Mountain Research and Development, Vol. 2, No. 3, 1982, pp. 307-316 PN-AAS-217 38936

SELECTING AND EVALUATING NEW TECHNOLOGY FOR SMALL FARMERS IN THE COLOMBIAN ANDES

JOHN H. SANDERS[1] AND DENNIS V. JOHNSON[2]

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INTRODUCTION

The tropical highlands of the Northern Andes are well suited to permanent, intensive cropping. Before the Spanish introduction of, and emphasis on, cattle raising, these areas were intensively cultivated by the Indian populations who grew maize, beans, squash, manioc, and other crops. Volcanic or alluvial soils are found in most of the region, and thus soil fertility is not as serious a constraint as it is in the tropical lowlands of the coast, the Llanos of Colombia and Venezuela, and the Amazon of those two countries and Ecuador. Moreover, the Northern Andes generally has sufficient rainfall and a distribution pattern which permits two crops per year. With favourable soils and climate, human population densities have always been high. Based on calculations using the most recent censuses for the three countries, approximately 53 percent of the population of the Northern Andes, almost 25 million people, is concentrated in the mountain areas. Excluding Venezuela, the statistics become 69 percent and 23 million, respectively. Small farmers predominate numerically in the Northern Andes; however, large farmers control most of the land in the more fertile valleys, forcing many of the small farmers to locate on the steeply sloping mountain lands.

Rapid industrialization in the region after World War II and the concentration of agricultural policy and technological change on large farms, encouraged an extremely rapid rural to urban migration. In the 1950s urban population increased at a rate of 5.7 percent in Venezuela and 6.8 percent in Colombia. These rates slowed in the 1960s and 1970s but were still 2.5 percent and 4.5 percent in Venezuela and Colombia respectively from 1970 to 1976 (Sanders and Lynam, 1981b). There have been high social costs in the form of increased anti-social behaviour (robbery, prostitution), high unemployment and underemployment, and a difficulty in maintaining minimal public services in this rapid transfer of rural into urban poverty. Hence, there is a growing concern with the development of technology not only to increase total crop production but also to focus the technology toward small farmers and thereby reduce the rates of rural to urban migration.

In the early stages of economic development most agricultural research in developing countries has been oriented toward export crops, such as sugar-cane, coffee, cacao, cotton, rubber, and oil palm (Boyce and Evenson, 1975; Ruthenberg, 1977). Moreover, much of the research in Latin America has had an "engineering" or large farmer bias oriented toward more sophisticated systems, regardless of whether these systems are profitable, or whether they shifted the comparative advantage in labour-intensive cropping activities from small to large farmers. Research often focused on mechanical innovation or varietal development to facilitate mechanization, usually of the harvest. However, agricultural technology can also be directed to improve yields of food crops rather than to facilitate the substitution of labour in export activities. Yield-increasing technology would be expected to benefit principally the small farmers in the production of crops such as beans and potatoes which have large seasonal labour requirements and whose operations are difficult to mechanize on slopes.

This paper reviews two efforts in Colombia by different agencies to develop food crop technology oriented toward small farmers. The first is the Cáqueza Project, undertaken by the IDRC (International Development Research Centre) of Canada in collaboration with ICA (Instituto Colombiano Agropecuário). This project concentrated on maize and potato technology. The second is represented by CIAT (International Center for Tropical Agriculture), located near Cali, one of the ten international agricultural centres presently engaged in research on food crops in developing countries. CIAT has developed and tested technology for small farmers in the cultivation of field beans, manioc, and maize.

The experience of the Cáqueza Project is first reviewed; then the CIAT experience in designing new technology for field bean production is analysed in detail. Field beans are grown predominantly in association or in relay with maize; hence new technology in maize is also considered. Since all three crops—beans, maize, and potatoes—are principally produced by small farmers outside the prime agricultural regions of Latin America, the experience in technology selection and evaluation may be relevant for a large number of crops and regions. These two examples represent the only substantive research on this subject in the Northern Andes known to the authors.

[1]Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907, U.S.A.
[2]7919 Bellfort Avenue, Houston, TX 77061, U.S.A.

