels. The demand for mechanization calls for a broader range of alternatives than is currently available. The lack of alternatives is particularly striking when compared with the ample range of small and medium-sized machines being used in Asia.

Technology development should be focused on two groups of products. First, it must be directed toward reducing the costs of high-value commodities, such as vegetables and livestock products, that have export potential. The second focus should be on those urban staples that form the basis of the poor's diet and where a comparative advantage may either exist (but requires maintenance of technological advances) or be developed through cost-reducing technologies. The traditional income disparities of Latin America persist, but the locus of poverty is shifting from rural to urban areas. Food availability to the urban poor could be addressed partly by imports for the cases where comparative advantages cannot be developed. To reduce the share of food in the expenditure of the poor without solely relying on foreign exchange and to guarantee adequate levels of food self-reliance, increased staple production with cost-reducing technologies is a must. To further alleviate urban poverty, more emphasis on the development of the informal sector will be required.

The trend to more elaborate foods with higher value added implies a lessening of the paramount importance that breeders used to give to the physical characteristics of the products based on what was interpreted as consumer preferences. If the product will be used as raw material for feed or flour production, for example, its size, shape and color loses importance because the relative cost of its nutrients is what really matters for least-cost mixtures.

The extent to which agricultural technology can address the rural equity issue should, for various reasons, be reassessed. Firstly, rural poverty has stopped increasing, despite the bleak conditions of the last decade. Secondly, the feasibility of strategies to alleviate poverty is severely constrained by limited governmental resources. Thirdly, the ability of resource-poor farmers to make productive use of small amounts of capital is now seen as an asset. Finally, the employment buffer of society is being transferred from the agricultural to the service sector.

The time is ripe to pursue strategies that will speed the transformation of subsistence-based farmers into small-scale entrepreneurs. This will increase labor productivity and create rural employment opportunities outside agriculture. For some small-scale farmers this transformation may be achieved by increasing the productivity and market orientation of their farms. For others, it may imply moving out of agriculture to other types of economic activity. A major technological challenge of the 1990s will be to integrate small-scale agriculture within more comprehensive forms of productive rural development, for example, through postharvest processing, and developing small-scale agroindustries and other rural service activities.

Summary and conclusions

Structural adjustment policies, with more open economies, are creating a tough environment for agriculture, but one in which the economic incentives are less distorted. Such an environment will allow agricultural technology to perform on its own merit, rather than at the mercy of support measures. It is imperative that this opportunity be successfully used, and that technological improvements contribute significantly to economic growth. If technology generation and diffusion are unsuccessful, pressures to revert to policy interventions may develop, influence exerted by special interest groups would once again distort economic incentives, decrease export competitiveness and reduce growth, thereby increasing the distance between the Latin American and Caribbean region and developed countries.

For the agricultural sector, many recent trends point to the same direction: the urgent need for increased efficiency and modernization to maintain growth rates with lower area expansion, and the need for resource conservation leading to sustainable agricultural systems. In other words, more efficient and sustainable technologies must be put in place. Cost-reducing technologies are needed to allow expansion of domestic markets and increase of external competitiveness. Whether growth will be internally or externally induced is somewhat a futile discussion; increased efficiency is a must for more open economies. The new technologies, designed in the context of increasing linkages of agriculture, will, in turn, generate more income and ensure that internal growth will also exert an important pull effect into agriculture through higher derived and aggregate demands. In this context, it is imperative to link small and medium-sized farms to expanding markets.

To realize agricultural growth on a technological basis, it is important that the increased mobility of production factors be recognized. We will see further differentiation between regions and countries, along the development paths that were described earlier.

Environmental issues will increasingly become a key bargaining element between the region and its present or potential trade partners. A better understanding of issues, such as the interrelationships between the choice of development path, the access to developed countries' product and capital markets, poverty and the environment, is urgently needed to facilitate this international bargaining process.

Production systems research in the context of a land use perspective is increasingly in high demand, as concern for sustainability (where higher productivity and improved equity are aligned with conservation of natural resources) transcends the commodity approach, thus placing issues in the context of better knowledge of agroecologies and their socioeconomic context.

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Section 2

CIAT'S COMMODITY PORTFOLIO REVISITED: INDICATORS OF PRESENT AND FUTURE IMPORTANCE

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Introduction

As part of CIAT's strategic planning exercise, a group of CIAT's mandate and other commodities was analyzed for the commodities' relative contribution to the Center's three major objectives: growth, equity and preservation of the natural resource base. This section explains the methods used for the analysis and discusses the results.

Methods for ranking research priorities and implications for CIAT

Since the CGIAR system became involved in strategic planning, a number of methods for ranking research priorities have been reviewed (Davis et al., 1987; Norton and Pardey, 1988; TAC, 1988; Mueller, 1989). We will begin by summarizing some of the major findings of these reviews, thereby setting the stage for the approach we have used at CIAT.

First, we should distinguish between single and multiple criteria models. Single criterion models include congruency analysis, as applied by Janssen et al. (1989) for the 1989 CIAT internal annual review. Precedence, the principle of increasing or reducing the budget in line with the previous allocation, is also a single criterion model. Single criterion models can provide very rough first indications on the relative magnitudes of priorities. However, no single criterion allows all the different components of an institution's set of objectives to be scrutinized. Sufficient detail for more sophisticated analysis is not provided.

Multiple criteria models are therefore a better approach when a thorough reassessment of priorities is required. Within multiple criteria models, an important distinction should be made between models with built-in criteria weighing, and models

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without criteria weighing. In the first case, the model considers different criteria and weighs them to arrive at an order of priorities. Mathematical programming models (Romero and Rehman, 1989) or hierarchical selection of priorities (Saaty, 1986) belong in this group. In the second case, the values of different commodities with respect to different criteria are obtained, but the actual priorities are defined outside the model, through interpretation of the results by decision makers. Scoring models are an example of this approach. The choice of whether to use a model allowing built-in criteria weighing or to interpret outside the model depends on how well the objectives of the decision makers can be expressed in mathematical terms and how clearly their decision process can be mapped.

In much of the literature, a distinction is also made between the current value of production (in congruency analysis) and the expected benefits of research (in producer and consumer surplus analysis). The expected benefits of research constitute a more relevant criterion than the current value of production, but the assumptions required to estimate them are more susceptible to error. This problem can be partly overcome through consultation, for example by means of a Delphi-type questionnaire (Herdt and Riely, 1987). However, the need to make assumptions often reduces the credibility of this type of analysis, shifting the discussion away from results toward rationales and procedures.

Another issue is the relationship between research costs and research benefits. Ideally, this relationship should be established through a continuum from low to high costs (the research production function), allowing the optimal size of programs to be determined. Such an analysis is theoretically possible, but practically tedious to execute for more than a few crops. Consequently, it is difficult to apply a true cost-benefit framework, and the analysis will be normally constrained to the comparison of expected benefits at a single level of funding.

The literature reviews cited above distinguish benefit-cost models from multiple-scoring models. The distinction appears to be based on the greater use of economic and mathematical concepts in the reported benefit-cost analyses than in the multiple-scoring analyses. This distinction, however, is rather confusing. Within a multiple-scoring model, there is no reason why the expected benefit-to-cost ratio cannot be included as one of the criteria.

Where do these considerations lead CIAT's commodity analysis? First, to the realization that a multiple criteria model is preferable to a single criterion one. Second, to the conclusion that there is no reason to consider cost-benefit analysis and a multiple-scoring model as mutually exclusive, but that the first method can be absorbed into the second. Third, to the awareness that the credibility of the commodity analysis depends on the effective participation of commodity experts.

Let us end this introductory section on a cautionary note. In its analysis of priority assessment methods, TAC states: "no model will ever be a substitute for collective judgement."

CIAT's commodity evaluation approach

The approach to commodity evaluation adopted by CIAT blended several different methods of ranking priorities, using a two-stage analysis (Figure S2.1). Although we had restricted ourselves to a Latin American context, the number of commodity options remained large. In the first stage, we scored commodities according to a small number of simple criteria and, in a hierarchical selection of priorities, discarded some of them. The criteria used to discard certain commodities involved certain superficial judgments, but these were deemed necessary to reduce the number of commodities requiring a more penetrating analysis.

Thus, in the second stage, a smaller group of commodities was studied in greater detail. A single benefit-cost criterion, as favored by J. Ryan (personal communication) or a single congruency analysis as applied by McIntire (1985) appeared too restrictive to examine the roles of the different commodities. It was therefore decided to develop criteria for each of CIAT's four principal objectives: growth, equity, preservation of the resource base, and institutional complementarity.

Although the use of a single criterion was ruled out, it was agreed that agricultural research should be considered as a long-term investment, and that benefit-cost assessments should therefore form the backbone of the analysis. With respect to economic growth and equity, there were no conceptual problems in developing a framework for benefit-cost analysis, although some considerations, such as nutrition, employment, and expected future value of the commodity, were perhaps not sufficiently included. With respect to resource preservation and institutional considerations, the investment concept is not clear and not easily applicable, so other criteria were identified.

Scores for some criteria in relation to some commodities could be obtained directly from original data sources. To obtain the other scores a partial equilibrium model and a simple general equilibrium model were used. Most of the data needed to feed these models were gathered by CIAT's economists.

For a number of critical parameters of an essentially subjective nature, such as the expected supply shift in case of successful research, the lead time of research, and the speed of adoption of improved technology, assumptions were made in consultation with experts on specific commodities. These consultations took two forms: whenever

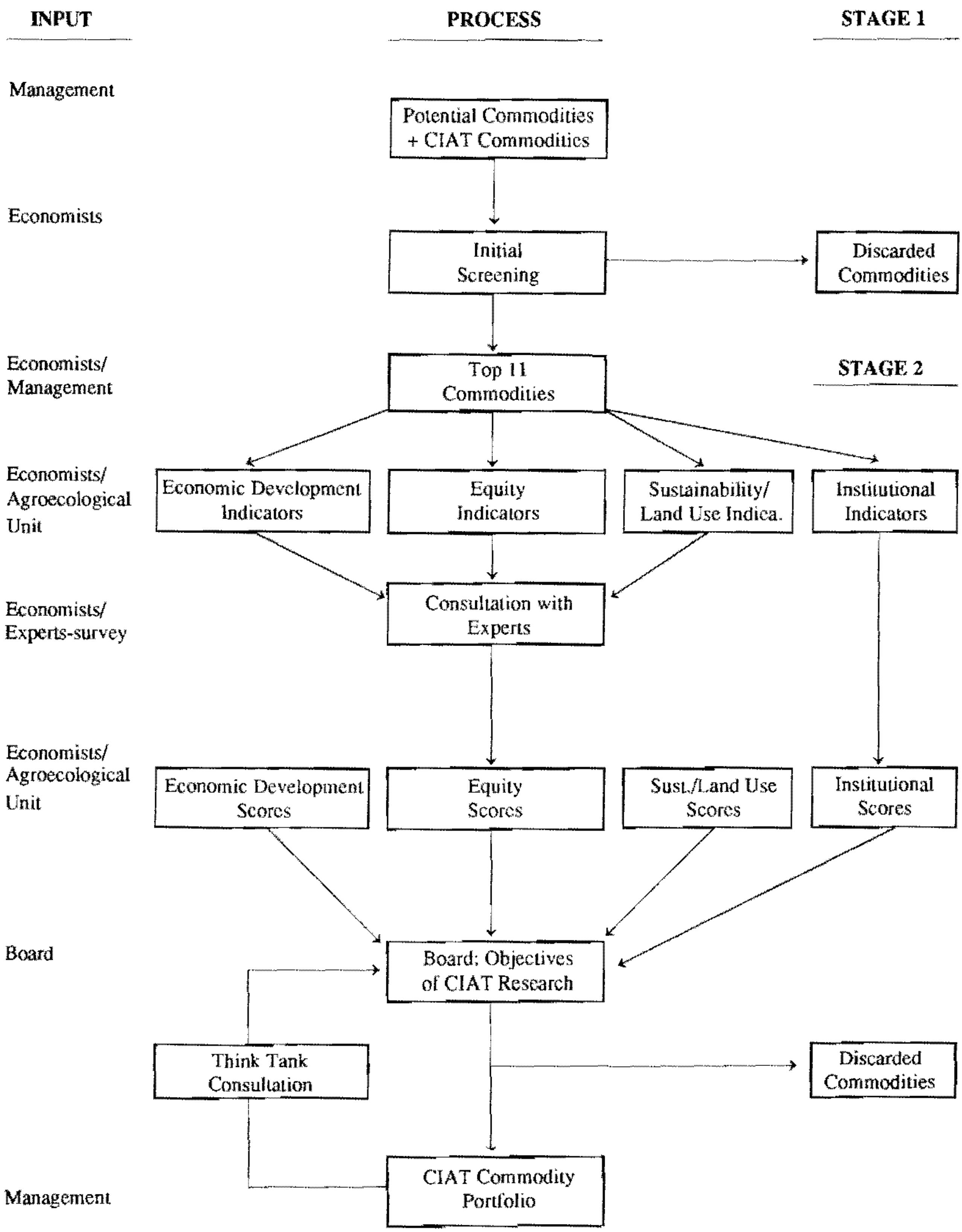

Figure S2.1. A flow chart to summarize CIAT's commodity selection process.

possible, the economic and technical prospects of the commodity were discussed with an expert; additionally, a questionnaire was developed to elicit judgments on the type and rate of technical change that could be expected for a given commodity as a result of research by CIAT. The questionnaire was accompanied by a commodity profile to orient the expert with respect to the social and economic factors relevant to the commodity. The questionnaire was sent to several specialists for each commodity. In the case of sorghum, soybean and cotton, the responses prompted adjustments to CIAT's own assessments. In the case of banana and plantain, the data used should be viewed with care, because little specific information on technical changes could be obtained.

The approach applied by CIAT can thus be summarized as an initial screening, followed by the application of a multiple criteria model, built around a benefit-cost analysis and estimated by means of an expert consultation procedure. The approach has led to clearly interpretable data on the expected benefits of research in total and for different target groups, but no effort has been made to weigh the different criteria used or to reach final decisions on the compositon of CIAT's commodity portfolio (Figure S2.1).

Commodity screening

Nineteen commodities were selected for the initial screening. These were beans, beef, cassava, citrus (oranges and lemons), cotton, milk, plantain and banana, rice, sorghum, soybeans, vegetables (snap beans, tomatoes and onions), cocoa, coffee, groundnuts, palm oil, rubber, sugar and wood products (Table S2.1). All these commodities are agricultural products in the sense that land is a principal factor in their production. Marine products, eggs, poultry and pork were excluded because they are not usually land dependent. Beef and milk production can also be divorced from the land, but this is not often the case in Latin America and the Caribbean.

These commodities were screened for three criteria: the current value of production in Latin America and the Caribbean, as a proxy for the significance of the commodity; the share of Latin America in total developing-world production, in order to assess whether research in Latin America would contribute significantly to global development; and the case for international research, which was assessed by reviewing the existing strength of research by national programs or producer organizations.

To assess the value of production and the share of Latin America in total developing world production, we used the data set developed by Davis et al. (1989) for use by TAC. As the authors admit, this data set is not perfect, but nevertheless we considered it an adequate source for the initial screening. The case for international research was

Table S2.1. Outcome of initial screening of commodity options.

Commodity[a]	Value of Latin American production (million US$)	Percentage of total developing-world prod.	Decision taken[b]
Beans (<u>Phaseolus</u>)[c]	4,131	61.30	I
Beef	10,023	61.94	I
Cassava[c]	6,209	21.76	I
Citrus (oranges and lemons)	7,302	61.95	I
Cotton	2,700	14.13	I
Milk	11,845	30.40	I
Plantain and banana	9,530	39.53	I
Rice	4,070	6.59	I
Sorghum	1,716	33.21	I
Soybeans	6,214	64.34	I
Vegetables[d]	1,887	21.68	I
Cocoa	1,443	35.08	V
Coffee	11,930	65.81	M
Groundnuts	340	4.73	V
Palm oil	118	4.48	V
Pineapple	417	24.15	V
Rubber	70	1.38	V
Sugar	3,701	50.46	M
Wood products	24,815	20.80	L

a. Data prepared for TAC by Davis, Oram and Ryan (DOR), 1989.
Beans: DOR-data do not distinguish <u>Phaseolus</u> and non-<u>Phaseolus</u>. Data presented are farmgate values as estimated by Janssen, Sanint and Seré (JSS) for the 1989 presentation in CIAT's annual review.
Snap beans: Estimates by Henry and Janssen (n.d.) for the snap bean economic study.
Rice: Values for Latin America corrected with JSS calculations.

b. I = Included for further analysis.
V = Discarded because of low value of production.
M = Discarded because of apparent lack of merit of international research.
L = Decision depends on CIAT's position with respect to land use research.

c. For beans, values in other target regions included Africa, West Asia and North Africa; for cassava, Asia was included.

d. Snap beans, tomatoes and onions.

assessed on the basis of our existing knowledge of research strength, without further consultation.

Table S2.1 shows the outcome of the screening process. Because of their low value of production, cocoa, groundnuts, palm oil, pineapple and rubber were discarded. Coffee and sugar both have strong research programs by producer organizations and were discarded because of an apparent lack of merit for international research. Wood products were not discarded as such, but the relevance of (agro)forestry research was considered to depend more on the importance that CIAT would give to land use than on the value of this mixed bag of products. The share of Latin America in total developing-world production turned out to be a redundant criterion.

Application of the multiple criteria model

Eleven commodities remained after the initial screening. Apart from CIAT's commodities (beans, beef, cassava, milk and rice), these were plantain and banana, citrus, cotton, sorghum, soybeans and a group of vegetable products. These commodities were evaluated for the potential contribution research could make to economic growth, equity, and the preservation of natural resources, and for the institutional complementarity of research by CIAT. For the evaluation of these commodities, data (Tables S2.2 and S2.3) were obtained from a large number of sources.

Economic growth

Criteria. Technology development aims to contribute to economic growth through the more efficient use of scarce resources. In the context of agricultural research this has normally been interpreted as increasing production per unit of land or per unit of labor. The estimation of technological benefits has conventionally been restricted to the direct effects on the supply and demand of the commodity in question.

Recently, there has been increasing awareness of the indirect effects of technological change. When the supply of a certain commodity increases, this triggers off demand for other products. For example, if more rice is produced, more combine harvesters will be needed, more rice mills will be built and more fertilizer will be used. At the same time, the income of producers will increase, and they will expand their consumption of other commodities. The resulting demand for goods and services allows other people to earn an income. The extra value added in this way, outside the immediate commodity sector, is referred to as the linkage effect (Mellor and Lele, 1973). The extent of the linkage effect differs among commodities, according to input

Table S2.2. Data sources: Prices.[a]

Source	Initial price	Minimum price of supply	International price	Price elasticity of supply	Price elasticity of demand
Fundação Getulio Vargas. 1988. Precos recibidos pelos agricultores. Brazil.	CAL				
FAO production yearbook. Various years.	CAA, BAN		BAN		
Lynam, J.K. (1)					CAA
Economics sections of CIAT's cassava, bean, rice and tropical pastures programs.	BF, MI(5), RI, SOY, CIT	CAL, CAA, BEA, BEL, BF, MI(5), RI	CAA, BF, MI(6)	CAL, CAA, PL, BAN, BEA, MI, BEL(7), SO(11), RI, SOY, CIT	CO, BEL(10), RI, SOY, CIT
FAO. 1970-84. Economía mundial del banano.		BAN			BAN
World Bank. 1988 ed. Commodity trade and price trends, Washington, DC.			RI, SOY		
FAO. Monthly bulletin of statistics.	BEA, BEL, SO		BEA, BEL, SO		
IMF. International financial statistics, prices of basic commodities	CO, SO		SO, CO		
CVC. 1988. Manual de costos de producción agropecuaria. Cali, Colombia.		SO, CO			
Project FAO-RLAC/CIAT (2)					BF
Pinstrup-Andersen, P. et al. (3)					MI
Valdez, A. (4)				BF	
Janssen, W. (8)					SO

(Continued)

Table S2.2. (Continued)

Source	Initial price	Minimum price of supply	International price	Price elasticity of supply	Price elasticity of demand
Askary, H. and Cummings, J.T. (9)				SO, CO	
FAO. 1979. Review of food consumption surveys 1977, vol.2. Rome.					BEA
Lynam, J.K.; Sanint, L.R.; Sáez, C.; Ibañez-Meier, C.; Gontijo, A.; and Janssen, W. (12)					CAL
Ministerio de Agricultura. 1989. Anuario de estadísticas del sector agropecuario. Colombia.	PL				
Federación Nacional de Cafeteros de Colombia (13).		PL			
Sanint, L.R.; Rivas, L.; Duque, M.C. and Seré, C. (14)					PL
Instituto de Economía Agrícola. Informações economicas. Gov. de Estado de São Paulo, São Paulo, Brazil.		SOY, CIT			
Fundação Getulio Vargas. Agroanalysis. Several issues. Rio de Janeiro, Brazil.			CIT		

a. BEL = Beans, LA
BEA = Beans, Africa
BAN = Banana
BF = Beef
CAA = Cassava, Asia
CAL = Cassava, LA
CO = Cotton
MI = Milk
PL = Plantain
RI = Rice
SO = Sorghum
SOY = Soybeans

(Continued)

Table S2.2. (Continued)

Source	Initial price	Minimum price of supply	International price	Price elasticity of supply	Price elasticity of demand

For snap bean data sources, see Henry, G. and Janssen, W. (eds.). n.d. Snap beans in the developing world. [Proceedings of an international conference.] CIAT, Cali, Colombia. (In press.)

(1) Lynam, J.K. 1987. The cassava economy of Asia: Adapting to economic change. CIAT, Cali, Colombia.
In addition to: Konjing Chaiwat and Issariyanukula Apisith. 1985. Output demand and marketing of rice and upland crops in Thailand. In: Food policy analysis in Thailand, edited by Theodore Panayotou. Agricultural Development Council, Bangkok, Thailand.

(2) Rivas, L.; Seré, C.; Sanint, L.R.; and Cordeu, J.L. 1989. La demanda de carnes en países seleccionados de América Latina y el Caribe: Proyecto colaborativo FAO-RLAC/CIAT. FAO-RLAC, and CIAT, Cali, Colombia. 195 p.

(3) Pinstrup-Andersen, P.; Ruiz de Londoño, N.; and Hoover, E. 1976. The impact of increasing food supply on human nutrition: Implications for commodity priorities in agricultural research and policy. American Journal of Agricultural Economics 58(2):131-142.

(4) Valdez, A. 1975. Some economics aspects of the cattle industry in Latin America. In: Potential to increase beef production. CIAT, Cali, Colombia.

(5) BF, MI: Estimated by using data from IBGE; Min. Agricultura Colombia; and Rivas, L. and Seré, C. Análisis de precios de productos e insumos ganaderos. Documentos de trabajo nos. 18, 28 and 55, of 1986, 1987 and 1988, respectively. CIAT, Cali, Colombia.

(6) BI, MI: Estimated by using data from IMF, International financial statistics, various years; and FAO montly bulletin, various years.

(7) Estimated by using data from:
* Pachico, D.; Lynam, J.K.; and Jones, P. 1987. The distribution of benefits from technical change among classes of consumers and producers: An ex ante analysis of beans in Brazil. Research Policy 16(5):279-285.
* Luna G., C.A. and Janssen, W. 1990. El comercio internacional y la producción de fríjol en Colombia. Coyuntura Agropecuaria 7(1):107-139.
* Plasencia, J. 1986. Frijol, oferta, demanda e inversión en la investigación agrícola. INIFAP, Mexico.

(8) Janssen, W. 1986. Market impact on cassava's development potential in the Atlantic coast region of Colombia. CIAT, Cali, Colombia. 357 p.

(9) Askari, H. and Cummings, J.T. 1976. Agricultural supply response: A survey of the econometric evidence. Praeger, New York, NY, USA. 443 p.

(10) Estimated by using data from:
* Pachico, D. and Seré, C. 1985. Food consumption patterns and malnutrition in Latin America: Some issues for commodity priorities and policy analysis. In: Trends in CIAT commodities. Internal document, Economics 1.10. CIAT, Cali, Colombia.
* Gray, C. 1982. Food consumption parameters for Brazil and their application to food policy. IFPRI, Washington, DC, USA.

(Continued)

Table S2.2. (Continued)

Source	Initial price	Minimum price of supply	International price	Price elasticity of supply	Price elasticity of demand

(11) Estimated by using data from:

* Borren, C. 1984. Sorghum production in the Atlantic coast of Colombia. In: Cassava economics. CIAT, Cali, Colombia. (Typescript.)
* Seré, C. and Estrada, R.D. 1987. Potential role of grain sorghum in the agricultural systems of regions with acid soils in tropical Latin America. In: Gourley, L.M. and Salinas, J.G. Sorghum for acid soils. INTSORMIL, ICRISAT and CIAT, Cali, Colombia. p. 145-169.

(12) Lynam, J.K.; Sanint, L.R.; Sáez, R.; Ibañez-Meier, C.; Gontijo, A.; and Janssen, W. 1987. The cassava economy of Latin America: A food staple in transition. CIAT, Cali, Colombia.

(13) Federación Nacional de Cafeteros de Colombia. 1989. Bases tecnológicas: Costos e ingresos de actividades agropecuarias de diversificación, Colombia.

(14) Sanint, L.R.; Rivas, L.; Duque, M.C.; and Seré, C. 1985. Análisis de los patrones de consumo de alimentos en Colombia a partir de la encuesta de hogares DANE/DRI de 1981. Revista de Planeación y Desarrollo 17(3):39-63.

Table S2.3. Data sources: Volume and quantity.[a]

Source	Initial quantity	Demand growth	Supply growth	Production distribution	Consumption distribution
FAO production yearbook and FAO trade yearbook. Various years.	PL, BAN, CAA, CAL BEL, BEA, CO, SO, RI, SOY, MI, BF	SO, CO	PL, BAN, SO, CO		
Economic sections of CIAT's cassava, bean, rice and tropical pastures programs.		CAL, PL, BAN(2) RI, SOY, CIT, BF, MI(6)	CAL, RI, SOY, BF, MI(6)	CAA, BEA, PL(4), BAN (3)	CAL
Trends in CIAT commodities (tables). Various years.			CAA, BEL, BEA		
Instituto Brasileiro de Geografia e Estadística (IBGE). 1980. Censo agropecuario. Brazil.				CAL, BEL, SO, CO, BF	
Instituto Brasileiro de Geografia e Estadística (IBGE). 1980. Estudo nacional de despesa familiar. Brazil.					BAN, BEL(7) SO, CO
FAO. 1988. Commodity review and outlook.		CAA			
FAO. 1979. Review of food consumption surveys, 1977, vol.2. Rome.					BEA
Sanint, L.R.; Rivas, L.; Duque, M.C., and Seré, C. (1)					PL, SO, CO, CIT, BF, MI
Fundação Getulio Vargas. Agroanalysis. Several issues. Rio Janeiro, Brazil.				RI, SOY, CIT	RI, SOY
USDA World citrus situation and o.	CIT	CIT			
Janssen, W. (5)	BEL, BEA	BEL, BEA -			

(Continued)

Table S2.3. (Continued)

Source	Initial quantity	Demand growth	Supply growth	Production distribution	Consumption distribution
Rivas, L. (8)			MI		

a. Food balance sheets (1979-81) were used for estimating calories and proteins in all commodities.
For snap bean data sources, see Henry, G. and Janssen, W. (eds.). n.d. Snap beans in the developing world. [Proceedings of an international conference.] CIAT, Cali, Colombia. (In press.)

The "k-shifts" and the percentage of adoption for the initial and the final year, as were used in the partial equilibrium model, have been derived from information collected from the "Expert Consultation Survey" (May 1990). In several cases these values were adjusted to include additional data from the economics sections of CIAT.
For explanation of abbreviations see footnote a in Table S2.2.

(1) See note (14) in Table S2.2.

(2) BAN: average of (a) George and King. 1971. Consumer demand for food commodities in the United States with projections for 1980. Giannini Foundation monographs no. 26; and (b) FAO. Trade yearbook.

(3) BAN: average of Brazil, Ecuador and Colombia in: (a) Memoria de la Reunión Regional de INIBAP para América Latina y el Caribe. 1987. Costa Rica.
(b) AUGURA. 1987. Producción y comercialización del banano. Revista Nacional de Agricultura (Colombia) no. 878.

(4) PL: in (a) Buriticá, P. 1985. El plátano: Situación en Colombia y su sistema de generación de tecnología. Informe UPEB 8(65).
(b) Soleibe-Arbelaez, F. 1979. Importancia socioeconómica y sistemas de producción de plátano en Colombia. Federación Nacional de Cafeteros, Bogotá, Colombia. (Typescript.)

(5) Janssen, W. 1989. Dry bean production and consumption in the year 2000: Projections, thoughts and guesses with emphasis on Latin America and Africa. In: Beebe, S. Current topics in breeding of common bean. Working document no. 47. CIAT, Cali, Colombia. p. 329-350.

(6) BF and MI: Estimated by using data from:
* World Bank. Informe sobre el desarrollo mundial. Various years.
* FAO production yearbook. Various years.
* Trends in CIAT commodities. various years.

(7) See note (10) in Table S2.2.

(8) Rivas, L. 1974. Some aspects of the cattle industry on the north coast plains. Technical bulletin no. 3. CIAT, Cali, Colombia.

intensity and the share of the extra income spent on domestic products (Hazell and Roell, 1983).

The direct and indirect technology effects provide monetary estimations of the contribution of a commodity to economic growth. They are logical, rational and discriminatory criteria, but both are somewhat susceptible to the assumptions and structure of the model used, as explained later. To support or challenge the consistency of the estimated effects, some proxy variables were included as additional economic growth criteria. These were the current value of production, the expected growth in demand and the potential for foreign exchange earnings.

Measurement. How were the different criteria measured? For the current value of production, the average production given in FAO production yearbooks for the three most recent years for which data were available was multiplied by the average world market price during the last decade, as supplied by IMF or FAO price statistics. The expected growth in demand was assessed by analyzing commodity demand with respect to income and urbanization and by reviewing the supply of alternative products. The potential for foreign exchange earnings was assessed qualitatively by considering the tradeability of the commodity, the present volume of trade, the expected growth in world market demand, and the potential for import substitution.

The direct effect of technology on supply and demand was estimated by using a partial equilibrium model: MODEXC (see Appendix 1 to this section, p. 52-54). Table S2.4 shows the assumptions used in the model.

In the analysis of technological impact over time one wonders whether some of the parameters of the partial equilibrium model, such as the elasticities or the extent of demand and supply, would not change. We therefore simulated the effect of technological change as influenced by autonomous shifts in demand and supply. This did not deal with possible changes in elasticities, but it did assess the impact of technology in a dynamic fashion. We applied a 10% discount rate and aggregated the research benefits as simulated from 1990 to 2025 to arrive at a net present value (NPV).

Supply and demand functions are normally only known close to the observed market equilibrium. Extrapolation to prices higher or lower than those observed is somewhat speculative and, in the case of linear functions, often produces substantial supplies at negative prices. We used the specification of Lynam and Jones (1986), which states that supply is only possible at positive prices. For further discussion of this specification see Pachico et al. (1987) and Antony et al. (1988).

Table S2.4. Data used in the partial equilibrium model (MODEXC) to estimate research benefits.

Product	Region	Value of production (million US$)	Supply elasticity	Demand elasticity	K[a]	Supply growth (%)	Demand growth (%)	Consumption share of 40% poorest consumers (%)	Share of small producers in production (%)	Lead time of research (yr)
Banana	Latin America (L.A.)	7,504	0.4	-2.0	1.17	1.5	2.2	--	12	6
Bean	L.A.	2,459	0.6	-0.5	1.28	1.6	1.7	39	55	4
	Africa	1,672	0.4	-0.4	1.26	2.2	3.0	85	90	4
Snap beans[b]		1,470	0.8	-0.6	1.31	2.5	3.1	74	95	4
Beef	Tropical L.A.[c]	8,580	0.5	-0.4	1.46	1.0	1.5	25	26	4
Cassava										
Fresh	L.A.	628	0.5	-0.8	1.09	0.8	1.0	19	58	8
Processed		2,103	0.5	-0.8	1.24	1.6	2.0	60	50	6
Processed	Asia	1,767	0.5	-2.2	1.23	1.2	4.0	--	90	6
Citrus	L.A.	1,341	0.3	-2.0	1.20	2.0	2.0	19[d]	53	6
Cotton	L.A.	3,388	0.5	-5.0	1.12	0.8	1.4	25	25	6
Milk	Tropical L.A.	10,325	0.7	-0.8	1.25	1.4	1.6	26	50	4
Plantain	L.A.	514	0.5	-1.2	1.28	0.8	1.7	33	52	6
Rice[e]	L.A.	4,070	0.5	-0.5	2.80	1.8	2.0	36	18	2
Sorghum	L.A.	1,232	0.5	-5.0	1.34	2.0	3.0	25[d]	13	6
Soybean[f]	Tropical L.A.	2,362	0.5	-5.0	1.50	2.0	3.0	25[d]	3	6
Vegetables[g]	L.A.	1,887	0.8	-0.7	1.31	2.5	3.0	25	80	6

a. K = The factor which expresses the shift in supply. Defined as:

$$K = \frac{\text{Initial supply + Expected extra supply because of technological change}}{\text{Initial supply}}$$

b. Total for L.A., Asia and Africa.

c. Tropical Latin America refers to the whole of Latin America and the Caribbean, excluding Argentina, Chile and Uruguay.

d. Considered as fully tradeable commodity.

e. In rice very significant technology adoption has occurred over the last 20 years. In light of this, future rice research benefits are estimated somewhat differently to other commodities.

f. For soybean, southern Brazil was excluded.

g. Includes tomatoes and onions.

Lindner and Jarrett (1978) showed that the extent and distribution of research benefits depend strongly on the type of supply shift. In all cases, we have applied a pivotal demand shift. This shift provides a conservative approximation of the total expected benefits of research and avoids exaggerated estimates. Nevertheless, a pivotal supply shift tends to depress expected producer benefits. This necessitated some adjustments in the analysis of equity contributions.

A partial equilibrium model has the shortcoming that the effect of technology on the supply and demand of other products is not included.

To measure indirect technology effects, a general equilibrium model was developed, based on previous work by Haggblade and Hazell (1989). The model allowed different types of technological change to be evaluated (see Appendix 2 to this section, p. 55-57). For CIAT's purposes the effect of a 10% shift in the slope of the supply function, coupled with a 10% reduction in the tradeable input-to-output ratio, was evaluated. In other words, we approximated the impact of technology which increases yields without requiring more inputs. This roughly reflects the impact of technology that increases yields at stable input levels per hectare.

By varying the tradeable and nontradeable input coefficients and the income elasticity of domestic demand (Table S2.5), the ratio of the expected income change outside the agricultural sector to the expected supply change because of new technology can be calculated. By applying this ratio to the net present value of the expected supply change, as obtained in the partial equilibrium model, the net present value of the linkage effect is obtained.

Results. The values of the commodities according to the different criteria are given in Table S2.6. The net present value of research benefits varies considerably, from just over US$3 billion in the case of beef and rice to only US$107 million in the case of plantain. Three of CIAT's mandate commodities have high expected values of research within a Latin American context. These are beef, rice and milk. For the other two CIAT mandate commodities, beans and cassava, the net present values of research benefits within Latin America are considerably lower, comparable with those for vegetables, cotton, banana or sorghum.

If we consider that, for both beans and cassava, CIAT has a global, not regional, mandate, the expected benefits of research on these crops improve considerably. For both crops the NPV doubles when other regions of the world where CIAT has an operational mandate are taken into account. In the case of beans the NPV improves even further when the snap bean, the vegetable brother of the dry bean, is included in the analysis. In a Latin American context the value of a bean or cassava program is

Table S2.5. Assumptions for evaluating linkage effects.

A: Commodity data for multiplier and linkage analysis

Commodity	Non-tradeable	Tradeable	Input use: Tradeable inputs	Ag. non-tradeable inputs	Other non-tradeable inputs	Income effect (expenditure elasticity)
Rice	x	x	0.16	0.01	0.20	0.5
Soybeans		x	0.12	0.01	0.25	0.5
Cotton		x	0.10	0.01	0.20	0.7
Sorghum		x	0.24	0.01	0.04	0.5
Citrus		x	0.05	0.01	0.25	0.7
Banana		x	0.10	0.01	0.08	0.5
Plantain	x		0.05	0.01	0.04	0.9
Tomato	x		0.15	0.01	0.30	0.8
Onions	x		0.15	0.01	0.04	0.8
Milk	x	x	0.05	0.05	0.30	0.7
Beef	x	x	0.03	0.05	0.25	0.5
Beans	x	x	0.10	0.01	0.04	0.9
Cassava	x		0.05	0.01	0.20	0.9

B: Input/output matrix

Intermediate demand

From: / To:	T	OT	NT	ANT	ONT
Tradeable (T)	f[a]	f	f	f	f
Other tradeables (OT)	--	0.11	--	0.02	0.18
Nontradeable (NT)	f	f	f	f	f
Ag. nontradeable (ANT)	--	0.09	--	0.02	0.17
Other nontradeable (ONT)	--	0.10	--	0.025	0.20

a. f = To be filled with data for the commodity under evaluation as given in A.

SOURCES: Due to time limitations, input-use estimations are based on subjective assessments by CIAT's economists.

Table S2.6. Decision-making criteria for choosing CIAT's commodity options, that is, (beans (BE), rice (RI), cassava (CA), milk (MI), beef (BF), banana (BAN), plantain (PL), citrus (CIT), sorghum (SO), soybean (SOY) cotton (CO) and vegetables (VEG). Objective: ECONOMIC GROWTH.

Criteria	BE		RI	CA		MI[a]	BF[a]	BAN	PL	CIT	SO[a]	SOY[a]	CO	VEG
	LA[b]	LA+[b]	LA	LA	LA+	LA	LA	LA	LA	LA	LA	LA	LA	LA
NPV of research benefits at 10% (million US$)	594	1418	2957	503	1579	1910	3230	1040	107	226	619	1248	336	499
NPV of multiplier effect (million US$)	241	523	2319	319	1221	1219	1621	358	29	258	454	1050	375	214
Potential foreign exchange earnings from new technology[c]	*	*	*	*	***	**	**	***	--	***	***	***	***	*
Future demand growth (<=> pop. growth)	=	≥	=	≤	≥	>	>	=	<	=	>	>	<	>
Current value of production (million US$)	2459	5601	4070	1461	3228	8714	6852	7504	514	1300	1237	2362	3393	1887

a. Tropical lowlands of Latin America.

b. LA = tropical Latin America, which excludes Argentina, Chile, and Uruguay.
LA+ = tropical Latin America, plus Asia (for cassava), Africa and snap beans for beans.
It should be noted that in the future, semiarid Africa will receive cassava resources.

c. Includes import substitution. *** = high; ** = medium; * = low.

comparable with that of a sorghum or cotton program, but the mixed geographic responsibilities of CIAT suggest continued attention to the first two crops.

Technology that would allow sorghum and soybean to be grown on the acid savannas of the lowland tropics would have a considerable payoff. In the case of soybean, the present value of the direct benefits is more than a billion dollars. In case of sorghum, in a Latin American context, the benefits are higher than for beans and cassava. The NPV of research benefits for vegetables is lower than expected. Although the demand for vegetables will grow rapidly, it will do so from a small basis. For cotton and citrus, the NPV of research benefits is also small. In the case of cotton, this is caused by the limited potential for technological improvement. In the case of citrus, the commodity turned out to be less important than estimated during the first stage.

For all commodities, the inclusion of the linkage effect considerably increases the impact of research. The value of the linkage effect varies substantially among commodities. In beans and beef, it is less than 40% of the NPV of direct research benefits, but in citrus or banana it is larger than the direct research benefits. If agriculture is to be an engine of economic growth, commodities such as citrus or soybean would appear more important than commodities such as beef or beans. In general, the relative linkage effect is higher for tradeable than for nontradeable commodities.

The potential foreign exchange earnings for Latin America are high for commodities such as soybean, cotton, citrus and banana. The expected foreign exchange earnings from dried cassava exports in Asia remain high. Beef takes an intermediate position, and for rice, cassava in Latin America, bean, plantain and vegetables, the export potential is low.

Future demand growth is low only for cotton, because of substitution by artificial fibers, and for plantain, where urbanization is expected to decrease effective demand. It is high for animal proteins (beef and milk), animal feeds (soybean cake, sorghum) and vegetables. For the other commodities, future demand growth is expected to be roughly equal to population growth.

Not all commodities have secondary products, but for those commodities that do, this does influence future prospects. There is high future demand for cassava in the animal feed sector. For citrus, the expectations in the juice market are very favorable. High urban demand is expected for soybean oil.

The current value of production of CIAT's commodities compares favorably with that of the alternative commodities considered. CIAT's choices, made 20 years ago, were well founded. Although production of CIAT's commodities may have risen less than some others, it did so from a large initial value. Soybean, cotton and banana have comparable values of production. For the other products, these are considerably lower.

Equity

Criteria. In Latin America, poverty has become more widespread in recent years. Although the share of poverty is still higher in rural areas, poverty in urban areas has increased from 31% to 45% during the last decade (CEPAL, 1990). The availability of food for the poor needs to receive major emphasis in the future.

Latin American development has been characterized by the intensive use of capital, with low labor absorption and often labor displacement. Larger producers are benefiting more from public policies, farm mechanization and input subsidies than smaller ones (FAO, 1988). This has been one of the driving forces of urbanization and the increase in landless agricultural labor. In addition, small-scale farmers have been pushed to less fertile or marginal lands.

The criteria used to assess the contribution of commodities to CIAT's equity objective were technology-derived benefits to poor consumers, defined as the consumers of the lowest two (40%) income quintiles; the percentage small-scale farmers benefiting from new technology; the technology-derived employment effect; total calories for human consumption; and total proteins for human consumption. Poor consumers and small-scale producers were defined in such a way that, on the basis of income, the two groups are broadly comparable.