SMALL FARMERS AND FOOD CROPS IN THE NORTHERN ANDES

Three closely related characteristics of the mountain region of northern South America justify the concern for new technologies for small farmers: human population numbers, staple food production, and small farm size. These may be discussed most readily by briefly examining each country in turn.

Venezuela's extremely rapid urban industrial development from oil exploration and processing has stimulated large-scale rural to urban migration and has drawn population from the Andean region. Compared with Colombia and Ecuador, the population of the Andean region of Venezuela is very small. This region is defined here as consisting of the states of Trujillo, Mérida, Barinas, and Táchira and in 1978 it had an estimated 13 percent of the country's population. According to the agricultural census of 1971, this region had a high ratio of rural inhabitants (45 percent), counted 71 percent of its population as being engaged in agriculture, and was characterized by small farmers. Farms of less than 10 ha made up 59 percent of the regional total. Nearly 60 percent of all farms of less than 10 ha were in the Andes. Coffee was the chief cash crop and provided 56 percent of the national production. The Andean region was also important in the Venezuelan production of staple food crops, providing 51 percent of the potatoes, 25 percent of the beans, and 19 percent of the maize.

In Ecuador the role of the mountain region is much more significant. The census of 1974 revealed 48 percent of the population residing in the ten provinces which make up the Sierra region. In that region 62 percent of the population was classified as rural dwelling, even with the inclusion of Quito's population. In 1973, 99 percent of the potatoes and 99 percent of the flour maize (two of the principal food crops), and 98 percent of the beans were grown in the Sierra.

Colombia's mountainous region is more difficult to treat as a unit because in official statistics departmental totals include both highland and lowland areas, a consequence of the historical delimitation of departments. Not surprisingly, 75 percent of the Colombian population is found in the highlands and enclosed valleys where the three largest cities are located (Blutstein *et al.*, 1977). In the mid-1970s, Colombia had a population ratio of 64 urban to 36 rural. The census of agriculture in 1971 revealed that 73 percent of the farms in the country were less than 10 ha in size. Arias (1981) estimated that farms of this size class account for 70 percent of the agricultural production in the highlands. Crop production data are not available for the highlands alone, but examination of the 1977 edition of the *Atlas de Colombia* clearly demonstrates that maize, potatoes, and beans are highly concentrated in the Andes.

STAGES OF TECHNOLOGY DEVELOPMENT

There are two distinct stages in technology development. The first is a borrowing process from more developed countries, regions, or farmers. Direct borrowing, such as the importation of complete factory systems of poultry production, led to rapid expansion of broilers and increased demand for feed grains in Latin America in the late 1960s and the decade of the 1970s (CIAT, 1980a). More widespread is the borrowing of components of new technology, such as hybrid varieties or new fungicides. Since biological and chemical innovations are usually sensitive to environmental differences, these innovations need to be regionally tested for adaptation. Finally, the development of short-stature crop varieties to respond to high fertilization levels without lodging, can be used for cross-breeding using available germ-plasm. From this "borrowing-adaptation" process has come the increasing fertilizer consumption in developing countries and the spectacular successes of the Green Revolution with its short-stature wheat and rice varieties, primarily grown under irrigation in Asia (Dalrymple, 1978).

The greater the flow of relevant new materials and the more rapidly the evaluation can be done, the better the adaptation process will function. After this stage of selection and evaluation of crop varieties from similar agroclimatic regions, there follows the breeding of plant material adapted for the soils, climate, diseases, insects, and other relevant characteristics of the specific region (Evenson and Kislev, 1975; Herdt and Barker, 1977; Ruthenberg, 1977). This stage requires the identification of constraints to increase in yield in particular regions and then the development of plant characteristics or other technology to overcome these constraints.

Some of the stage one "borrowed-adapted" technology will not be successful on the farm even though it is successful under the more intensive management and higher input conditions of the experiment station. An effective evaluation system of new technology will include experiment station, regional, and farm trials. The failures at the different levels will create a demand for region-specific technology production. The response to this demand will move the experiment station into the second stage of technology development.