Measurement. Assessing technology-derived benefits to poor consumers proved straightforward. Total research benefits had already been calculated. Consumer surplus was therefore multiplied by the consumption share of poor consumers as given in Table S2.4.

Measuring the share of small producers in production led to major discussions. Welfare theory tells us that for nonexport commodities in general (in a partial equilibrium framework), consumer surplus is positive, whereas producer benefits might be negative. Our model showed similar results. Positive consumer benefits are to be expected, but negative producer benefits seem less realistic, and might have been caused by the use of a pivotal shift to obtain conservative expected benefits. Thus, the estimated producer surpluses were rejected as a measure of impact on producers' equity. Total producer surplus, including exogenous impact, was then evaluated. Although positive, this measurement confounds the technology impact with demand and production growth. This measure was rejected as well. An alternative is to argue that, in the long run, the commodity's equilibrium price may be equal to its price prior to technological change, due to substitution effects. Producer benefits can then be calculated as $P_1 (Q_1 - Q_o)$ (price after impact times the additional quantity). However, this is an heroic assumption, and hard to substantiate. As a compromise, the percentage of small farmers benefiting from new technology was measured and should be evaluated in light of total benefits.

The employment effect of technology was calculated by using the general equilibrium model described earlier. The total effect consists of (a) the direct effect, that is, the change in employment within the commodity subsector, and (b) the indirect effect, that is, the change in employment outside the subsector, calculated through the linkage effect of the model (see Appendix 3 to this section, p. 58-59).

The availability of total calories and proteins was calculated from FAO's food balance sheets.

Results. The results for the equity criteria are summarized in Table S2.7. The figures for technology-derived benefits to poor consumers are similar to those for total benefits. Among CIAT's commodities, rice stands out, with a high estimate of approximately US$2.6 billion. This seems acceptable, given that rice is the most popular carbohydrate in Latin American diets. The results again show that the inclusion of Africa and Asia for beans and cassava, respectively, significantly increases the importance of these two crops. The estimates for most other commodities are average to low.

Rice, beef and milk are produced more by large-scale farmers than are beans and cassava. More benefits will therefore accrue to small-scale farmers for the latter two crops. Large-scale farmers are also the main producers of banana, sorghum, soybean and cotton.

The results of the employment effect criterion show that the highest scores are typically achieved by crops with a high labor requirement for harvesting and processing, such as cassava and banana. Conversely, crops, such as beans (in Latin America), actually show loss of employment due to technological change. Extra employment in harvesting and marketing cannot compensate for the loss of employment in production.

As regards the results for total calories and proteins, the figures for total calories for rice and cassava (including Asia) stand out. The scores for banana, plantain, citrus, sorghum, cotton and vegetables are relatively low. The remaining crops show intermediate values. In the case of total proteins, beans, rice, milk and beef show high scores, with the other crops having low to intermediate values.

Table S2.7. Decision-making criteria for choosing CIAT's commodity options, that is, beans (BE), rice (RI), cassava (CA), milk (MI), beef (BF), banana (BAN), plantain (PL), citrus (CIT), sorghum (SO), soybean (SOY), cotton (CO) and vegetables (VEG). Objective: EQUITY.

Criterion	BE		RI	CA		MI	BF	BAN	PL	CIT	SO	SOY	CO	VEG
	LA[a]	LA+[a]	LA	LA	LA+	LA	LA	LA	LA	LA	LA	LA	LA	LA
Technology derived benefits to poor consumers (million US$)[b]	415	1903	2595	461	741	742	1498	43	40	75	62	134	21	137
Share of small producers in production (%)[c]	55	76	18	52	67	50	26	12	52	53	13	3	25	80
Technology derived employment effect (thousands man-years)	-63	53	98	-60	171	110	67	224	5	103	59	156	37	33
Total calories for human nutrition (million kcal/day)	38.8	63.1	106	29.8	86.5	48.5	26.4	16.8	9.6	5.8	2.3	23.4	6.6	4.7
Total proteins for human nutrition (thousands kg/day)	2393	3979	2100	187	542	2818	1746	223	87	0	60	0	0	185

a. LA = Tropical Latin America, which excludes Argentina, Chile and Uruguay; LA+ = tropical Latin America, plus Asia (for cassava), Africa and snap beans for beans.

b. For consumers of lowest two income quintiles (lowest 40%).

c. For consumers with income < US$3000 per family.

Only the direct intake for human consumption was considered in the nutrition criteria. This discriminates against cassava, soybean and cotton seed (meal), a considerable share of the production of which is used for animal production. These crops would show higher values if indirect protein consumption had also been measured.

Sustainability

Criteria. Natural resource conservation criteria were divided in two groups. The first group concerns the negative impact that the studied commodities have on the environment at present. To understand this negative impact we reviewed the amount of soil erosion and depletion, pesticide use and contributions to deforestation associated with the cultivation of these commodities. The other group looks at the potential contribution that improved commodity technologies can make to the enhancement of the natural resource base. Here we considered the commodity's annual or perennial nature, its potential for rotation and adaptation to the environment and the possibility of reducing input use.

Both the "negative impact" and "technology contribution" criteria were evaluated for the three ecosystems that were proposed for CIAT's interventions in the field of natural resource management. These ecosystems are the savannas, forest margins and mid-altitude hillsides.

Results. In consultation with several experts, and based on existing data, a qualitative assessment was made for the selected zones (Table S2.8).

For the hillside zones, erosion is evidently a principal concern. Cassava and, to a lesser extent, beans and degraded grass pastures contribute to erosion. Vegetable production is often characterized by pesticide abuse.

Improved pastures that allow intensive milk production and permanent crops, such as citrus and, to some extent, plantain, can substantially reduce erosion and soil depletion. For beans, cassava and vegetables, improved technology can correct the conservation problems that their cultivation brings at present. Additionally, vegetables can improve the depressed incomes of many smallholders on the more favored parts of their farms, thereby reducing overexploitation of the land.

In the acid savannas of Latin America, monoculture of soybeans and, to a lesser extent, rice and degraded pastures have created severe soil nutrient runoff. Again, for soybeans and vegetables, pesticide use in these regions has become hazardous.

Table S2.8. Assessment of the relative contribution of commodity technology to the conservation of the natural resource base in specific ecozones in Latin America[a], that is, beans (BE), rice (RI), cassava (CA), milk (MI), beef (BF), banana (BAN), plantain (PL), citrus (CIT), sorghum (SO), soybean (SOY), cotton (CO) and vegetables (VEG). Objective: NATURAL RESOURCE CONSERVATION.

Zones	Impact[b]	BE	RI	CA	MI[c]	BF[c]	BAN	PL	CIT	SOR[c]	SOY[c]	CO	VEG
Hillside zones	Negative impact	**	*	***	**	**	*	*	*	*	*	*	**
	Potential positive contribution	**	*	**	***	**	**	**	***	*	*	*	**
Savanna zones	Negative impact	*	**	*	*	*	*	*	*	*	***	*	**
	Potential positive contribution	*	***	*	**	***	**	*	**	**	**	*	*
Forest margins	Negative impact	*	**	**	**	***	**	*	*	*	*	*	*
	Potential positive contribution	*	**	**	*	**	*	**	**	*	*	*	*

a. Ecozones for Latin America and the Caribbean determined by CIAT's Agroecological Studies Unit.

b. * = small; ** = medium; and *** = large contribution.

c. Tropical Latin America, which excludes Argentina, Chile and Uruguay.

Well-managed pastures form the key to improved resource use in this ecosystem, but this has to be complemented with crop-pasture rotations. The preliminary results of the integration of newly developed acid-tolerant rice lines into pasture establishment and renovation suggest there is a high potential for such systems. Soybeans and sorghum could fulfill similar roles in crop-pasture or crop-crop rotations. Perennials, such as citrus or banana, would allow rational land use on sloping savanna facets.

The forest margins include both current and previously forested zones. With respect to the former, policy interventions are a necessary ingredient prior to the introduction of improved technologies in order to stop further encroachment. The intensification potential of land use in already deforested areas as brought about by appropriate technologies appears to be high, but should be carefully monitored to avoid frontier expansion because of improved agricultural profitability.

Settlers' crops, such as beans, rice and cassava, play a role in the degradation of the ecosystem. Often they are followed by cattle ranching on unsustainable pastures. In Bolivia and Brazil, cattle ranching, independent of previous small-farmer colonization, has formed a major threat to the ecosystem.

The same crops are those on which technology could have positive impact, because they are so closely associated with the settlers' survival strategies. Perennial crops would again have a significant advantage, not only for soil conservation, but also for the stability that they bring to the production system. This would mainly concern banana, plantain and citrus.

Institutional considerations

Criteria. Two criteria were proposed: the current level and capacity of research by national programs for a specific commodity; and the contribution of research by international centers, if any.

Results. For CIAT's current commodities, sufficient information exists on the level and capacity of national research. However, for other commodities, data were scanty, and subjective assessments had to be used.

In evaluating the results, the old dilemma arises again as to whether CIAT should work with those national programs that are weak or with those that are relatively strong. In this analysis the views prevailed that CIAT should work with programs of intermediate strength. In Table S2.9 the results of institutional considerations are shown.

Table S2.9. Decision-making criteria for CIAT's commodity options, that is, beans (BE), rice (RI), cassava (CA), milk (MI), beef (BF), banana (BAN), plantain (PL), citrus (CIT), sorghum (SO), soybean (SOY), cotton (CO), and vegetables (VEG). Objective: INSTITUTIONAL CONSIDERATIONS.

Criteria	BE		RI	CA		MI	BF	BAN	PL	CIT	SO	SOY	CO	VEG
	LA[a]	LA+[a]		LA	LA+	LA	LA				LA	LA		
Current investigation by national programs[b]	I	I	I	W,S	W,S	W,S	I	W,S	I	W,S	I	W,S	W,S	I
Current investigation by other international research efforts	CRSP		IRRI WARDA	IITA		ILCA ILRAD		INIBAP IRFA IITA CATIE		--	INTSORMIL ICRISAT	--	--	AVRDC
Lead time of research (years)	4	4	4	8	6	4	4	6	6	8	7	4	4	4

a. LA = Tropical Latin America, which excludes Argentina, Chile and Uruguay; LA+ = Tropical Latin America, plus Asia (for cassava), Africa and snap beans for beans.

b. W,S = weak and strong; I = intermediate.

The current research efforts of national programs in beans in Latin America and rice appear appropriate for successful collaboration. It should be noted that producer organizations may play a vital role in national research, as is the case for rice, so that assessments of the strength of the national system as a whole may differ from those of specific programs. The remaining commodities invariably showed weak national program research in Latin America and the Caribbean.

Little or no research is conducted by international research centers on citrus, soybean and cotton. However, it must be kept in mind that considerable research on these crops is being done by the private sector in the developing world.

In the case of cassava, and milk and beef, although other international research is being conducted, this is not directly related to Latin America and the Caribbean. In the case of banana, considerable research is being conducted by the private sector, in addition to international centers.

Conclusions

Table S2.10 provides a summary of the scores of each commodity for each group of criteria. CIAT's present commodity portfolio emerges as being very relevant, within the framework imposed, and the geographical limits to the analysis. For example, if for cassava some spillover benefits to Africa were considered, its relevance would be even higher. Apart from the present CIAT commodities, sorghum and soybeans might make useful contributions to CIAT's portfolio, because their potential is so clearly focused in one agroecological zone. Citrus warrants attention from the sustainability point of view.

Let us look at each group of criteria to obtain an idea of the relative ranking of the commodity options.

From the point of view of growth, the commodities with the highest scores are rice, milk and beef. Although they all rank low for one of the criteria, potential foreign exchange earnings, they perform better than the rest for other growth-related aspects, including the current value of production.

The second group of criteria, equity, has two clear winners, beans and cassava, especially when CIAT's global mandate is considered. Rice has very high scores for equity among poor consumers, but not for producers. Milk and beef are somewhat less important in this respect than rice. None of the commodities currently outside CIAT's present portfolio appears relevant from the point of view of equity.

Table S2.10. Summary of the contribution[a] of various commodities to CIAT's objectives in Latin America (LA).

Commodity	Economic growth	Equity	Natural resources: Negative[b] impact	Natural resources: Positive[c] contribution	Institutional considerations
Beans					
LA	*	**	*	*	***
Africa	**	***	**	**	**
Rice	***	**	**	**	**
Cassava[d]					
LA	*	***	**	*	**
Asia	**	**	***	**	**
Milk	***	**	**	**°	**
Beef	***	**	***	***	***
Banana	**	*	*	*	*
Plantain	*	*	*	*	*
Citrus	*	*	*	***	*
Sorghum	*	*	*	*	***
Soybeans	**	*	**	*	**
Cotton	*	*	*	*	*
Vegetables	*	*	**	*	***

a. Small contribution (*), intermediate contribution (**), and large contribution (***).

b. Negative impact of present cultivation practices on the natural resource base.

c. Possible contribution of improved commodity technology to resource conservation within selected agroecosystems (see Table S2.8). For cassava and beans some contribution outside Latin America has been assumed.

d. The present analysis does not include benefits of CIAT's cassava research to Africa, where IITA has the operational mandate. It is recognized that CIAT's cassava research offers potential for African conditions.

In terms of resource preservation, tropical pastures have an important contribution to make to the reduction of soil erosion and depletion, but they also have an important current negative impact, through pasture degradation and ranching in forest margins. The role of cassava and beans for both negative and positive dimensions grows by taking into account the production outside Latin America. Citrus production has an important role to play, especially in the hillsides. In the savanna zone, soybeans cause problems and need attention.

Finally, with respect to institutional aspects, tropical pastures, beans and sorghum have relatively short lead times for research, and the opportunities for complementing national and international efforts appear good. Rice, cassava and soybeans also appear productive in this respect, albeit to a lesser extent.

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Appendix 1: MODEXC, a model to calculate economic surpluses

MODEXC is a user-friendly, menu-driven model that can be run on Lotus 123. It is based on the technology evaluation method proposed by Lynam and Jones (1985) and applied, among others, by Pachico et al. (1987) and Antony et al. (1988).

MODEXC simulates the evolution in market equilibrium, as both supply and demand shift. Supply shifts in the model arise from two sources: (1) the technological change under evaluation (the objective of the analysis) and (2) other technological changes and supply shifts associated with autonomous growth in the production sector. From the demand side, the autonomous shifts that take place are associated with population growth, higher incomes and variations in the prices of substitutes. The model performs annual calculations of consumer, producer and total benefits emerging from the technological change being evaluated, as well as from changes associated with autonomous supply shifts.

The model uses three criteria to determine the economic benefits associated with investments in agricultural research:

1. The net present value of economic surpluses;
2. The internal rate of return (IRR) of research investments; and
3. The benefit-to-cost ratio.

The mathematical model.

[1] $S_0 = C\,(P\text{-}M)^d$ Initial Supply Function

[2] $S_1 = CK_aK_1\,(PK_2\text{-}M/K_3)^d$ Total Supply Function, including both the technological and autonomous shifts in supply

[3] $D_0 = \beta\,P^{\eta_p}$ Initial Demand Function

[4] $D_1 = \beta K_d\,P^{\eta_p}$ Shifted Demand Function

Where:

P = Commodity price
M = Minimum supply price

$$d = \frac{E_p (P_0\text{-}M)}{P_0}$$ where E_p is price elasticity of supply

P_0 = Initial market equilibrium price

$$C = \frac{Q_0}{(P_0\text{-}M)^d}$$

Q_0 = Initial market equilibrium quantity

K_a = $(1+\delta)^t$ = Autonomous supply shift

δ = Annual rate of growth in supply due to autonomous forces

t = Time

β = Intercept of the demand function

η_p = Price elasticity of demand

K_d = $(1+\gamma)^t$ = Demand shift, where γ is the net annual growth in demand

K_1,K_2,K_3 = Supply shifters due to technological change

The model considers three alternative scenarios for the supply shift, depending on the type of technological change, as follows:

1. When $K_1>1$ and $K_2=K_3=1$, a pivotal divergent shift is assumed.

2. When $K_2>1$ and $K_1=K_3=1$, a nonpivotal and divergent supply shift is assumed.

3. When $K_3>1$ and $K_2=K_1=1$, a nonpivotal and convergent supply shift is assumed.

Results. MODEXC calculates, in two stages and for each year of evaluation, quantity and equilibrium prices over time. In the first stage, it calculates quantities and prices on the assumption that autonomous changes only occur in the system. In the second stage, it calculates quantities and prices on the assumption that both autonomous changes and changes brought about by technological innovation occur. Three types of economic surpluses are estimated by the model: those caused by autonomous changes, those associated with technological change, and the sum of the previous two.

MODEXC has an option for measuring the economic surpluses in closed or in open economies. In the latter case, the model estimates the total production, as well as domestic consumption and trade (imports or exports).

To calculate benefit-to-cost-ratios and the internal rate of return on research investments, the model allows for the incorporation of research expenditures that take place 10 to 20 years after the implementation of the new technology.

Appendix 2: Estimation of linkage effects

The model distinguishes five supply sectors:

- Sector 1 includes the data on the tradeable commodity to be evaluated. If a nontradeable commodity is evaluated, sector 1 stays empty.
- Sector 2 includes the supply of all other tradeable commodities. For sectors 1 and 2, a fixed (world market) price is supplied to the model.
- Sector 3 includes the data on the nontradeable commodity to be evaluated. If a tradeable commodity is evaluated, sector 3 stays empty.
- Sector 4 includes the supply of all other agricultural nontradeable goods.
- Sector 5 includes the supply of all nonagricultural goods and services that are nontradeable.

For sectors 3, 4 and 5, intermediate and final demands are defined. The supply and demand in sectors 3, 4 and 5 need to be balanced in the model.

Income is defined as the difference between the total value of production and the value of intermediate demand. In the case of nontradeables, a term is included that defines the income increase to consumers because of the price effect of the technological change.

The model has linear supply and demand equations. It is written in a microcomputer spreadsheet and is solved by an iterative procedure.

Supply.

$$Si = a_i + b_i * P_i \qquad (1)$$

For i = 1 to 5

Where:

S = Supply
P = Price
a,b = Supply equation coefficients

Final demand.

$$D_i = c_i + d_i \cdot P_i + e_i \cdot Y_i * (1\text{-}s) \qquad (2)$$

For i = 3 to 5

Where:

d = Final demand
s = Savings quota
Y = Income
c,d,e = Demand equation coefficients

For the tradeable sectors (1 and 2) all supply is cleared at a fixed price.

Intermediate demand.

$$ID_i = \Sigma_j^5 f_{ij} \cdot S_j \qquad (3)$$

Where:

f_{ij} = Intermediate demand fraction from sector j to sector i

ID_i = Intermediate demand for production of sector i

Total demand.

$$TD_i = D_i + ID_i \qquad (4)$$

Where:

TD = Total demand

Income. (5)

$$Y = \Sigma_j^5 S_j * P_j - \Sigma_i^5 \Sigma_j^5 f_{ij} \cdot S_j \cdot P_i + (D_3^T \cdot P_3^T - D_3^o \cdot P_3^o)$$

The first term after the equal sign expresses total supply; the second term expresses the input use by the different sectors; the third term expresses the income increase to consumers because of the possible price effect of technological change in a nontradeable commodity. The superfix (T) indicates that technological change has occurred, superfix (o) that it has not occurred.

Equilibrium.

$$S_i = TD_i \qquad (6)$$

For i = 3 to 5

Parameter values. a_i, b_i, c_i, d_i and e_i are calculated on the basis of expected supply and demand elasticities, price levels and equilibrium quantities. For the assumptions on the parameters, see Table S2.5.

The commodity under evaluation has a price elasticity of supply of 0.8. Agricultural and other nontradeables are considered to have perfect elastic supply.

Price elasticities of demand were put at -0.5 for nontradeable sectors. Expenditure elasticities change with the product under evaluation. The expenditure elasticity reflects the extent to which extra income is spent on nontradeables vis-à-vis tradeables.

The equilibrium quantities of the model reflect the Colombian economy to some degree. Total income is close to US$50 billion, and the contribution of the agricultural sector is 25%. The share of the nonagricultural nontradeable sector is about 40% of the total economy.

The value of a CIAT tradeable or nontradeable commodity does not reflect its real contribution to GDP. In all cases, the initial value was put at US$1 billion. When the other nontradeable sectors have fully elastic supply, the relative size of the different sectors does not influence the size of the multipliers obtained. These depend only on the relative input use and on the income elasticity of domestic demand.

Evaluation of technological change. By inputting into the model the input use and income elasticity for the individual commodities and by simulating a supply shift in sector 1 or 3, the impact of technological change on the production of the commodity itself, as well as in other sectors, can be evaluated. By dividing the income change outside the commodity with the production increase as caused by the technological change, the multiplier is obtained. This figure is multiplied by the net present value of production increases as obtained in the partial equilibrium model to obtain the net present value of the linkage effect.

Appendix 3: Estimations of the employment effect of new technology

The employment effect of new technology was estimated for the final year of the planning period (2025).