On-farm testing is a critical phase of the research evaluation process once a new technology has produced better yields on the experiment station or in regional trials than existing farm practices. This on-farm testing appears to be more efficient in identifying constraints to yield increase than socio-economic interviewing. In farm trials the researcher has to be concerned with the farmers' objectives. Thus, the following three questions must be answered: (1) does the new technology work on the farm, i.e., provide improved yields over the farmers' practices? (2) can the farmer make money with the new technology? (3) does the new technology fit into the farmers' present or potential production system? Figure 1 demonstrates how the answers to these questions give feedback to researchers on further requirements for technology design, creating an increased demand for the development of indigenous research capacity and materials. Farm trials also indicate to the extension service the technology which performs well and,

therefore, can be passed on for further testing, demonstration, or farm recommendations.

The following two sections of this study analyse the Cáqueza Project and the CIAT Bean Program for their performance in technology development for small farmers.

THE CÁQUEZA PROJECT

The Cáqueza Project in eastern Cundinamarca (Figure 2) was modelled on previous rural development projects, especially the Puebla Project in Mexico. It was initiated in March 1971 and continued for five years. It concentrated upon maize and potatoes on small farms. Regional trials of new varieties and increased fertilization were undertaken in 1971 before farm recommendations were made. Traditional maize varieties generally performed better than the hybrids due to the increased agronomic requirements of the hybrids especially for improved soil preparation. To attain the high yield potential of the new varieties, higher fertilization levels, better soil preparation, and higher planting densities were required. Moreover, the hybrid varieties proved to be more susceptible to storage insects. Hence, the orientation of the new technology introduction turned towards improved agronomic practices (Zandstra *et al.*, 1979).

The regional agronomic trials without new varieties tripled maize and doubled potato yields. This was accomplished with a new technology consisting of higher planting density, insect control, and increased fertilization in maize; and improved seed tuber selection, higher planting density, and increased fertilization for potatoes (Zandstra *et al.*, 1979). In spite of larger potential gains, there was little adoption of new maize technology compared with potatoes. The principal reason given was that potatoes were a more dependable cash crop whereas maize was produced primarily for food and feed consumption on the farm with much less certainty of receiving a reasonable price at harvest. Hence, there were experiments with various policies to reduce risks, and agricultural credit was provided.

The Cáqueza trials were intensive experiments in regional testing of new technology, farm promotion, evaluation of adoption, and the design of an economic policy to provide incentives for adoption. However, the project suffered from a lack of a detailed on-farm technology evaluation of the impact of improved agronomy on the farmers'