Estimation of the indirect effect. If constant labor productivity outside the subsector influenced by technological change is assumed, the indirect effect can be estimated as a linear relationship with the extra production in the rest of the economy, as generated through the linkage effect.

The relationship between employment and production is expressed by average labor productivity. At a conservative estimate of 1.5% GDP growth per year from now to the year 2025, at a constant employment rate of the total population of 57%, and at a ratio of 1.46 between total production and total value added (as observed in the general equilibrium model), the expected labor productivity in the year 2025 can be estimated as:

$$US\$1812 \times 1/0.57 \times 1.46 \times (1.015)^{38} = US\$8172 \text{ per year.}$$

Where:

US$1812 = GDP/head in 1987 (World Bank, 1989), and the other terms are as expressed above.

The extra production outside the subsector, caused by the linkage effect, can be calculated in the general equilibrium model. By dividing this by the production change due to technology within the subsector, the "production to production multiplier" is derived for each commodity. This last multiplier was applied to the extra production as estimated in the partial equilibrium model for the year 2025. The value obtained was divided by the expected labor productivity per person in the year 2025, to find the years of employment caused by the indirect effect.

Estimation of the direct effect. Assuming that agricultural production technology normally aims to increase yields per hectare without major changes in the use of labor per hectare, the direct employment effect can be estimated on the basis of the following data:

1. Total production in tons with and without technological change (P_o and P_t).

2. Yields in tons per ha with and without technological change (Y_o and Y_t).

3. Estimated labor use in days per ha in land-related activities in the year 2025 (L).

4. Estimated labor use in days per ton in volume of production-related activities (T).

5. Labor days per year (LD).

Assuming that the labor use per ha and per ton stay the same before and after technological change, the number of years of direct employment within the commodity subsector before technological change is calculated as:

6. $(P_o/Y_o*L + P_o*T)/LD$

   and after technological change as:

7. $(P_t/Y_t*L + P_t*T)/LD$

By subtracting (6) from (7), the effect of technological change on employment in the commodity subsector is found.

Estimation of the total effect. By summing the direct and indirect effects, the total employment effect for the year 2025 is obtained.

Section 3

SELECTED COMMODITY TRENDS[1]

Introduction

The outlook for the commodities that CIAT proposes to work on has been analyzed within the general socioeconomic context of Latin America and other mandate continents. This analysis helps to establish a base on which to plan CIAT's future activities. The data used comprised published statistical information (mainly from FAO), which is variable in its quality and reflects differences in the development of statistical data collection systems among countries and the present economic importance of individual commodities for specific countries. It should be kept in mind that statistics aggregated at the national level may mask important shifts in productivity of crops in specific regions, for example, displacement of crops from prime land to marginal land fostered by the development of cultivars better adapted to marginal conditions. Furthermore, given the limited time since release, several of CIAT's materials have achieved farmer acceptance, but the areas involved are still too limited to be reflected in aggregate national yield statistics.

The task force shares the view that economic growth in developing countries during the 1990s will stem from an increase in both trade and technological development in the agricultural sector. These technological developments will provide impetus for effective demand that will produce broad-based participation in the development process. The projections developed in this paper are based on these moderately optimistic economic growth prospects. Demand projections are based on an assumed per capita income growth rate of 1.5% annually and population growth rates on estimates by the World Bank for individual countries.

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Latin America

Beans. Beans are a traditional food crop produced by a variety of production techniques by small farmers in large areas of Central and South America. During the past two decades, annual growth in bean production was slightly greater than 1%, well below the population growth rate of 2.4%. Annual production in the most recent decade increased to an average of 2.3%, primarily because of increased output in Mexico, Central America, and the Southern Cone countries of Argentina and Chile. Coupled with rising imports, the availability of beans increased by 2.5% annually over the 1976-1986 period.

The positive performance of the bean production sector during the past decade was primarily a result of increases in area cultivated, not increases in productivity. Annual increases in bean hectarage averaged 2.5% in Brazil and the Southern Cone countries, and over 3.0% in Mexico and Central America. Although productivity growth was negative in the 1976-1986 period, it was not as low as that of the earlier decade.

Some observations should be made with this brief analysis of area and productivity growth. For some countries, such as Guatemala and Costa Rica, the expansion of bean hectarage may well have been overestimated. In both countries, improved varieties were released and afterward adopted by large numbers of farmers. In Costa Rica, these new varieties spread to more than 21,000 hectares and outyielded traditional varieties by about 240 kg/ha. In Guatemala, these varieties were adopted for use on more than 12,000 hectares and outyielded traditional varieties by about 340 kg/ha. As a result, during the 1982-1986 period, average yield increases from the mere diffusion of improved varieties was probably 26 kg/ha in Guatemala and 100 kg/ha in Costa Rica. Although FAO statistics show negative yield tendencies for both countries, the evidence of release and adoption does not confirm such data.

Some causes for FAO's statistics of negative yield tendencies may have been, first, improved varieties have higher profitability and so lead to increases in credit requests. Such credit requests often play an important role in estimating area planted. Second, production statistics are often based on market availability. These data are later traced back to area figures by assuming a constant yield per hectare.

The increase in area in Brazil and Mexico occurred in nontraditional production areas. Beans have shifted toward these areas, partly because of comparative production advantages, as was the case in Mexico. Here, beans have been moving into a semiarid area (the northern highlands), which has one rainy season lasting 60 to 90 days. Early bean varieties are able to produce an acceptable harvest during this short growing season, whereas most other crops are not. In other countries, beans shifted to nontraditional areas because of low profitability. In Brazil, for example, the more productive soybeans (and also maize and rice) have pushed beans from prime to marginal land. To stop further marginalization, profitability increases are critical, that is, there should not only be increased returns to land, but also even greater increases in returns to labor. Varieties that fit appropriately into the farm system and accept selective mechanization will be instrumental for improved labor productivity.

The potential of management practices and improved input use (fertilizer, selective chemical control) to increase productivity has not been sufficiently exploited in many bean production areas. With increasing commercialization of bean production, more and more farmers will intensify their bean production systems. An example is the heavy use of chemical controls by bean farmers in eastern Antioquia, Colombia, a region well integrated into the urban market. The farmers spray their beans an average of six times per crop cycle. Another example is the (poorly documented) growing bean production under irrigation in Brazil, because of its high payoff in the short term. Strategic cultural practices and crop management research to anticipate these intensification trends will be the necessary complement to genetic improvement for obtaining productivity increases.

Beans are an important source of dietary protein for the low- and middle-income rural and urban populations of Latin America. With 70% of Latin Americans living in urban areas, the availability of beans at affordable prices is an important policy consideration. Although the income elasticity of bean consumption is positive only for low- and middle-income ranges, commercial opportunities for bean producers will continue to increase. The reasons are, first, urban population will continue to increase; second, the impact of urbanization on bean consumption is not always negative, as it is for most traditional staples. In countries, such as Colombia, urban bean availability is higher than rural bean availability because beans are not grown in many areas of the countryside. Third, with rising incomes, bean consumption shifts from less to more preferred grain types. Although this does not raise consumption in kilogram per person, it does increase expenditures per capita. Evidence from several countries (Honduras, El Salvador, Peru, Colombia) suggests that varieties have to be improved simultaneously for both agronomic and commercial traits in order to be successfully adopted. Bean producers will increasingly pay close attention to consumer preferences in bean consumption characteristics. Bean storage and marketing will demand increased research and policy attention.

Projections of present aggregate production and consumption trends do not point to a deficit in bean supplies as far as year 2000 (Table S3.1). However, the level of aggregations conceals the fact that Brazil and the Andean region are projected to have annual deficits of 351,000 and 107,000 tons, respectively, by the year 2000. The estimate for Brazil is pessimistic, but reflects the lagging productivity growth and consequent marginalization. If new technological options, such as irrigation or

Table S3.1. Beans in Latin America: 1984-1986, and outlook for production and consumption balances (in thousands of tons) in the year 2000.

Region or country	1984-1986			2000		
	Production	Consumption	Balance	Production	Consumption	Balance
Brazil	2465	2514	-49	2945	3296	-351
Mexico	989	1104	-115	1643	1536	107
Andean region	260	294	-34	298	405	-107
Central America	290	309	-19	462	442	20
Caribbean	120	125	-5	146	158	-12
Southern Cone	334	85	249	496	104	392
Total	4458	4431	27	5990	5941	49

increased adaptation to acid soils, are successfully developed, the real deficit might be less. For the Andean region, the estimated deficit equals 34% of production. It is mainly concentrated in Peru and Ecuador, and forms a bleak but real prospect for bean utilization in this region.

Mexico and Central America are expected to have surpluses. For Mexico, this depends on the continued expansion of beans in the northern highlands. Because future expansion will involve higher costs, production growth may, in fact, decrease, thereby reducing Mexico's surplus. For Central America, production growth is increasingly dependent on improvements in productivity per hectare, which requires improved planting material and input use. After excluding the exporting countries of Argentina and Chile, the total deficit for tropical America is projected to be 343,000 tons.

Bean production is carried out on farms that often produce many other crops. The importance of beans on these farms is defined by the relative profitability with respect to the other crops. On many small farms, competing crops include vegetables, fruits or coffee. Because beans are easily substituted by these crops, bean productivity will have to be as high as that of these crops in order to be included in production plans.

On large farms, beans compete with soybeans, cotton, sorghum, maize and sugarcane. Labor productivity will be the key to maintaining or increasing the role of beans on these farms.

In the 1970s and 1980s, when productivity per hectare went down, the shift to nontraditional production areas allowed bean production to keep up with population growth. Strong urban demand nevertheless caused bean prices to rise in many countries. In the 1990s, these trends have to be reverted. Improved varieties and improved management should increase productivity and allow total production to grow more rapidly than the population of the continent in order to diminish pressure on consumer prices.

Beef and milk. In 1986, tropical Latin America had about 240 million head of cattle (19% of the world stock), which produced 5 million MT of beef in carcass weight (10.5% of the world output). In 1979-1986, average net exports of beef amounted to 4.7% of total production, whereas 12% of total milk production was imported. At the same time, the region produced 30 million MT of milk (6.5% of world output). This has resulted in relatively high levels of per capita consumption of beef (14 kg) and milk (96 kg in 1979-1986), a fact reflecting the wide land-to-man ratio and the abundance of cattle in the region.

Beef and milk are staples in Latin American diets. Their combined food budget share is above 20%, even in the diets of the lowest income quintile of the population. This wage-good attribute explains the high priority these commodities have in food policies.

During the 1970s, when incomes were growing rapidly, production growth rates were above those of population, and prices trended upward. During this period, poultry prices declined, because of technical change and overvalued currencies which decreased the domestic cost of imported grains, and induced a substantial process of substitution in consumption. The recession of the 1980s affected beef demand, and production growth rates declined below those of population.

Net imports of dried-milk powder increased substantially during recent years because of low international prices, the ample availability of dried-milk food aid, and the ease of introducing powdered milk into the domestic market. This contrasts with the structural protection of domestic beef markets because of the lack of facilities to handle and distribute highly perishable imported meats.

The lack of productivity gains in ruminant animal production, as reflected by aggregate national statistics, underestimates, to a large extent, the contribution of technical change in this sector to overall growth of the agricultural sector. That is, both technical change and infrastructure contributed to the shift of livestock production to more marginal lands, releasing land with better soils for crop production. Thus, the contribution has been to sustain productivity levels in spite of using land resources of lower productivity. This is clearly shown in the case of Brazil, where the Cerrados region has substantially increased its share of the national herd; for example, the share of the cattle inventory in the states of Goiás and Mato Grosso evolved from 15% in the 1950s to 31% in 1985. In Colombia, the Eastern Plains in the Meta Department held 0.6% of the national herd in the 1950s, and by 1985 this share had risen to 6.1%. To a large extent, these shifts were made possible by the introduction of pasture germplasm adapted to these acid soils, particularly *Brachiaria decumbens* and, lately, *Andropogon gayanus*. The latter grass was developed jointly by CIAT and several national programs, and is now being grown on more than 500,000 ha throughout the region.

Beef projections show a trend toward decreasing self-sufficiency levels, with tropical Latin America importing about 360,000 MT of beef in 2000 (Table S3.2). The Andean region would be almost self-sufficient, with some room for exports; while Central America would continue being a net exporting region. Part of this potential demand will be met by poultry. The task force expects poultry prices to decrease further, although at a lower rate than in the past. Given the structural protection of the beef market, it is expected that most of the potential demand would be absorbed through increased prices. Technical change can clearly contribute to reducing the upward pressure on prices, thus benefiting consumers. In Central America, given the limited outlook for income growth, it is expected that exports will grow.

The outlook for international prices is moderately optimistic; thus, even if domestic incomes do not grow or poultry prices drop dramatically, the international market will create a floor price, as has been shown in the past by Brazil, which has shifted from being a net importer to a large net exporter.

Tropical Latin America will continue to be a net importer of milk and dairy products, with decreasing self-sufficiency levels (Table S3.3). International prices are expected to rise slightly and milk food aid to decrease. Domestic prices are above present international prices in most countries through governmental efforts to maintain a certain level of domestic production. Technical change in pastures could contribute to reducing domestic prices and generating income and employment for, on the whole, small- to medium-sized farmers.

The major implications of the above for technology design are:

* Given the trends of increased consumption of animal products in most countries of Latin America and in the developing world in general, together with the magnitude

Table S3.2. Beef in Latin America: 1984-1986 situation and outlook for production and consumption balances (in thousands of tons) in the year 2000.

Region or country	1984-1986			2000		
	Production	Consumption	Balance	Production	Consumption	Balance
Brazil	2095	1768	327	2,658	2,702	-44
Mexico	960	968	-8	1,273	1,541	-268
Central America	323	281	42	539	450	89
Caribbean	260	377	-117	308	509	-201
Andean countries	1369	1359	10	2,169	2,101	68
Trop. Latin America	5007	4753	254	6,947	7,303	-356
Southern Cone	3199	2833	366	3,991	3,514	477
All Latin America	8206	7586	620	10,938	10,817	121

SOURCE: FAO and CIAT estimates.

Table S3.3. Milk in Latin America: 1984-1986 situation and outlook for production and consumption balances (in thousands of tons) in the year 2000.

Region or country	1984-1986			2000		
	Production	Consumption	Balance	Production	Consumption	Balance
Brazil	12,248	12,996	-748	16,728	19,496	-2768
Mexico	7,508	8,885	-1377	12,043	13,779	-1736
Central America	1,481	1,803	-322	1,736	2,619	-883
Caribbean	1,709	2,469	-760	2,295	3,253	-958
Andean countries	6,582	7,586	-1004	8,752	11,353	-2601
Trop. Latin America	29,528	33,739	-4211	41,554	50,500	-8946
Southern Cone	7,643	7,696	-53	9,604	9,586	18
All Latin America	37,171	41,435	-4264	51,158	60,086	-8928

SOURCE: FAO and CIAT estimates.

of available resources (land and cattle), the benefits of technical change in animal production and pastures will be substantial.

* The higher capital costs to be expected in the next decade will increase the pressure to improve the return to capital in the sector. This implies that in the predominant extensive systems, efforts to augment production per animal will increase in importance vis-à-vis increases in carrying capacity.

* The higher opportunity cost of capital and limited public resources for research imply that research will have to be more market driven, emphasizing shorter term benefits. This may imply increased emphasis in upgrading pasture systems at locations closer to markets, where sustainability can be addressed more directly, in contrast to the extreme frontier. The lack of funding for infrastructure will limit the payoff of such investments. Screening for germplasm should continue to be done under severe conditions. Pasture management research should respond to market demands.

* The reduction of subsidies for frontier development will, all else remaining the same, raise the relevance of crop-pasture integration. The devaluation of domestic currencies will also promote domestic grain production. Both forces operating in the same direction will have implications for the development of appropriate pasture germplasm and, in particular, establishment techniques. This interaction will increase the complexity of the issues involved and will require a more holistic resource management approach.

* The expected further increase in poultry consumption will reduce potential demand for beef to some extent, but will also reduce pressure on governments to control beef prices for urban consumers, and will also dampen price cycles. It will additionally permit a more efficient aggregate use of domestic resources.

* By focusing research increasingly on regions with small- to medium-sized operations, pasture research will affect milk production more directly. In this way, pasture research will start of affect positively the incomes of small- and middle-sized producers. Much of this technology will also be applicable to beef operations. For beef, the technological benefits will directly increase producers' income because export markets will create a floor price. Producers should then have the resources to fund at least part of the adaptive research required.

Cassava. During the 1970s and early 1980s, there was a decline in total cassava production, mainly because of decrease in production in Brazil, from 26 to 23 million MT in 1976-1986 (Table S3.4).

Table S3.4. Cassava production: its relative importance in Latin America and per capita production levels during 1966-1988.

Country	Production (1000 MT)			Percentage of total	Per capita production
	1966/68	1976/78	1986/88	1986/88	1986/88 (kg)
Brazil	27,061	25,611	23,570	77.16	167
Mexico	0	58	1	0.00	0
Andean countries and Paraguay	3,573	4,890	5,957	19.50	67
Central America	92	108	162	0.53	6
Caribbean region	566	739	698	2.29	25
Temperate South America	272	197	159	0.52	3
All Latin America	31,564	31,603	30,547	100.00	74

Cassava is a small-farm crop that is grown in marginal areas where soil fertility and moisture limit the growing of alternative crops; nevertheless, cassava farmers usually sell a large part of their production.

Urban consumption of fresh cassava is less than that of rural areas; increasing urbanization leads to decreasing per capita consumption of fresh cassava. However, with the development of new technology, fresh cassava is now much more attractive as a convenience food, and pilot studies have indicated increasing demand.

Cassava is also being increasingly used in animal and shrimp feeds. In the southern states of Brazil and Paraguay, large quantities of cassava are fed to animals on the farm; whereas in Colombia, Ecuador and Panama, cassava is dried and processed by the feed industry. The rapid increase in demand for animal feeds, coupled with the deficit of cereals in tropical regions of Latin America, indicates a large demand for dried cassava in this market, if cassava prices are competitive with those of cereals.

A series of studies carried out in Latin America in the mid-1980s clearly shows that, in the absence of price distortions, cassava is highly price competitive with cereals in tropical Latin America.

The premises behind examining cassava's future prospects are (a) governments will not revert to heavy subsidies for competing products, overvalued exchange rates, and massive importations of grains; (b) the animal and shrimp feed industry will continue to grow rapidly; and (c) official government agencies will continue to direct efforts to assisting the rural poor.

The major markets for cassava are seen to be "conserved fresh cassava," animal feed and refined flours. The new cassava conservation technology is expected to greatly increase demand for conserved fresh cassava. The incentive for farmers to increase cassava production and their incomes must be a stable minimum or floor price for their product. The animal feed industry effectively guarantees that floor price if farmers can dry their product.

The urban dweller in tropical areas currently consumes large quantities of flours. The traditional flour in Latin America is maize, except in Brazil where it is cassava. Wheat flour is now, however, an important basic ingredient in the Latin American diet. Foreign exchange is scarce; hence, countries are turning to alternatives to wheat imports. Cassava, suitably processed, can be an effective alternative because flour is used in preparing many foods besides bread; hence considerable demand for cassava is predicted for this market. With adequate research and development funds and political support, we speculate that flour would be a major growth area for cassava in the coming decades.

Another important use of cassava is as starch. However, the starch industry is closed, being managed by a limited number of multinationals; thus, it is difficult to assess cassava's future in this market. There are various reasons to believe that research investment in cassava will increase in the coming years. The establishment of dynamic alternative markets for the crop has created renewed interest by farmers who are demanding new technology. Furthermore, the tendency for Latin America to have democratic governments will lead to greater attention being paid to the numerous small-farmer segments and, hence, to the crops they grow, including cassava. For cassava, such attention is likely to be reinforced by the realization that the rate of return on cassava research is likely to be high because, as yet, so little has been done at the national level; progress should, therefore, be rapid.

Land distribution in Latin America is highly skewed. Land reform programs in the past have usually been weak or ineffective. If land reform is effectively carried out in the more marginal areas of Latin America, it is probable that cassava will play a significant role in the establishment of the production base.

Rice. Rice is a relatively new staple in the Latin American diet. A significant increase in consumption took place over the period 1920-1950, when per capita consumption of paddy equivalent went from 14.2 to 30.3 kg. This coincided with the rapid expansion of frontier lands, where rice has always played a fundamental role as a settler's first crop. In 1966-1986, thanks to the release of modern semidwarf rice varieties, per capita consumption continued its expansion from 36.8 to 45.4 kg. At the same time, real retail prices were falling rapidly. Rice demand responds well to changes in both income and its own price.

Although much of the rice area in Latin America corresponds to upland rice (68%), most of the production is from irrigated areas (62%). In Brazil, the largest producer (with 55% of production and 71% of area in Latin America), upland rice accounts for approximately 80% of the total rice area under production. Most rice farmers in the region are smallholders (fewer than 20 ha), but most production comes from large farms. Rice is, on the whole, a commercial crop. Farmers are highly responsive to modern, production-increasing technologies, particularly those that have access to irrigation (total or supplementary).

Rice constitutes a major staple commodity, accounting for more than one fourth of the caloric intake in countries such as Brazil, Panama and Cuba. Its importance is greater among consumers in low-income strata, where it is a wage good.

Production was projected by using the adjusted 1966-1986 trend, imposing an upper limit of 5% per year. To avoid exaggerated productivity projections, a yield ceiling of 6 tons/ha was imposed. The area involved is calculated on the basis of projected production and yields. A 10% statistical significance level was enforced for trends. If the condition was not met, zero growth was applied.

For Latin America as a whole, the current 1984-1986 observed deficit of 1.2 million MT will remain constant toward the year 2000, which implies an increase in the self-sufficiency ratio from 93% to 95% (Table S3.5). There are sharp contrasts when these figures are examined regionally.

Tropical Latin American countries will see their current deficit expand from 1.6 to 2.4 million tons, whereas the Southern Cone countries will increase their surplus from 0.4 to 1.4 million tons. Among the many implications of this projection is the possibility of increased regional trade from the latter to the former subregions. As mentioned elsewhere, discrepancies in projected production and consumption figures may imply

Table S3.5. Paddy rice in Latin America: 1984-1986 situation and outlook for production and consumption balances (in thousands of tons) in the year 2000.

Region or country	1984-1986			2000		
	Production	Consumption	Balance	Production	Consumption	Balance
Brazil	9,482	10,325	-843	13,094	14,478	-1384
Mexico	605	794	-189	780	1,172	-392
Central America	682	700	-18	965	1,015	-59
Caribbean	1,749	2,040	-291	2,906	2,686	220
Andean countries	3,718	3,992	-274	4,950	5,897	-947
Trop. Latin America	16,236	17,851	-1615	22,695	25,257	-2562
Southern Cone	975	529	446	2,047	664	1383
All Latin America	17,211	18,380	-1169	24,742	25,921	-1179

SOURCE: FAO and CIAT estimates.

increased trade and/or changes in the price of the commodity, which, in turn, affects supply and demand.

A more detailed look at these numbers shows that, by year 2000, Brazil, the largest rice producer in the region, will see its relative importance diminish from 55% to 53% of production. Its projected deficit will grow from 0.8 million tons in 1984-1986 to 1.4 million tons in 2000. However, given the great potential of the "várzeas" (riverside lowlands), it is believed that production, as projected here, has been underestimated. Despite low per capita consumption levels in Mexico, projections show a larger deficit toward the year 2000 from 0.2 to 0.4 million tons.

Irrigated and favored upland rice conditions are mostly found in the Andean countries. Both area and yields grew at an impressive rate throughout the past two decades, particularly in the earlier 1966-1976 period. Crop management practices are a major limitation in a region where new varieties have expressed the major part of their genetic potential. Deficits for Colombia and Venezuela may have been overestimated, given that production has stagnated and therefore a zero growth rate in production was assumed. Crop management, as well as policy factors, are behind this stagnation. In contrast, the surplus projected for Ecuador will be larger, given that the new irrigation projects under way and partly completed will incorporate 80,000 new hectares into rice production.

In Central America, favored upland rice is the norm. The lowest yields are found in Panama, the largest producer in the region, where subsistence rice farmers represent 60% of the total number of farmers. Projected deficits are small and could easily be overcome with the imminent release of new varieties and a more focused research and extension effort.

In the Caribbean, both Cuba and the Dominican Republic exhibited outstanding growth rates in production over the past two decades and, consequently, their deficits are expected to decrease. The traditional exporters, Guyana and Suriname, confront institutional problems at present and will have difficulties expanding their markets.

Although per capita rice consumption levels in the Southern Cone countries are modest (wheat is the predominant carbohydrate), production shows a vigorous growth. Surpluses are overestimated, particularly in Uruguay, where the area involved has increased fourfold, a feat hard to believe, given the quantity of additional water that this implies.

Stability and high levels of self-sufficiency are synonymous in rice. Only 4% of world rice production is actually traded (compared with 16% in maize and 22% in wheat). International rice prices dropped from US$400/ton in 1981 (2.2 times the price of wheat) to US$215/ton in 1985 (1.1 times the price of wheat), and up again to US$380 in 1987 (3.0 times the price of wheat). Therefore, given the important role of rice in the diets of the urban poor, achievement of high rates of self-sufficiency has become a policy goal for countries in the region.

The expanding activity of commercial agriculture, with its continued pressure on the small farmer to integrate into the economy, together with the permanent incorporation of small- and medium--sized farmers into new rice production, imply that crop management research must include adequate machinery. This research must take into account that rice is not only grown by large producers, who received most attention in the past, but also by small- and middle-sized producers.

The demand for raw materials of agricultural origin to be transformed by agroindustry also questions rigid breeding standards related to rice acceptability and consumer preferences; acceptability refers to consumers' perceptions at a point in time and is therefore susceptible to changes.

Improving harvest and postharvest technology and practices for rice is an area of high potential impact; waste reduction is a primary means to increase food availability without intensifying pressure on the natural resource base.

Except under unfavored upland conditions (the Brazilian Cerrados and most traditional small farms), it has been demonstrated that rice technologies are interchangeable between irrigated and upland conditions. Our new germplasm for unfavored upland conditions is already being evaluated in terms of adaptability, both to the environment and to various cropping systems.

The Rice Program believes that there exists a large potential for improving yields both through new and more diversified germplasm for irrigated and upland conditions, and through the adoption and improvement of integrated rice management practices. Only then will rice preserve its current role in the Latin American diet as the most important carbohydrate.

Sorghum. Latin America produces about 11.5 million tons of sorghum. Most sorghum is grown on medium- to large-scale farms, except in Central America and the Caribbean, where it is grown on small-scale farms. Sorghum production is widely distributed over the continent, from Mexico to Argentina. For the whole of Latin America, sorghum production has not increased over the last decade. The aggregate figure, however, masks a rapid redistribution of production. In the mid-1970s, Argentina produced over 6 million tons of sorghum, but by 1988 its production had falled to 3.5 million tons. In contrast, Mexico, which produced 4 million tons in the mid-1970s, in 1988, produced more than 5.5 million tons. In the Andean region, production almost doubled over the same period, from 0.77 million to 1.48 million tons.

Average sorghum yield levels are about 2700 kg/ha and have grown at a rate of 0.4% per year. In Argentina and Mexico, average yield levels are around 3.2 tons/ha. In Central America and the Caribbean, yields range from 1 to 1.5 tons/ha. In the Andean region, yields are below 2.3 tons/ha. The Andean region shows the best yield development, with a growth of 1.6% per year. In Brazil, where sorghum is not important, yields have fallen by 2.4% per year.

Sorghum is mainly grown for animal feed, although, in Central America and the Caribbean, it also is used for human consumption. Sorghum is a crop which adapts well to poor soil conditions and which can be conveniently used in rotations. Its ability to produce acceptable yields on poor soils makes it an attractive option as a cheap calorie source for animal feed. The use of sorghum also reduces the demand for maize as animal feed and so facilitates the availability of maize for human consumption.

Between 1976-1978 and 1986-1988, sorghum imports into tropical Latin America increased from 1.1 million to 2.1 million tons. Use of sorghum in tropical Latin America grew from 6.9 to 10.1 million tons, an increase of 3.9% per year. The self-sufficiency index fell from 84% to 79%. During the 1980s, economic growth in most countries of Latin America was negative, and the increase in sorghum utilization was mainly a result of the increasing market share of poultry at the cost of red meats. If, in the 1990s, economic growth speeds up, demand for sorghum will probably grow at a rate considerably higher than the 3.9% of 1980s.

The adaptation of sorghum to acid soils will increase production potential, which, in turn, will facilitate a rapid increase in domestic supply. On these acid soils, the opportunity costs for land are low, and sorghum would probably by produced more cheaply than on better lands. For sorghum production costs to be in line with world market prices, such a reduction is urgently necessary.

Sorghum research should thus be centered on the development of sustainable, low-input, production systems for the acid-soil tropics. A first step toward this objective is the development of acid-soil tolerant lines that require few inputs. Later research should focus on including sorghum in rotation schedules with pastures, legumes and other cereals. Utilization research should include the reduction of fungal diseases in sorghum panicles that reduce harvestable weight and generate health problems in animal and human consumers. Utilization research should also include increasing protein contents of the grain.

The private sector has been active in sorghum research in Latin America, concentrating on the production of hybrids. However, these hybrids are often based on parental materials that are successful in temperature zones, but are not necessarily the best for acid-soil tropics. International sorghum research should thus work in close collaboration with both national programs and the private sector to improve the quality of hybrid materials and to ensure rapid and effective diffusion of results.

Soybeans. Latin America produces about 26 million tons of soybeans, mostly on medium- and large-sized mechanized farms, in monoculture and in subtropical agricultural systems, where soybeans are rotated with cereals. Area expansion was impressive over the past decade (14.4% per year) and yields grew at an annual 2.0%

in the same period, to reach 1.8% tons/ha, which is close to the world average of 1.9 tons/ha.

About 4.0 million tons are grown in the tropical savannas of South America, mostly in the Brazilian Cerrados, but also in small areas of Bolivia, Venezuela and Colombia. Stresses in these acid and aluminum-saturated soils are significant and, currently, large quantities of lime and fertilizer are needed to compensate for the soybeans' poor adaptation. Photoperiod (daylength) is also a contraint in the tropics, because the present germplasm, not being well-adapted, flowers too soon for high yields. Insects and viral diseases are also limiting. Poor seed germination, associated with climate (rain and high temperatures at planting), low quality seeds and poor storage facilities, is also limiting.

For upland acid-soil savannas, rotations in crop-based and crop-pastures systems ideally should include some kind of legume with a strong market, such as soybeans. Soybeans are also suitable for irrigated systems involving rotations.

Derived demand for protein sources (flour for feed rations, concentrates and isolates) is expected to remain strong and growing, both locally and in other regions. Demand for unsaturated vegetable oils is also growing fast. Most tropical Latin American countries are deficient in vegetable oil and cake production; soybeans are therefore attractive to animal production and vegetable oil subsectors. Because soybeans are in great demand, there is ample scope for research toward a soybean germplasm that is better adapted to tropical conditions.

Africa

The economy. The economy of sub-Saharan Africa has been consistently weak for several decades. By the 1980s, per capita income had fallen to about three-quarters of the level reached in the late 1970s. This poor performance has resulted from external economic shocks, weak domestic economic management and unusually high population growth. Recently, many African countries have adopted much needed structural adjustment programs, and efforts currently under way are impressive. Positive adjustments are being made in currency exchange rates, fiscal deficits, export and domestic commodity pricing policies, trade regulations, and governmental economic management.

The agricultural sector is of paramount importance to Africa. By 1985, 75% of the population earned their livelihood in agricultural production. Average per capita income in this sector was estimated to be US$242 in 1985, which was only 44% of that of the nonagricultural sector. Overall, there has been modest growth in the agricultural sector, but high population growth rates of 3.3% in the 1980s have resulted in decreasing levels of output on a per capita basis.

The key to economic development in sub-Saharan Africa is the agricultural sector. It is the only sector in which future employment opportunities can be readily created. Second, it offers the best opportunity for earning foreign exchange from tradeables; and finally, it can provide for a nation's food security needs. Unlike the situation in other developing regions, increases in the output of agricultural nontradeables in sub-Saharan Africa are not market driven. Growth in income levels are insufficient to stimulate an increase in the demand for basic food commodities. To develop agricultural technology that is adoptable within such an economic environment is challenging. Because economic returns to production are low and risks for cash input use are high, only those technologies that are low-cost and with minimal risk will meet the test of acceptability.

Beans. Beans are the principal source of dietary protein for over 70 million people living in sub-Saharan Africa. Consumption levels reach 50 kg per capita annually in the countries of Burundi and Rwanda. Beans are a staple crop produced by small farmers, primarily for subsistence, with occasional marketing of surpluses. Production is concentrated in the more productive and highly populated areas of eastern Africa, the Great Lakes Region, and widely scattered highland areas of southern Africa.

Bean production in Africa is subject to severe ecological constraints. First, beans are often grown on hillsides, on highly erodible soils. Second, fertilizer availability for the crop is extremely limited; hence its lack of use may enhance soil depletion and a shift away from beans to less demanding crops such as sweet potato or cassava. Third, the disease and insect complex in Africa is different from Latin America. Bean fly, which is an important pest in Africa, is not present in Latin America.

Although beans are not a native crop on the continent, they have been integrated into the agricultural system by very creative means. In many parts of the continent, bean-banana intercrops are important. In other areas, such as Rwanda, beans are grown in varietal mixtures. These mixtures reduce production risks and enhance crop resistance to diseases.

Over the past two decades, bean production has grown at an annual rate of 3%, slightly less than the 3.3% population growth rate for the region. In the 1980s, the annual growth rate in production slowed to 1.6%, down from the 4.4% rate in the previous decade. The Great Lakes Region had the slowest growth in production during the past decade at 0.4%, whereas the eastern and southern regions grew at 2.9% and 2.6%, respectively. The increases were achieved by augmenting the area under cultivation, whereas yields were relatively unchanged. Now, however, the increase in bean production from area expansion is occurring at a decreasing rate: a disturbing indication for future production growth.

Projections of present production and consumption trends to the year 2000 suggest that a significant deficit in production will occur (Table S3.6). A 760,000-MT deficit is projected if trends over the past ten years continue, equaling 18% of the expected consumption by the year 2000. Most of this deficit will occur in the eastern highlands and Great Lakes Region.

Land scarcity is a major economic constraint to increasing production in the densely populated countries of Burundi and Rwanda, and in selected areas of Kenya and Tanzania. In response, farmers have adopted intensive land use techniques to increase overall food production. In selected areas of Uganda, Tanzania, Ethiopia, Zambia and the Kivu Province of Zaire, lack of labor is more of an economic constraint to increasing bean production than land.

The estimated deficits correctly reflect land scarcity in the Great Lakes Region and parts of eastern Africa. Technological progress is urgently needed in these areas. Such technological progress should be of a drastic nature, as is the case in certain areas of Rwanda, where bush beans are being replaced by the more productive climbing beans. Adapting the bean crop to nontraditional production areas (e.g., acid soils) may be another effective response to projected deficits.

The potential of bean production to keep up with demand increases is better in southern Africa. In this region, the possibilities of introducing beans in nontraditional areas are less constrained than in the two other regions. This can be illustrated by the acceptance of Carioca, a Brazilian variety, in the Central Province of Zambia, where previously only cowpea was produced.

For the landlocked regions of Africa, there is evidence that high calorie crops (maize, sorghum, roots and tubers and bananas) are increasingly replacing beans within intercropped systems and in direct competition. For beans to remain economically competitive, production technologies that reduce variability in output and/or increase yields will need to be developed. In multiple-cropping systems, beans are often of secondary importance. Therefore, the development of bean production technologies that are complementary to existing production systems will be required in these areas. Production technologies that help beans compete effectively with other crops are needed in areas where monocropping is the norm. The fragile agroecological environments in which beans are produced are highly susceptible to soil erosion, with accompanying losses in soil fertility: factors that require special consideration in agricultural research.

Table S3.6. Beans in Africa: 1984-1986 situation and outlook for production and consumption balances (in thousands of tons) in the year 2000.

Region or country	1984-1986			2000		
	Production	Consumption	Balance	Production	Consumption	Balance
Eastern Africa	1090	n.a.[a]	n.a.	1509	1926	-417
Great Lakes Region	593	593	0	746	968	-222
Southern Africa	497	478	19	817	840	-23
Others	182	173	9	210	312	-102
Total	2362	n.a.	n.a.	3282	4046	-764

a. n.a. = not available.

SOURCE: FAO and CIAT estimates.

Cassava. Cassava is a very important food crop in sub-Saharan Africa, providing more than 200 calories per day per capita for over 160 million people. Even in areas where cassava is not a major staple, it often plays an important role in household food security because of its resistance to drought and pests. Cassava's central role in the African diet takes on special importance as this is the region, of any in the world, where per capita food production has been declining most rapidly. At issue in the short term is the role of cassava in reversing that trend; and in the longer term, the contribution cassava can make to the overall development of African agriculture.

Zaire and Nigeria are Africa's leading cassava producers (Table S3.7), accounting for 28% and 24% of production, respectively. The next four largest producing countries are all located in eastern and southern Africa: Tanzania, Mozambique, Madagascar and Angola. Overall, coastal West Africa (including Nigeria) and Central Africa (including Zaire) each accounts for one third of production, and eastern and southern Africa account for 30% of the total. The semiarid regions of West Africa produces 5%. In the 1970s and 1980s, cassava production increased at an annual rate of 2.6% and 2.7%, respectively, that is, more slowly than the population growth.

It is predicted that the factors that have encouraged the expansion of cassava production in the past are likely to continue to be major influences on production

Table S3.7. Cassava production: its relative importance in Africa and per capita production levels during 1966-1988.

Country	Production (1000 MT)			Percentage of total	Per capita production
	1966/68	1976/78	1986/88	1986/88	1986/88 (kg)
Angola	1,523	1,733	1,973	3.43	214
Burundi	907	465	576	1.00	115
Cameroun	740	747	677	1.18	65
Central African Rep.	626	897	500	0.87	185
Chad	125	169	307	0.53	58
Congo	468	565	695	1.21	379
Benin	475	656	672	1.17	156
Equatorial Guinea	41	50	56	0.10	136
Gabon	165	232	260	0.45	246
Ghana	1,525	1,842	3,040	5.29	221
Guinea	443	622	510	0.89	80
Côte d'Ivoire	522	1,008	1,292	2.25	116
Kenya	480	612	533	0.93	24
Liberia	257	285	329	0.57	142
Madagascar	1,068	1,465	2,266	3.94	208
Malawi	140	273	163	0.28	21
Mali	32	50	73	0.13	9
Mozambique	2,225	2,800	3,340	5.81	231
Niger	172	194	197	0.34	30
Nigeria	8,588	10,633	14,233	24.77	140
Rwanda	220	411	381	0.66	58
Senegal	238	75	47	0.08	7
Sierra Leone	76	88	115	0.20	30
Somalia	21	30	42	0.07	6
Sudan	167	99	75	0.13	3
Tanzania	3,467	5,145	5,742	10.00	234
Togo	492	386	392	0.68	124
Uganda	994	2,620	2,397	4.17	144
Zaire	9,667	11,942	16,251	28.29	497
Zambia	148	172	230	0.40	30
Zimbabwe	44	51	86	0.15	10
Africa	36,056	46,320	57,452	100.00	123

trends in the future. These factors include cassava's low labor input requirements and ability to produce a crop on degraded soils and under drought. Even without technical change, it is likely that cassava production will continue to increase by expanding into new areas of drought risk and low soil fertility.

In many parts of Africa, cassava is predominantly grown by women, whereas men cultivate cash crops and, in West Africa, yams. Average yields are 6.8 tons per hectare, and considerable increases in production and yield should be possible by introducing disease-and-drought tolerant varieties and biological agents for controlling mealybug and green spider mite.

Most cassava is consumed as human food. Less than 2% is used as animal feed, and small amounts are used to make starch. Cassava as human food is consumed in a variety of forms, the roots and leaves being eaten as a boiled vegetable in large parts of Africa. The most common form of consumption in West Africa is "gari," a dry toasted flour made from grated and fermented cassava. In eastern Africa, cassava is commonly made into flour from dried roots or root pieces.

Cassava research should address three principal issues: (1) a major effort has to be undertaken to improve cassava's role as a subsistence and famine relief crop. Such research should be focused on low-input, low-fertility conditions, for use in regions with frequent food security problems. (2) For those regions that do not face food shortages, cassava research should turn to more development-oriented goals. That is, the crop's potential for generating income and employment is key to its role. The development of marketable surpluses is fundamental to the success of this strategy and should be supported by the third objective of cassava research; that is, (3) for these marketable surpluses to generate significant "value added," and to supply ample demand in the rapidly urbanizing environment, processing methods and fresh-root storage should be improved. These issues, in turn, lead to questions about the type of product, the demand parameters for different products, the interventions needed in processing technology and marketing channels, and the effect of pricing policies on substitutes. Cassava has a potential role as a farm income source in current production areas, if marketing channels to growing urban aras can be opened, and as a stabilizing component in farming systems in marginal, food-deficit areas.

Asia

The economy. Asia, the largest and most populous developing region in the world, is highly heterogeneous in resource endowment, social and political systems, and economic performance. This analysis does not pretend to cover this wide range of situations. It emphasizes countries of particular relevance to CIAT's cassava research.

Growth in the agricultural sector has proceeded at a relatively high rate over the past two decades, but not as high as that achieved by the economy as a whole. Agriculture has generally been discriminated against by policies to protect domestic industry. In some countries, subsidies for agriculture have compensated for low prices of farm outputs; however, in the aggregate, agriculture has performed worse than it would have without government price interventions.