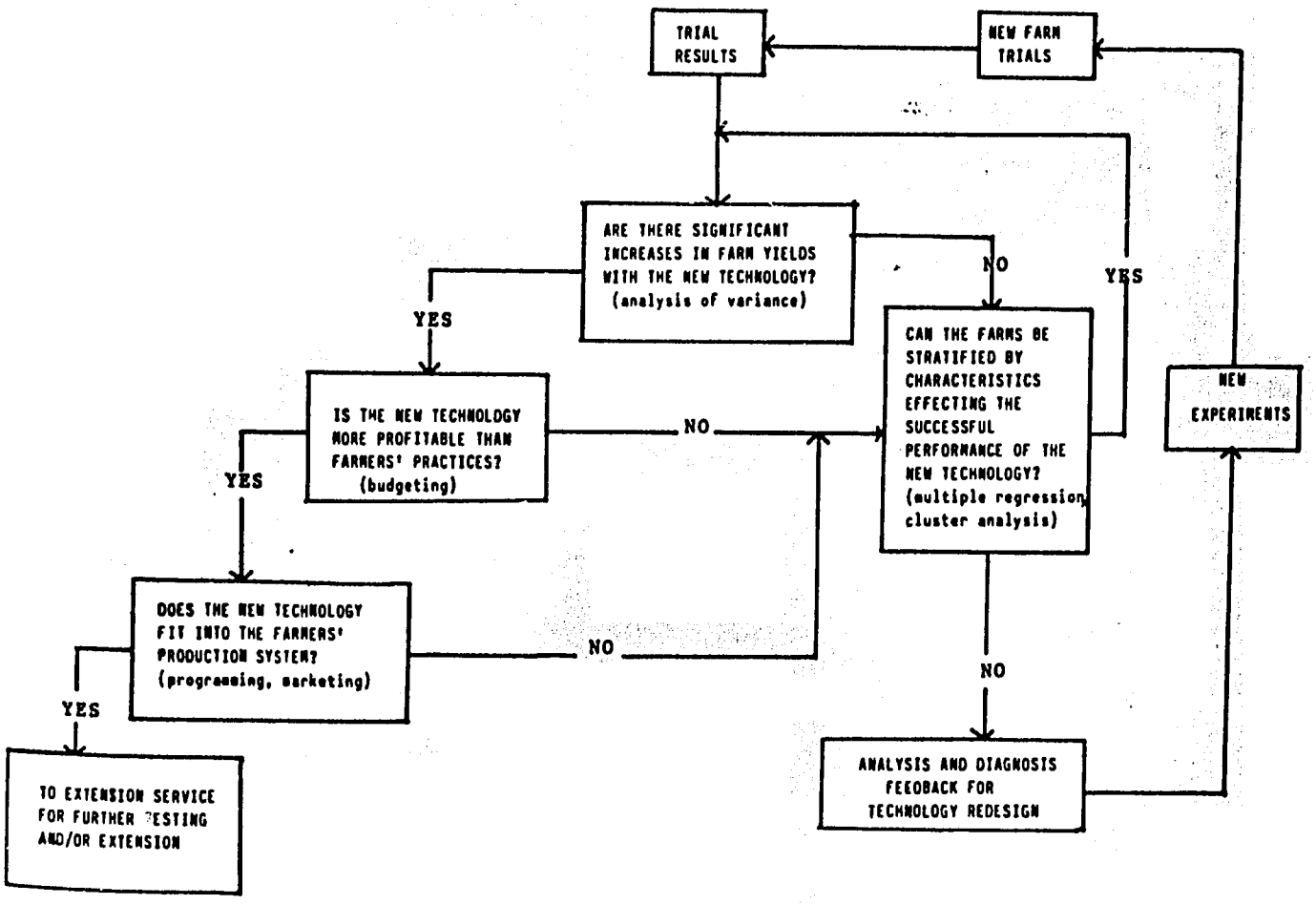

FIGURE 1. Flow chart for new technology evaluation in farm trials.

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fields. It is unlikely that these simple agronomic innovations were able to increase yields on farms as much as was claimed from the regional trials. Unfortunately, yield data of the actual on-farm performance were never reported. Hence, the only feedback to the ICA research stations came from the regional trials. The Cáqueza Project devoted little attention to the necessary evolution of the research system into the second stage of technology development to respond to the region-specific yield constraints. Rather, attention shifted in the later stages of the project from technology development to economic policy concerns.

CIAT BEAN TECHNOLOGY DEVELOPMENT

In 1977 the Bean Program of CIAT, after four years of experimentation on several research stations, defined a series of new technologies for farm trials in three regions of Colombia. Two of the regions, eastern Antioquia and southern Huila, were the principal bean producers, each with approximately one-fifth of Colombia's production. The third was a marginal coffee region in the Cauca Valley. With the decline of world coffee prices until the 1981 Brazilian frost and an expected national concentration of coffee growing in areas of prime rainfall and soil conditions, the marginal coffee producers needed to diversify. These small farmers are already accustomed to intensive production methods and are market oriented for their coffee sales. Moreover, beans grow well at these elevations.