Since 1980, Asian economies have made major structural adjustments that will allow them to face the future with more flexible economies that are poised for rapid growth. Diversification will probably be demand led and will be best stimulated by programs that have the broadest impact on increasing rural incomes. Thus, market forces rather than governmental solutions are likely to be the locomotives of development; nevertheless, governments should be in a position to support new development. Furthermore, demand-led growth in Asian economies will probably increase in regional or domestic markets rather than in international trade. In the more marginal areas, environmental degradation will accelerate unless rural incomes increase, because rural poverty is a major cause of environmental degradation in the region.

We can summarize the trends in Asia as follows: the 1960s was the decade of production; the 1970s, the decade of new directions and equity concerns; the 1980s, the decade of the private sector and policy concerns; and the 1990s is likely to be the decade of sustaining technical and institutional excellence in support of economic development.

Cassava. In the last 20 years, Asian cassava production more than doubled from about 20 million to about 47 million MT, a growth rate of more than 5% per year (Table S3.8). The largest producer in Asia is Thailand, with 38% (18 million MT) of total production in 1984-1986 and an estimated production for 1988 of 23 million MT. It is well known that the Thai cassava industry is based on the export of cassava pellets to the EEC and other developed-country markets. The Thai cassava industry has brought wealth and stability to large areas of the country.

The imposition of quotas on cassava exports by the EEC (effective 1982) has, surprisingly, not halted the continued increase in cassava production, apparently because (1) farmers have an asymmetric supply response to price, that is, once they start growing cassava, they tend not to stop, even as prices decline below their entry point, because of a lack of viable alternatives; and (2) the Thais have proven remarkably adept at finding new markets: 6 years ago it was predicted that Thai cassava production would decline with the imposition of quotas, but history does not reflect that.

Table S3.8. Cassava production: its relative importance in Asia and per capita production levels during 1966-1988.

Country	Production (1000 MT)			Percentage of total	Per capita production
	1966/68	1976/78	1986/88	1986/88	1986/88 (kg)
Brunei	2	2	1	0.00	4
Burma	12	22	95	0.20	2
China	1,535	2,506	3,440	7.29	3
India	3,976	6,234	4,557	9.66	6
Indonesia	11,112	12,527	14,278	30.26	83
Kampuchea	27	108	111	0.23	14
Laos	11	44	88	0.19	23
Malaysia	243	357	388	0.82	24
Philippines	499	1,549	1,764	3.74	30
East Timor	13	0	0	0.00	0
Singapore	3	1	0	0.00	0
Sri Lanka	366	630	444	0.94	27
Thailand	2,188	12,809	19,039	40.35	357
Vietnam	994	2,661	2,973	6.30	47
Asia	20,982	39,449	47,178	100.00	20

Excluding Thailand, cassava production has increased at a healthy rate of 2.7% per year for the last 20 years. The increase apparently was caused by demand-led diversification of cassava's end uses. Thus, in India, cassava production in traditional forms in Kerala has declined, whereas in Tamil Nadu, cassava starch production increased from 0.7 million MT in 1973-1974 to 1.5 million MT in 1984-1985. Similarly, in Indonesia, cassava has moved increasingly into the starch market, which, in turn, provides the basic raw material for numerous food products. In the coming years, cassava is expected to continue to move into new markets and that Asian native ingenuity will continue to find new uses for cassava as it has in the past. In addition, the poultry feed market is growing extremely rapidly in Asian countries.

Certain Southeast Asian countries have fallen out of the mainstream of the Pacific economic miracle. Annual growth rates in cassava have been very high in these countries over the last two decades: Burma 13%, Kampuchea 10%, Laos 12%, and Vietnam 8%. These countries indicate the fundamental role that cassava plays in maintaining food supplies under crisis conditions and when economies revert almost to subsistence levels. Cassava will continue to play this role; what is new, however, is the realization that cassava has an important role to play in rapidly developing economies such as those of Indonesia and China.

Section 4

A GIS APPROACH TO IDENTIFYING RESEARCH PROBLEMS AND OPPORTUNITIES IN NATURAL RESOURCE MANAGEMENT

P. G. Jones, D. M. Robinson, and S. E. Carter*

Over the past 8 years the Agroecological Studies Unit (AEU) at CIAT has been conducting crop-specific agroecological analyses in a variety of environments. Fieldwork in similar ecosystems, with similar land use but in different countries, led to the hypothesis that where climate, soils and land use were similar, then the types of problems amenable to research also tended to be similar. The method described below is an attempt to investigate this relationship systematically, and to assess the most important resource preservation problems across Latin America and the Caribbean.

The approach taken by the AEU had four stages. In Stage 1, all of Latin America and the Caribbean were mapped in broad environmental classes. Then, in Stage 2, based on predetermined criteria, a short list of environmental classes was chosen. Stage 3 involved the systematic description of actual land use in the selected environmental classes. In Stage 4, the most important agroecosystem clusters (areas with similar environments and land use patterns) and their respective problems were then evaluated for relevance to CIAT's current and future research.

Stage 1: Continental environment description

The scope of this first stage was vast. It covered all areas of Latin America for which CIAT might expect to be able to support a reasonable commitment in natural resource management research. This forced us to make certain assumptions and to choose criteria for the environmental classification. First, the classification had to be simple enough to be mapped by using available data. Second, it had to be consistent with the data from which it was drawn. Third, it had to reflect the environmental requirements of actual or potential commodity crops for research by a center of tropical agriculture. Finally, environmental criteria had to reflect the experience of scientists working in the center.

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The AEU has detailed data for parts of the continent. However, as the scope of this study was broader than these specialized data we opted for more general information consistent across the continent. As the climate database is the most complete available for Latin America, the first step was to classify climates and discard logistically unfeasible classes, thereby reducing the total area under consideration.

Environmental classification. The analysis used files of regularly gridded data (METGRID) on climate, soils and elevation. These files were interpolated from the climate database, developed in the AEU, which contains mean monthly information from over 7500 stations across Latin America. As a basis for interpolation, the 10-minute grid of a digital terrain model (NOAA, 1984) and the central pixel from a raster version of the FAO Soil Map of the World (UNEP/GEMS/GRID, 1988) were used. From these files we constructed a point quadrat approximation of rainfall, temperature, soils and elevation for the continent at a spatial resolution of approximately 18.5 km.

Interpolation of the climate data was done by weighted inverse-squared distance from the nearest four stations in the database, corrected for altitude by using a standard tropical atmosphere lapse rate model based on data from Riehl (1979). The spatial spread of climate stations is highly variable, but tends to be more dense in areas where there is a high variation in altitude and slope and where the majority of the population is found.

Five environmental criteria were selected on the basis of consultation with CIAT's commodity scientists. These were:

Length of growing season. This was calculated as the number of wet months in which rainfall exceeds 60% of potential evapotranspiration as calculated by the Linacre (1977) method.

1.	Humid	Over 9 months wet
2.	Seasonally wet	9 to 6 months wet
3.	Seasonally dry	6 to 3 months wet
4.	Arid	Less than 3 months wet - REJECTED

The truly arid classes were excluded because CIAT has had relatively little experience with rainfed crops or natural resources in these areas.

Temperature during the growing season. The classification for temperature was:

1. Lowland tropics, temperatures greater than 23.5 °C

2. Mid-altitude zone, temperatures from 18 to 23.5 °C

3. Highland zone, temperatures from 13 to 18 °C

4. Cold areas, temperatures less than 13 °C - REJECTED

These temperature cutoffs were selected on the basis of commonly accepted figures that have proved useful in the past for classifying the areas in which CIAT's mandate crops are grown. The cold areas were rejected because they represent an area in which CIAT has not worked, and in which other organizations have a comparative advantage.

Diurnal temperature range. This variable was added to distinguish areas with large diurnal temperature ranges from those with smaller ones. The distinction is similar to that between continental and maritime climates. In South America this variable does not indicate relative distance from the sea; rather; it reflects the "oceanic influence" that the Amazon basin has on South America's climate. Although this classification of the basin's influence does not fit in with any published classification of maritime or continental climates, the authors can find no words more descriptive. Diurnal temperature range plays an important role in the incidence of pests and diseases, particularly fungal diseases.

1.	Maritime	Less than 10 °C mean diurnal range
2.	Continental	Greater than 10 °C mean diurnal range

Annual temperature range. To distinguish between tropical and subtropical areas, we set the annual temperature range cutoff at 10 °C.

1.	Tropical	Less than 10 °C annual range
2.	Subtropical	More than 10 °C annual range

Soil acidity. This variable was used to divide soils into those likely to have serious acidity problems, and those unlikely to have such problems. A commonly used cutoff for tropical soils is a pH of 5.5 (Landon, 1984). Below this level the chemistry of many elements changes significantly in terms of toxicity and deficiency.

1. Acid soils, pH less than 5.5

2. Less acid and neutral soils, pH above 5.5

Summary. These variables in theory produced 128 possible environmental classes. On the one hand, this was an unmanageable number of environmental classes. On the other hand, conditions within each class still varied considerably. By eliminating the very dry and very cold areas the theoretically possible number was reduced to 72 classes. Of these, 9 combinations did not exist in reality, and a further 12 were discarded because they were too small for consideration or they were cool subtropical areas with a strong frost risk, precluding the production of crops within CIAT's experience.

Stratification. The next step was to stratify the remaining environmental classes in terms of their relevance for future CIAT work. Three broad criteria were used for stratification: potential for alleviating rural poverty (equity), potential for positively affecting the natural resource base (preservation), and potential for increasing food production (growth). To make stratifying possible with these criteria, four kinds of information were combined with the environmental classes by using the image overlaying capacity of a geographical analysis package, IDRISI (Eastman, 1988). The four kinds of information were:

Access. For each class we estimated the area accessible with current infrastructure, i.e., within 30 km of an all-weather road, navigable river or sea coast. The 60-km corridor along each road is a generous estimate, allowing for possible increases in access.

For many of the 51 classes this exercise did not greatly reduce the area. However, for the humid and seasonally moist classes it excluded areas such as the Darien Straits, the upper Rio Negro and the middle Xingú, which are truly inaccessible but not legally protected.

Legally restricted areas. The areas in each country in Latin America that are legally protected against conventional agricultural use were digitized from available maps collected by the AEU. These are mostly national parks, forest reserves, Indian reservations, ecological preserves or protected catchment areas. Some countries report no such areas, and in others the protection is only on paper. However, these areas represent a significant proportion of some environmental classes. We excluded them from our calculation of the potential agricultural area of an environmental class.

Rural and urban population density. Both rural and urban population are unevenly distributed in Latin America. We felt it important to identify the absolute size and relative distribution of the rural population in each environmental class and to indicate the distribution and size of urban markets.

As a first approximation we digitized population data transposed from a published population map (Times Atlas, 1985). The actual population represented by this map was calculated by computer and a new map plotted to represent the 1986 rural population. This information was overlaid on the map of environmental classes to provide an estimate of the rural and urban population in each class.

Rural per capita income. We included this variable as a crude measure of the magnitude of rural poverty at country level or, in Brazil, at state level. Even at these aggregate levels, our analysis revealed considerable variability. Within Brazil rural income per capita varied from around $US150 (in Maranhao and Piauí States) to over $US2000 (Mato Grosso do Sul) (IBGE, 1984; World Bank, 1987).

Results. The above socioeconomic information was overlaid onto the map of environmental classes. To achieve a crude assessment of an equity index, the mean rural income was extracted for each class. The importance of a class for the purposes of equity increases with the number of people involved, but decreases as rural income rises. We therefore divided total population by rural income to obtain an index which increased with increasing rural population and/or with increasing poverty. Table S4.1 shows the classes that ranked the highest for equity.

Ranking classes in terms of environmental degradation (or the risk of it) was more complex, because of the different types of degradation that exist.

Areas at high risk of intensification problems, such as the excessive use of pesticides, are to be found in areas with access to markets and hence purchased inputs. They are likely to be the more densely populated areas within each class.

A second type of degradation occurs when virgin land is converted to agriculture. Areas with relatively untouched native vegetation are likely to be those with low rural populations. A ranking was made of the area of each class with a population of less than 2 persons per km^2. This area can be interpreted as either the area available for the expansion of agriculture, or as native vegetation requiring protection.

A third important type of degradation results from nutrient depletion and erosion through the insufficient use of inputs or decreasing fallow periods. We have assumed that this will occur most frequently in settled areas that are more remote from markets, where there is less incentive to use inputs. The index we used was the area of each class with moderate to low population density (2 to 20 persons per km^2)

Table S4.1. Environmental classes ordered by rural poverty index.

Class		Rural	Rural	Rural	Rural
Number	Designation[a]	poverty index	pop.	pop./km^2	PCI[b] mean
2	T L S M A	16,480	7,462,384	3	453
9	T L D M W	11,988	6,264,550	16	523
8	T L S M W	9,304	5,860,458	12	630
3	T L D M A	7,619	4,122,772	8	541
17	T M S C A	6,912	7,133,114	8	1032
21	T M D M W	6,674	2,544,063	18	381
5	T L D C A	6,663	4,496,741	3	675
14	T M S M A	6,553	4,810,238	14	734
1	T L H M A	5,677	2,234,896	2	394
11	T L S C W	5,396	4,577,921	13	848

a. Designation:

Column	1	T = Tropical	S = Subtropical	
	2	L = Lowland	M = Mid-altitude	H = Highland
	3	H = Humid	S = Seasonally wet	D = Dry
	4	M = Maritime	C = Continental	
	5	A = Acid soil	W = Weakly acid to good soils	

b. Per capita income.

divided by rural income. Table S4.2 shows the ranking of classes according to this index.

A subjective assessment of productivity, giving values of 1 to 7 per unit area, was made and used as a basis for ranking environmental classes in terms of their potential contribution to growth (Table S4.3). The index for contribution to growth was calculated by multiplying the area of accessible, legally available land by its productivity value. The top ten classes ranked according to this index are shown in Table S4.4.

Stage 2: Selection of candidate environmental classes

This stage included the participation of CIAT's management committee and economists, as well as the AEU.

A summary table was calculated, which included all the environmental classes that appeared in the top five of the five rankings (one for equity, one for growth and three for preservation of the resource base) (Table S4.5). The table also indicates whether or not the class was in the top five in terms of CIAT's current commodity responsibilities. From the table, the most relevant classes for resource management research by CIAT appear to be 2, 17, 5, 8, 9 and 12. A surprise finding was the importance of class 2 for all criteria. Consisting mostly of seasonally wet forest, one would not have expected this class to rank highly in terms of rural poverty because of the general impression that it is sparsely populated. In fact, it has a high population, mainly in coastal areas, and the rural per capita income is very low, suggesting a large poverty problem.

The indices for growth, equity or preservation extracted from the GIS images may have been strongly influenced by total area. A sensitivity analysis was made, varying the weights according to growth, equity and the preservation of natural resources and also including factors for:

1. Internationality, i.e., the number of countries in which the class is found;

2. CIAT advantage, the percentage of area planted to CIAT's mandate commodities;

3. The importance to the Andean, Central American and Caribbean countries (i.e., excluding Brazil).

Table S4.2. Area by class with likely degradation by nutrient depletion (e.g., erosion or nutrient leaching and weed infestation).

Class Number	Class Designation[a]	Nutrient depletion degradation index	Rural pop.	Rural pop./km^2	Rural PCI[b] mean	Accessible area (km^2)
2	T L S M A	792	7,462,384	3	453	810,689
3	T L D M A	517	4,122,772	8	541	426,590
9	T L D M W	473	6,264,550	16	523	341,225
5	T L D C A	449	4,496,741	3	675	484,108
17	T M S C A	427	7,133,114	8	1032	615,922
6	T L D C A	386	3,471,035	4	882	530,767
21	T M D M W	308	2,544,063	18	381	130,436
18	T M D C A	292	3,379,676	7	826	362,535
12	T L D C W	283	4,704,845	7	954	375,999
1	T L H M A	235	2,234,896	2	394	325,642

a. See note a. in Table S4.1.

b. Per capita income.

Table S4.3. Relative productivity index.[a]

Temperature regime	Dry season (months) < 2	3-6	7-9
Lowland	3	4	2
Mid-altitude	4	4	2
Highland	4	3	1

a. Two points were added for non-acid soils and 1 point for subtropical areas. To form an index of potential economic impact this index was multiplied by the accessible area of each class.

Table S4.4. Environmental classes ordered by production potential index.

Class Number	Class Designation[a]	Subj. prod. index	Sum prod. index	Rural pop.	Accessible area (km^2)
2	T L S M A	4	3,242,757	7,462,384	810,689
5	T L S C A	4	1,936,433	4,496,741	484,108
17	T M S C A	3	1,847,765	7,133,114	615,922
8	T L S M W	6	1,819,042	5,860,458	303,174
12	T L D C W	4	1,503,994	4,704,845	375,999
9	T L D M W	4	1,364,902	6,264,550	341,225
11	T L S C W	6	1,085,185	4,577,921	180,864
6	T L D C A	2	1,061,534	3,471,035	530,767
1	T L H M A	3	976,925	2,234,896	325,642
3	T L D M A	2	853,181	4,122,772	426,590

a. See note a. in Table S4.1.

Table S4.5. Occurrences[a] of environmental classes in the first five rows of the subject rankings.

Class	Growth	Equity	Resource preservation 1	Resource preservation 2	Resource preservation 3	CIAT crops
2	X	X	X	X	X	X
17	X	X	X		X	X
5	X			X	X	X
8	X	X	X			
9		X	X		X	
12	X		X	X		
3		X			X	
1				X		
6				X		X
18						X

a. X = Class was in the top ranking 5 for this criterion.

The **growth** variable was divided into two separate components:

1. The production potential index, as previously defined.

2. A growth potential index. This included population, because currently populated areas have more inherent growth potential than those beyond the frontier.

The **equity** (rural poverty) index was redefined as rural population density divided by rural income, to exclude the size of the zone.

The indices for resource preservation were modified to include the production potential index wherever there was either high risk of problems of abuse or high risk of degradation from nutrient depletion and erosion. This was done to take into account the additional value of research to prevent the loss of a highly productive resource. The second index, which weighted the amount of virgin land, was deliberately set low because the usefulness of such land for agriculture depends very strongly on its value and quality.

The indices were standardized to zero mean and unit variance and were combined in an additive index with weights assigned according to the five scenarios given in Table S4.6.

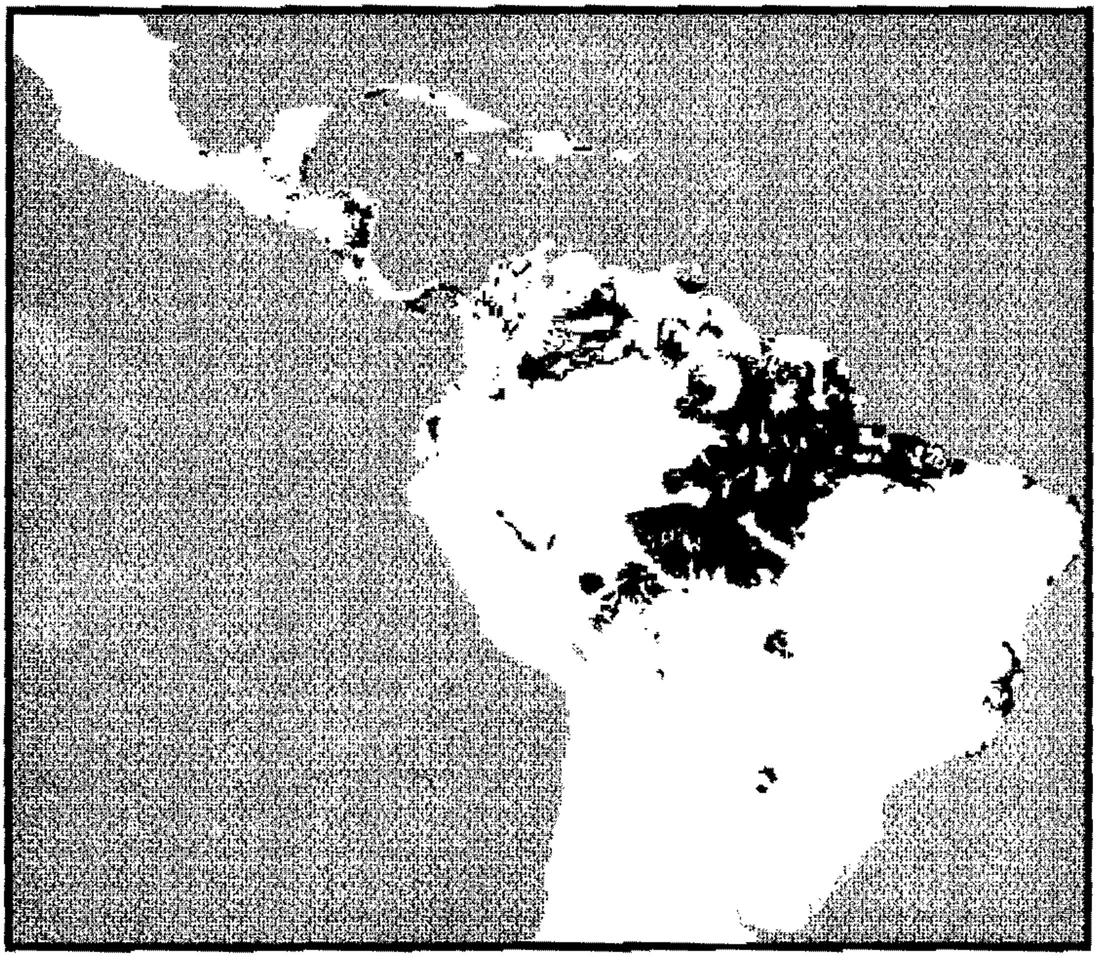
Table S4.7 shows the ranking of environmental classes for each of the five weighting scenarios. The order appears remarkably stable under the various weightings. Classes 2, 5, 8, 9, 11, 17 and 20 were selected for further study. Maps of their distribution and brief descriptions of each class follow.

Table S4.6. Weighting scenarios.

Scenario	Weights				
	1	2	3	4	5
Productive potential	4	4	8	4	4
Growth potential	6	6	12	6	6
Rural equity	10	10	10	10	10
Preservation					
1	5	5	5	5	5
2	1	1	1	1	1
3	4	4	4	4	4
Internationality	3	0	3	3	3
CIAT commodity	5	0	5	5	5
Area outside Brazil	5	0	5	0	10

Table S4.7. Results of sensitivity analysis on the environmental classes, using five different weighting scenarios.

Class ranking	Scenario				
	1	2	3	4	5
Top	8	9	8	2	8
	2	2	2	9	2
5	9	8	9	8	9
	17	17	17	17	17
	20	20	11	20	11
Second	11	21	20	21	12
	12	11	12	11	20
5	21	12	21	12	5
	5	5	5	5	21
	14	34	14	23	14

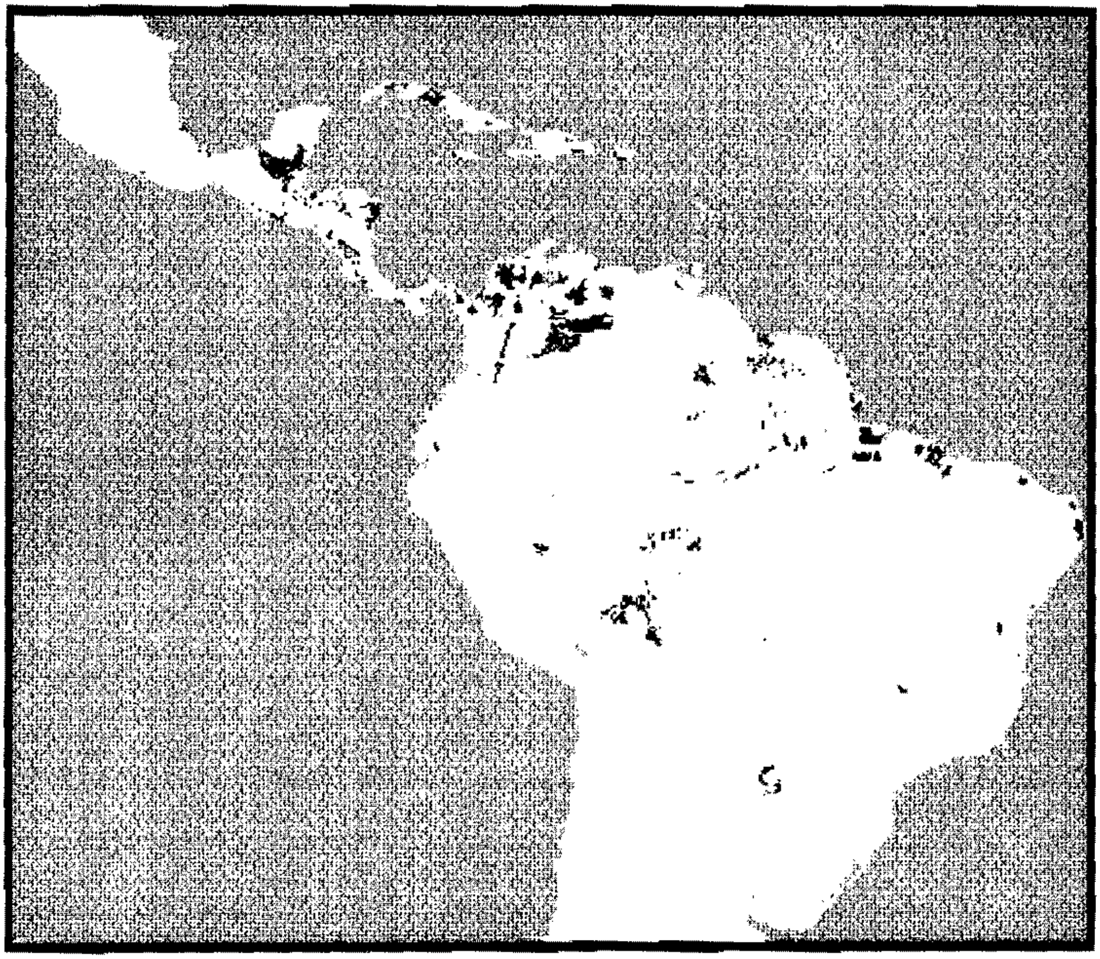


Map 1. Class 2: Seasonally wet lowland, maritime tropics, acid soils.

This class is heterogeneous. It includes highly populated areas of coastal Brazil, areas under sugarcane and cacao, and some similar areas in the Caribbean and Central America. It also includes large areas of semievergreen, seasonally dry forest in Brazil, Peru, Colombia, Bolivia and the Central American countries, together with the savannas (Llanos) of Colombia and Venezuela and areas of the northern Cerrados of Brazil.

Map 2. Class 5: Seasonally wet lowland, continental tropics, acid soils.

This class is the continental counterpart of Class 2. Much of the area consists of seasonally wet forest, with some lowland savannas. Large extents are inaccessible and lightly populated. Except where already deforested and degraded, much of this class merits conservation.

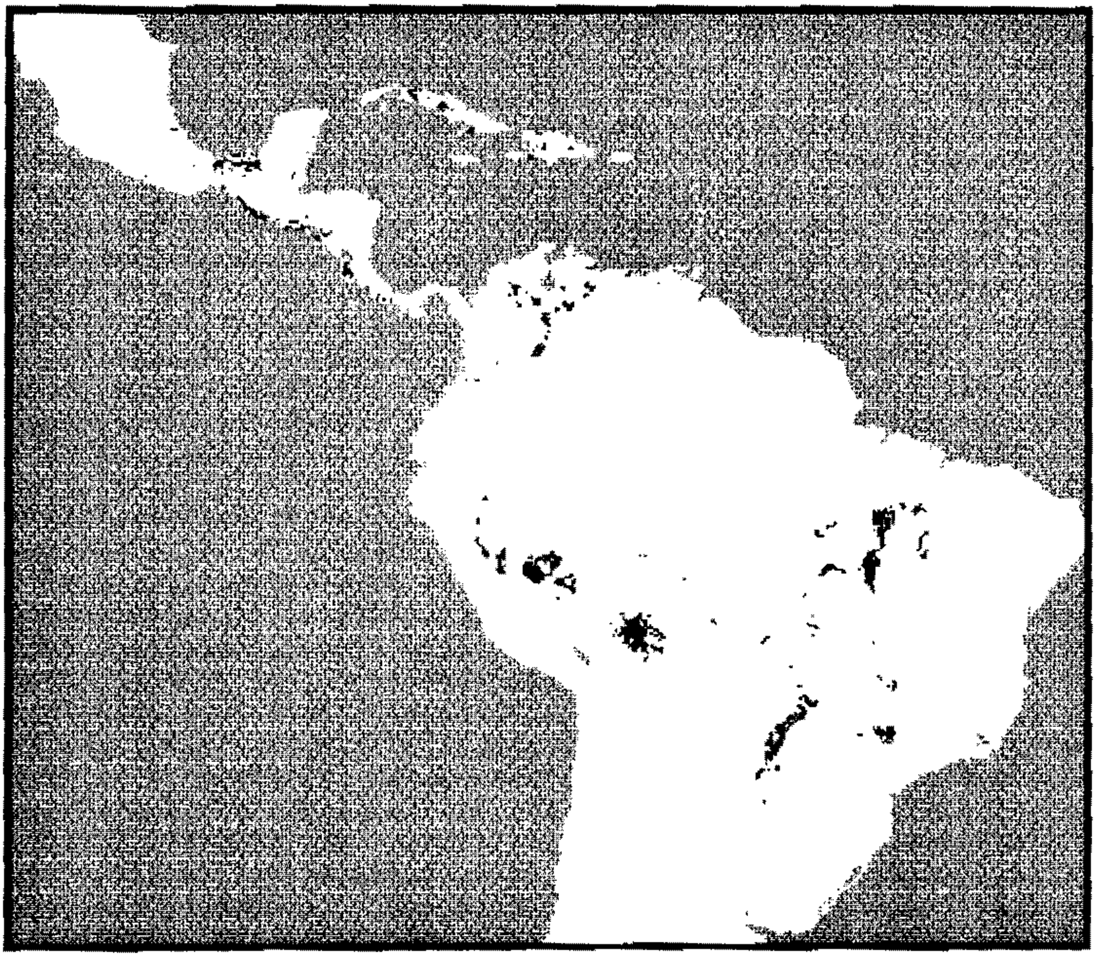


Map 3. Class 8: Seasonally wet lowland, maritime tropics, good soils.

This class includes heavily populated coastal areas throughout the continent, apart from Peru. An anomaly in this class, as seen in the map, is the inclusion of poorly drained areas in Bolivia, Colombia and some parts of the Amazon basin. Apart from these anomalous areas this class is generally highly productive.

Map 4. Class 9: Dry lowland tropics, maritime, good soils.

Although limited in extent, this class includes heavily populated coastal areas of Northeast Brazil, Venezuela, Colombia, Ecuador, Costa Rica and Mexico. It contains less densely populated areas of the Yucatán, Honduras and Bolivia. Much of this class consists of hilly land, containing much cotton and various annual crops. It is also an important class for sugarcane.

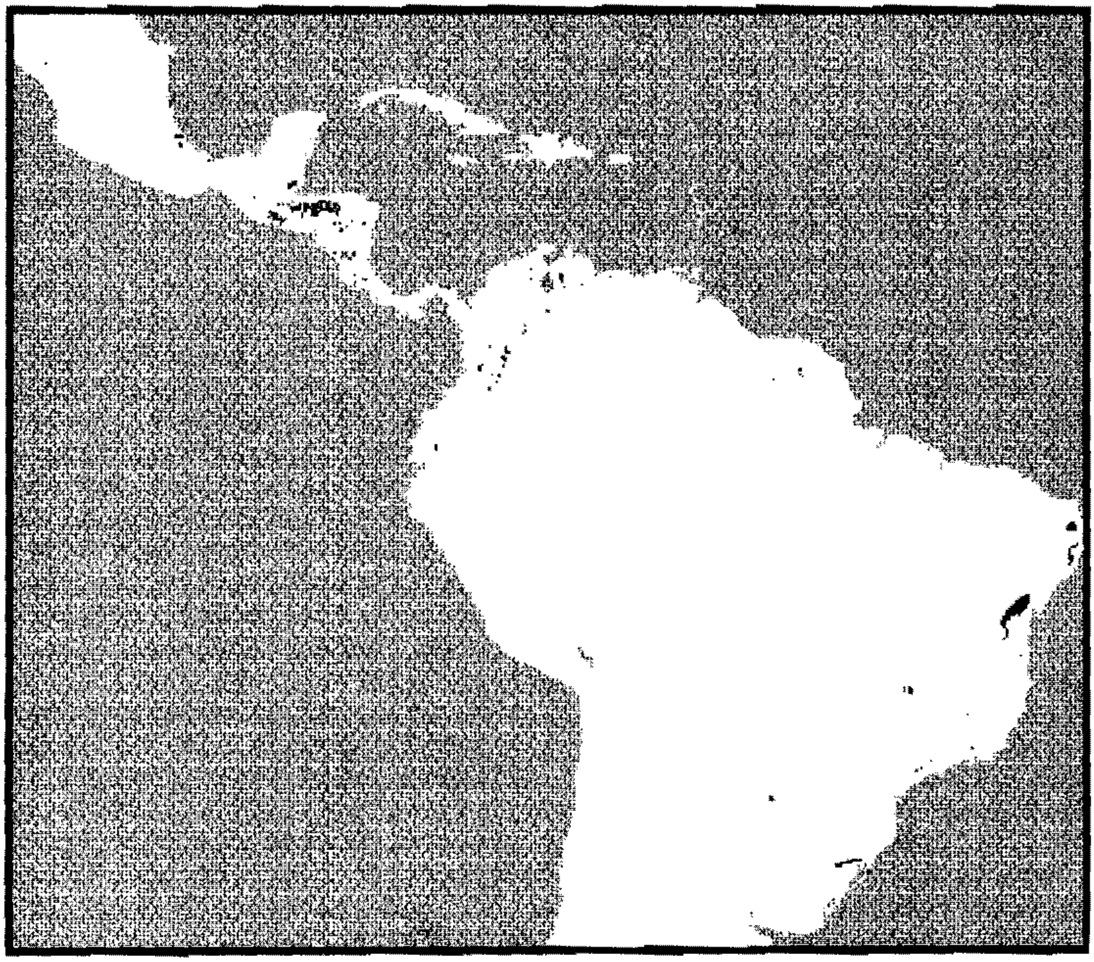


Map 5. Class 11: Seasonally wet lowland, continental tropics, good soils.

This class is the continental counterpart of Class 8. Although some areas in this class are highly populated and productive, other parts are remote, being found in relatively inaccessible areas in the continental interior.

Map 6. Class 17: Seasonally wet mid-altitudes, continental tropics, acid soils.

This highly heterogeneous class is closely associated with the poorer coffee-growing areas throughout Central America and the Andes. Large areas of this class in Brazil include the high cerrados around Brasília and the more broken terrain of the coffee-growing areas to the south. Apart from the savannas of Roraima (northern Brazil) and Guyana, and the northern extent of the Cerrados, all these areas are moderately to highly populated.



Map 7. Class 20: Seasonally wet mid-altitudes, maritime tropics, good soils.

Although of very small geographic extent, the hillside areas of this class have a high population. They are relatively wealthy coffee-growing areas found throughout Central America and the northern Andes. This class also contains the good soil areas found in the hills inland from the coast of Brazil, and is the "good soils" counterpart of Class 17.

Stage 3. The determination of land use clusters

The selection of environmental classes within which to concentrate research efforts does not suffice to identify and characterize researchable problems. Resource management problems depend as much on the nature of land use as on the nature of resources. The purpose of Stage 3, therefore, was to assess actual land use in the selected environmental classes. The most prominent combinations of land use and environment were then identified.

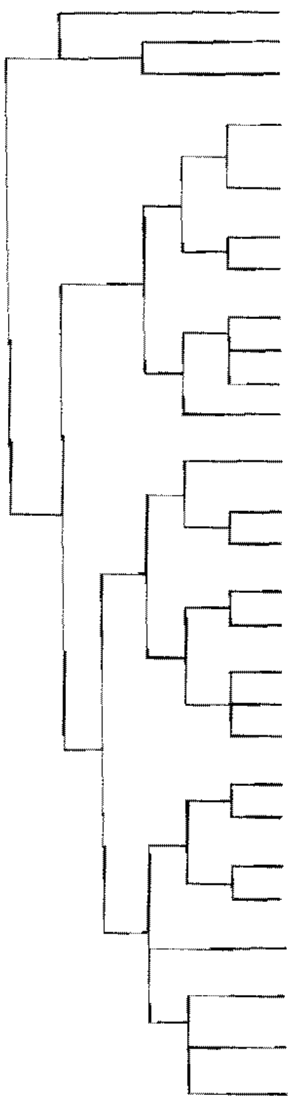
Method. The approach used was to map each contiguous area of a selected environmental class (referred to as a subzone) and determine a number of variables relating to its actual land use. A cutoff size of 600 km^2 reduced the number of subzones in the selected classes from over 500 to just over 300 and yet accounted for over 98% of the area.

Using maps, censuses, atlases and reports, simple variables were noted for physical, biological and agricultural characteristics. Socioeconomic variables were also included, such as principal farming systems, population density, urban dependence on agriculture, land distribution, percentage of area readily accessible and relative distance to market. Parallel to this, interviews were conducted with visitors to CIAT from different countries, and recent firsthand information was obtained on as many subzones as possible. This helped check against the secondary information that we were using for our descriptions.

The variables were used to determine generic production systems for each of the 300 subzones, for example, extensive cattle-ranching or intensive irrigation of annual crops. It is important to note that virtually all of the subzones had at least two modal production systems practiced by different people, for instance, extensive cattle-ranching by large landholders and shifting cultivation by small landholders.

Results. Where repeating land use patterns occurred within an environmental class, these were termed agroecosystem clusters, that is, groups of areas where climate, soil and land use were similar. Figure S4.1 shows that just over one third of the potential combinations of land use patterns and the seven environmental classes exist. There are land uses which are not significant in some environmental classes. Among those cells which are recorded, it is relatively easy to identify the most important agroecological clusters in terms of area and population.

The land use clusters were subjectively ordered to bring together similar types of land use. The resulting pattern in Figure S4.1 provides a basis for regrouping the agroecosystem clusters for general description. Regrouping can be done across



Land use clusters	Environmental class 2	5	8	9	11	17	20
Unused forest lands	1.68	0.17					
Rubber, nuts	2.58	1.88			0.77		
Fluvial and várzea systems	6.11	0.18	1.62		1.77		0.46
Intensive cane, poor lands	7.51						
Intensive cane, good lands			15.57	5.34	1.73		
Intensive irrigation			1.27		0.24		0.72
Brazil, mechanized coffee areas	3.17	4.09			0.23	19.73	
Mechanized, medium scale			1.24			0.18	
Cerrados type pastures, mech. cropping						31.07	
Poor lowland pastures, mech. cropping	11.27	29.22					
Lowland, extensive grazing, poor soils	3.35	1.06					
Good lowland, pastures, mech. cropping			3.39		2.10		
Poorly drained pastures	4.49	1.60	0.11		8.42		
Good lowland, pastures alone					0.54		
Highland, pastures alone						0.35	0.52
Poor lowland, pastures, manual cropping	37.42	7.25					
Good lowland, pastures, manual cropping			4.98		1.73		
Dry lowland, pastures, man./mech. cropping				5.10			
Dry lowland, pastures, manual cropping			0.79	13.92			
Goat grazing				4.44			
Hillsides, cattle, coffee, poor soil						3.02	
Hillsides, grazing, shift. cult., poor soil					0.08	6.78	0.22
Hillsides, cattle, coffee, good soil							3.51
Hillsides, grazing, shift. cult., good soil							2.89
Lowland, cattle, coffee	2.05		0.15	1.62	0.17		
Shifting cultivation			0.84	0.56			0.13
Small-scale cane and manual cultivation	0.26		0.05	1.47	0.23	0.42	0.26
Lowland, grazing, shift. cult. on slope	1.11	2.92	0.26	1.62			

Figure S4.1. Area of agroecological clusters in the seven environmental classes.

environments within a land use cluster or across land use clusters within an environmental class, as illustrated below.

Descriptions of major land use patterns within environmental classes

Classes 8 and 9: Intensive sugarcane, mechanized cultivation. These areas are characterized by intensive sugarcane production on estates, grazing of cultivated or induced pastures on large-scale farms, and mechanized cultivation of sorghum, soybean, cotton and irrigated rice. The small-farm sector generally concentrates on fruit and horticultural products. Tobacco is grown in some areas, together with beans, maize and some cassava.

Soils are good and the topography is flat, allowing mechanization. There is little or no remaining natural vegetation, except native grassland suitable for grazing. Fallowing is rarely practiced.

Growth potential is low in terms of area expansion, there being little land left still unused. The trend toward mechanized cultivation may diminish the importance of grazing. The small-farm sector accounts for as much as 80% of the rural population, but for only about 5% to 10% of the land.

The increasing profitability of large-scale mechanized crops might lead to the absorption of small-scale farmers, but this is less likely in certain areas where the small-farm sector is relatively prosperous, owing to the cultivation of higher value crops for urban markets.

The small-farm sector provides labor for estates and larger farms. Labor is also supplied from nearby urban populations.

Problems. These are:

1. Erosion risk is generally low, but soil compaction by heavy machinery may occur in some areas;

2. Salt buildup from poor irrigation practices is a risk in many places; and

3. Excessive use of pesticides and herbicides occurs frequently on commercial farms, especially with rice, cotton and soybean.

Spillover. The shift from grazing to cultivation will push cattle to less easily managed areas.

Classes 2 and 5: Lowland extensive grazing, poor soils. This pattern is found in the altillanura of Colombia, and in Mexico and Venezuela. The accessible area of these savannas is 4.41 million ha. Soils are highly acid, and the natural vegetation is savanna and semievergreen forest. The topography is flat, with only 5% to 20% of the area consisting of slopes with gradients ranging from 8% to 30%.

This land use pattern is distinguished from a further 29.2 million ha of savannas in Classes 2 and 5 by having insignificant cultivation, either perennial or annual, manual or mechanized.

Population density is low. Average farm size is almost 1000 ha, but decreasing. The principal production system at present is a cow/calf operation on native pastures. Markets are fairly remote, but isolation is not extreme.

The growth potential is high for acid-tolerant crops on mechanizable land.

Problems. These are:

1. There is moderate risk of erosion under native pasture, but this could become severe on even moderate slopes under inappropriate cultivation; and

2. Destruction of remaining areas of gallery forest.

Spillover. Intensification may marginally increase the demand for rural labor or speed the reduction of farm size.

Technology developed for these areas should also be applicable to poor lowland pastures of Classes 2 and 5, where mechanized cropping already exists. It may also be feasible to use it in cleared forest areas.

Classes 2 and 5: Poor lowland pastures, manual cropping. This is a widespread frontier area, consisting of nearly 45 million ha. It has varying degrees of access to markets, which are generally moderately distant to remote. Land and income distribution are highly skewed. About 50% of farmers have less than 10 ha, and control less than 10% of the land.

The natural vegetation is semievergreen forest. In some cases this has completely disappeared, but, overall, about 40% of the original forest remains. This is usually located on steep or inaccessible land.

About 4% of the land is under perennial crops, 11% under annual cropping and 30% under extensive grazing. In some areas, as much as 30% is under bush fallow. The topography is heterogeneous, but over half the area is flat and mechanizable. One third is undulating and the remainder mountainous.

Population density is low to medium, with a few areas of high concentration in coastal Brazil and the Caribbean. About 30% to 70% of farmers have between 1 and 10 ha of land.

Problems. These are:

1. Most areas show a marked contrast, according to whether they are used by small-scale farmers practicing shifting cultivation or by extensive graziers;

2. Competition for land is reducing fallow periods and inducing small-scale farmers to clear more forest; and

3. Where fallow periods are reduced because of land shortage and insecure tenure for smallholders, soil degradation is a problem.

Spillover. Technology developed for the lowland savannas may be suitable for the larger landowner in the forest margins, although such farmers are not at present pursuing much mechanized cropping. Mechanized cropping would increase competition for land and could increase forest clearance.

Classes 17 and 20: Well-watered mid-altitude hillsides. These areas are found throughout Central America, the Caribbean and Andes. They comprise:

hillsides with cattle and coffee on	poor soil	(3.02 million ha)
hillsides with cattle and coffee on	good soil	(3.52 million ha)
hillsides with grazing and shifting cultivation on	poor soil	(7.01 million ha)
hillsides with grazing and shifting cultivation on	good soil	(2.90 million ha)

This cluster also includes areas from Classes 14 and 23, which were not analyzed in this study but were judged to be similar.

Even at this level of classification, these areas are highly heterogeneous. The natural vegetation is mostly seasonally dry forest, but with some areas under humid or premontane forest. About 10% of this forest remains.

Access is generally good, but less so in poor soil areas with shifting cultivation. Population is highest in the coffee-growing areas and low in the non-coffee poor-soil areas. Land distribution is uniformly skewed, with approximately 80% of farmers holding roughly 20% of the land. Isolation is generally low to moderate, but poor mountain roads make travelling times long in some areas.

Perennial crops account for as much as 30% of the area, even in the better non-coffee areas. Annual crops are grown on 5% to 20% of the land, and between 20% to 60% of the land is under pastures. Bush fallow accounts for the remaining land, amounting to 10% to 30%, depending on the area.

Approximately 50% of the area can be classed as rolling, and as much as 40% to 50% is steep. About 10% of the area is flat.

Problems. These are:

1. Erosion is a serious problem almost everywhere, because of:

   * Overgrazing on steep pastures;
   * Fallow clearing by fire;
   * Poorly managed cultivation; and
   * In some cases, poorly managed coffee.

2. Pesticide overuse is prevalent in coffee-growing areas.

3. Although most of the remaining forest is on steep lands, there is still pressure for clearing.

4. Coffee washings are a frequent pollutant in streams and rivers.

Class 9: Extensive grazing and small-scale manual cultivation, in the dry, lowland areas of nonacid soils. This land use pattern occupies about 14 million ha, most of which is accessible. It includes an important portion of Northeast Brazil, the middle Sinú on Colombia's North Coast, and the Acapulco and Cancún areas of Mexico. The rural population density is moderate to high, and the total rural population is estimated at 2,700,000.

Between 30% and 50% of farms are less than 10 ha in size, and account for less than 5% of the land.

Natural vegetation, consisting of scrub, dry forest and wooded savanna, covers about half the area.

Agricultural land use is dominated by pastures, which account for about 30% of the total area. Bush fallow varies in importance, in some places reaching 40% of the area. Annual crops occupy about 10% of the land, but perennial crops are generally absent, except in parts of Northeast Brazil, where cashews and tree cotton occupy as much as 15% of the land.

Topography is predominantly flat (70%), with the remainder mostly rolling.

Problems. These are:

1. Risk of drought--unreliable rainfall increases risk of crop loss and soil erosion;

2. Declining soil fertility as low value of produce reduces fertilizer use; and

3. Competition for good land.

Classes 8 and 11: Extensive pastures and small-scale manual cultivation on nonacid soils in the seasonal lowlands. These classes occupy about 6.7 million ha in northern Colombia, Venezuela, Guatemala, Belize, Mexico, Paraguay and Brazil (the littoral in Ceará). The natural vegetation is seasonal forest. On average, half of the area retains this cover. Landholding patterns vary greatly. These areas are not densely populated, although the total rural population is around 2 million. Accessibility varies a great deal.

A small percentage of the land, less than 5%, is under perennials, and annual crops cover 5% to 40% of the area. Pastures account for about 40%, with the proportion rising to about 70% in some places. Bush fallow is unimportant.

About 40% to 90% of the area is flat, with 10% to 50% rolling. Steep slopes are generally absent, and do not usually exceed 30% of those areas in which they are found.

Problems. These are:

1. Forest clearance;

2. Inadequate management of pastures;

3. Insecure land tenure; and

4. Lack of social services and infrastructure.

Classes 2 and 5: Poor lowland pastures, mechanized cropping, some manual crops. This land use pattern is found in the large area of 40.5 million ha covering Brazil, Colombia, Panama, Mexico and Paraguay. Of this area, 29.2 million ha are lowland savannas environmentally similar to the altillanuras of Colombia, the balance being seasonally dry forest. These savannas differ from the Carimagua type by having significant areas under mechanized cropping, sometimes 30% of the land area.

The area characterized by this land use pattern has a population of 2.7 million. Access is variable, but over half the area has 100% accessibility. Distance from markets is usually moderate, with only a few areas being highly isolated.

About 50% to 90% of the area still has natural vegetation, but where this is savanna it is grazed. Virtually no perennial crops are grown, but in cultivated areas little land is left fallow.

The proportion of flat land is relatively low but can reach 25%. The rest is rolling, with steep lands accounting for less than 5% of the area.

About 50% of farmers use less than 8% of the land. Crops include upland rice, sorghum and some soybean.

Problems. These are:

1. Erosion--only about one third of the land is suitable for mechanized cropping, and small farmers often cultivate sloping land;

2. Soil compaction by heavy machinery; and

3. Soil depletion--soils are poor and not suitable for continuous cropping.

Class 17: Cerrados type pastures and mechanized cropping. This land use pattern, involving 31 million ha, is found almost exclusively in Brazil. Access is moderate and distances to market are medium.

Rural population density varies from low to medium. At one extreme there are almost no farmers with fewer than 10 ha, but at the other extreme, in the southeast, as many as 50% of farmers each farm less than this area.

Over 50% of the area still consists of natural vegetation, namely, campo cerrado, cerrado and seasonally dry forest. There are almost no perennial crops or managed forests. On average, 13% of the area is under annual cropping, but the proportion is higher closer to markets. Just under half the area is under pasture, and a significant proportion of the area is under some form of natural forest.

Only 54% of the total area has slopes with gradients of less than 8%, and fully 13% has slopes with gradients of 30% or steeper.

Problems. These are:

1. Erosion;

2. Soil compaction under mechanized cropping; and

3. Declining water table as a result of cropping.

Class 9: Extensive pastures, medium or large-scale mechanized and small-scale manual cropping, on good soils in dry lowlands. This type of land use involves about 5.1 million ha. It includes areas of Northeast Brazil and the Mato Grosso, the Bolívar savannas on Colombia's North Coast, and small areas in Nicaragua and Bolivia. Taken together, these areas have a moderately dense rural population. Between 30% and 70% of farms are smaller than 10 ha, and account for no more than 5% of the land.

Natural vegetation, which ranges from wooded savanna to seasonal forest, covers appproximately a quarter of the total area. Perennial crops are unimportant. Annual crops account for 5% to 10% of the area. The proportion of the area under pastures varies from 30% to 70%, and fallow from 10% to 30%. Topography is mostly flat to rolling. Most of the areas are accessible, but moderately isolated from urban markets.

Problems. These are:

1. Availability of water for crops and livestock;

2. Soil erosion;

3. Access to markets;

4. Labor shortages due to emigration; and

5. Lack of employment opportunity.

Stage 4: Selection of agroecosystem clusters

The land use patterns identified in Stage 3 were appraised for their size and human population, so that those of little significance for CIAT's purposes could be discarded where justifiable. Following the subjective grouping method employed above, the nine clusters described were reduced to six agroecosystem clusters. Although spanning different land use patterns, and also different environments, the "savannas" were grouped together as an easily recognizable group that would be potentially useful, for as long as the underlying differences are not forgotten. The six clusters were then evaluated by working groups to allow management a final decision on CIAT's resource allocations to natural resource management research.

The six clusters are as follows:

1. Areas of intensive agriculture, often sugarcane, mostly in lowland areas and on nonacid soils.

2. Areas of mechanized crop production, for instance, coffee, and found exclusively in Brazil. These were most extensive in the highlands, but some lowland systems contained a significantly large population.

3. Lowland and highland areas of extensive grazing and mechanized agriculture on acid soils. The Colombian altillanura was also included in this group, although mechanized crop production is not yet important there. These land use patterns characterize about 76 million ha and are by far the most extensive of all those identified. They also have large absolute populations, despite low overall densities.

4. Areas of extensive grazing and manual smallholder cultivation on acid soils. These are also very large (45 million ha) with large populations. They are mostly forest frontier areas or areas where seasonal forest once existed.

5. Areas of extensive grazing and manual cultivation by smallholders in the dry lowlands.

6. Highland areas of extensive grazing, shifting or smallholder cultivation, and perennial crops (notably coffee) on acid soils.

The only other significant land use pattern not evaluated was that dominated by extensive grazing on poorly drained pastures. This is found in a smaller area, but possibly with a higher total rural population, than the highland cattle-coffee systems.

Selection criteria and procedure. To evaluate the different clusters we used the following set of criteria, based on CIAT's three objectives of growth, equity and preservation of the natural resource base.

Group 1: Economic potential

Market demand	:	Demand for agricultural products is significant.
Area or volume of total	:	Spatial extent, and/or overall importance for agricultural production is high.
Intensification potential	:	Existing production systems could be intensified significantly.
Infrastructure	:	Physical communications and support services are good.

Group 2: Resource potential

Productivity index	:	Climatic and edaphic conditions are favorable for agriculture.
Expansion	:	There is scope for the expansion of agriculture.
Natural vegetation	:	There is a potential for conserving natural vegetation, significant areas of which remain.
Spillover	:	Intervention will have a positive impact elsewhere, or nonintervention will have a negative impact elsewhere.

Group 3: Resource problems

Ecological fragility	:	The area is ecologically fragile for agriculture.
Sustainability	:	Existing production systems are not sustainable for various reasons, including overuse of agrochemicals.
Deforestation	:	Deforestation is of concern for a large area.

Soil degradation	:	Soil resources are suffering significant degradation and/or erosion.

Group 4: Equity

Rural poverty	:	There are large numbers of poor rural inhabitants.
Employment opportunities	:	Significant employment opportunities can be generated through agriculture.
Food supply for the urban poor	:	The area supplies or could supply basic foods to urban areas.
Land distribution	:	Uneven land distribution is a major source of inequity.

Group 5: Technological considerations

Lack of appropriate technology	:	Appropriate technology is not currently used or is unavailable.
Relevance of technology generation	:	New technology (as opposed to other measures) could significantly contribute to increased food production and/or reduced pressure on natural resources.
Probability of technology generation	:	New technology can be generated to solve identified problems.
Time frame	:	New technology can be generated quickly.

Group 6: Institutional considerations

Institutional strength	:	Relevant institutions contain potential collaborating scientists.
CIAT's special advantage	:	Previous or current CIAT research can contribute to solutions.
Internationality	:	The agroecosystem is found in a sufficient number of countries.
Site availability	:	It is feasible to begin research soon at CIAT test sites or other known locations.

Each agroecosystem cluster was then scored for each criterion on a three-point scale from -1 to +1. Zero implied neutrality or irrelevance. As regards the technological considerations criterion, if there was no real lack of appropriate technology (giving a score of -1), then the remaining criteria were automatically scored as zero, because they became irrelevant.

The members of the working groups did this scoring individually. The scores for each criterion were then summed to give an overall score for the six clusters. A modal score was then computed. Where a strong difference of opinion arose, scores were discussed in detail for each criterion to resolve the disagreement.

We summed the modal scores for each criterion. We then needed to apply different weights to these scores, in accordance with different views on the relative importance of growth, equity and preservation of the resource base so as to derive a final selection. We therefore grouped economic and resource potential to give a single indicator of growth. Resource problems indicated the magnitude of preservation as an issue in each agroecosystem. As a fourth factor, we combined technological and institutional considerations to indicate feasibility.

Results. The results are given in Table S4.8, which indicates where resource management research would fit best with CIAT's various goals, and where research is most feasible. Giving different weights to the criteria of growth, equity, preservation and feasibility would have little effect on the ranking of agroecosystems in Table S4.8.

Based on these decision criteria and scores, the working group selected four clusters.

The first cluster (cluster 6 in Table S4.8) consists of the seasonally wet hillsides of the northern and central Andes, Central America and the Caribbean, where there are similar land use patterns. Intensive coffee production and cultivation of annuals, in association with extensive pastures, are very important. Cassava and beans are important staples in these areas, and cattle are common as a source of milk, meat and cash on both small and large farms.

The next (cluster 4) consists of lowland areas of manual cultivation and extensive grazing, with a seasonally wet climate. Continental and maritime instances of this land use pattern were combined to define the foci for research. This cluster has very large expanses of degraded pastures. The rehabilitation of these has long been a concern of CIAT's Tropical Pastures Program. A significant amount of upland rice and cassava is grown in these areas, particularly in Brazil.

Table S4.8. Selection criteria scores for the six main agroecosystem clusters.

Agroecosystem cluster	Growth[a]	Equity	Preservation	Feasibility[b]	Total
1. Fertile lowlands (intensive agriculture, often cane)	2	1	-3	1	1
2. Brazilian coffee areas (mechanized, mid-altitude agriculture)	2	2	-1	-1	2
3. Acid-soil savannas (extensive grazing and mechanized crops)	4	1	0	6	11
4. Forest margins (pastures and manual cultivation)	3	2	4	2	11
5. Seasonally dry (pastures and crops)	2	4	2	3	11
6. Hillsides (pastures, coffee, manual cultivation)	3	2	4	6	15

a. Combination of economic and resource potential.

b. Combination of technological and institutional considerations.

The third cluster (cluster 3) consists of extensive grazing and/or large-scale mechanized agriculture on the natural savannas of the Llanos and Cerrados. Lowland and mid-altitude, seasonally wet environments with this land use were combined to define the area on which to focus. Research at CIAT into the intensification of these extensive grazing systems through the incorporation of annual crop rotations has become increasingly important in recent years.

The fourth cluster (cluster 5) scored equally with the previous two. This consists of seasonally dry lowland areas on good soils with a predominance of pastures and manual crops.

CIAT management had judged that three agroecosystem clusters would be the maximum feasible with the resources envisioned. A further decision criterion was therefore needed. The commonality of environment was judged to be an appropriate one. Cluster 6, the well-watered hillsides; cluster 4, the forest margins; and cluster 3, the savannas, all have in common poor acid soils and reliable, well-watered growing seasons. It was therefore decided to give higher priority to these three (Figure S4.2).

The seasonally dry areas nevertheless remain an important concern of some of CIAT's commodity programs.

Conclusion

It was impossible to consider all the land use problems of Latin America and the Caribbean. However, by the above method, the AEU was able to identify specific widespread land use problems. Our approach has a distinct advantage over more subjective attempts to identify areas in which to conduct research, whether for agricultural development, environmental protection or a combination of these two goals. Agroecological zonification based on the physiological requirements of individual crops (FAO, 1978) alone cannot help in understanding sustainability problems. Similarly, studies to determine the ideal or potential uses of land, without studying the limitations imposed by actual land use, are of limited usefulness. A system such as ours, that takes into account both environmental and social variables, provides the means of selecting zones systematically, and hence to relate the results of research to other places and systems.

By tentatively defining the relationships between man's activities and environmental conditions, expressed as agroecosystem clusters, the AEU's work has provided a basis for the systematic study of agricultural systems and their environmental consequences.

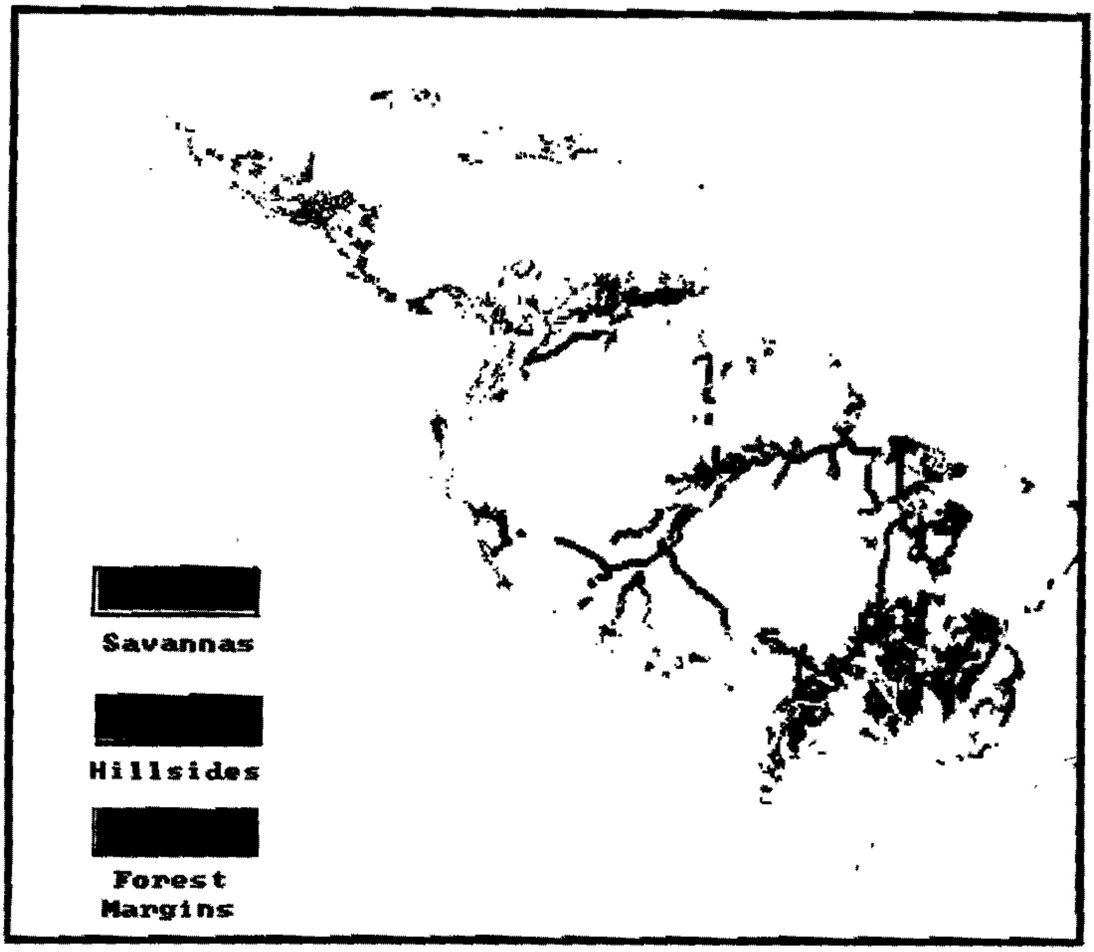


Figure S4.2. Agroecosystems selected for research by CIAT.

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1980	Portoviejo	Carta de Suelos
1982	Bahia de Caráquez	Mapa morfo-pedológico
1984	Quinindé	Mapa morfo-pedológico
1983	Santo Domingo	Mapa morfo-pedológico
1983	Quevedo	Mapa morfo-pedológico

Date	Map	Title
1983	Muisne	Mapa morfo-pedológico
1984	Guayaquil	Mapa morfo-pedológico
1984	Babahoyo	Mapa morfo-pedológico
1983	Quito	Mapa de aptitudes agrícolas

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