The three areas of farm trials are designated in Figure 2 as El Carmen for eastern Antioquia, Pitalito for southern Huila, and Restrepo for the marginal coffee region of the Cauca Valley. El Carmen, Antioquia is located on the western flank of the Cordillera Central, 35 km southeast of Medellín, 2,000-2,200 m in elevation, above the belt of coffee growing. The elevation and related temperature conditions of El Carmen place it in the lower level of the *tierra fría*. The topography is characterized by moderate-to-steep slopes and soils which vary in depth depending upon their age and length of time under cultivation. Soils are improved with cultivation through incorporation of crop residues, weed remains, and high levels of organic and inorganic fertilizers. The soils are derived chiefly from volcanic ash, are light in texture, and easily tilled. They tend to be highly acidic, of low natural fertility, and often so well drained that moisture retention is low. Organic matter content is high, above 18 percent, but the soils have a low cation exchange capacity (CIAT, 1980b). Rainfall averages 2,100 mm per year with two wet and two dry seasons (IGAC, 1973).

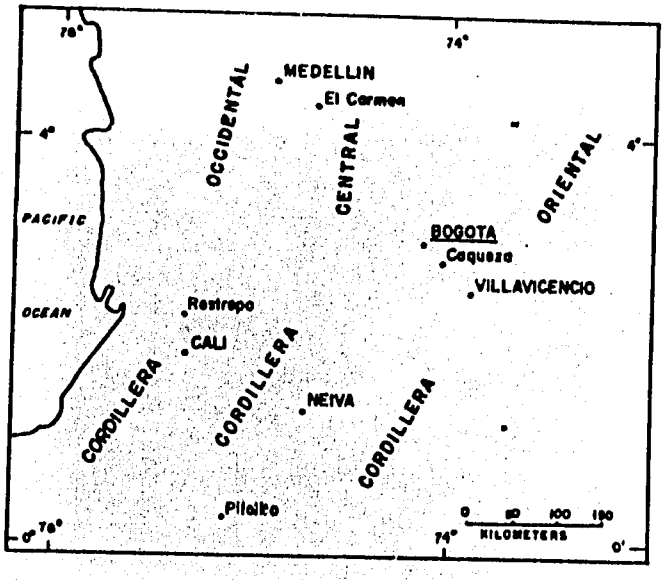

FIGURE 2. Map of central Colombia.

Pitalito, in the second principal bean producing area, is located in the southern portion of the department of Huila. The nearby *municípios* of Guadalupe, Suaza, and Timaná were also included in the farm trials. This general area is located on the western slopes of the Cordillera Oriental, near the headwaters of the Magdalena River, approximately 230 km south of Neiva at elevations ranging from 1,000 to 1,500 m within the *tierra templada*. Topography is moderately steep with slopes of 20-30 percent. More than 80 percent of the land is classed as having broken topography (IGAC, 1973).

Soils of southern Huila are alluvial deposits derived from sedimentary, igneous, and metamorphic rock, and volcanic ash. They are fertile, possess good texture, are not too prone to erosion and are suitable for agricultural exploitation. There is much regional variation in soils with 30 percent of them being overly acidic with high aluminium concentrations. An estimated 65 percent of the soils have low levels of phosphorous (IGAC, 1973; ICA, 1978). However, most bean producers avoid both these types of soils as beans are very sensitive to acidity and to low phosphorous levels. The area of Pitalito receives from 1,000 to 2,000 mm of rain per year. This occurs in two wet and dry seasons, as at El Carmen.

The third site of farm trials was at Restrepo in the Cauca Valley about 58 km north of Cali. Restrepo is on the eastern slope of the Cordillera Occidental at an elevation of 1,400 m within the coffee belt or *tierra templada*. Topographically, the area is one of moderate slopes. Soils are derived from either volcanic material or basalt, each representing about one-half of the area. Volcanic soils have excellent texture, good drainage, high levels of organic matter and phosphorous, and are preferred. The basalt-derived soils have poorer structure and drainage. Both soil types require supplementary fertilization for maximum agricultural production (FEDECAFE, 1971).

The mean annual precipitation of the Restrepo area is approximately 1,000 mm with a bimodal distribution. Rainfall-dependent agriculture is risky, since the minor wet season exhibits a wide variation in rainfall at the time of flowering of annual crops (FEDECAFE, 1971). The cultivation of shaded coffee, on even a marginal basis, is a strong indication that additional moisture is available from subsurface sources.

These three areas of bean field trials include a representative range of conditions of rainfall and elevation for the

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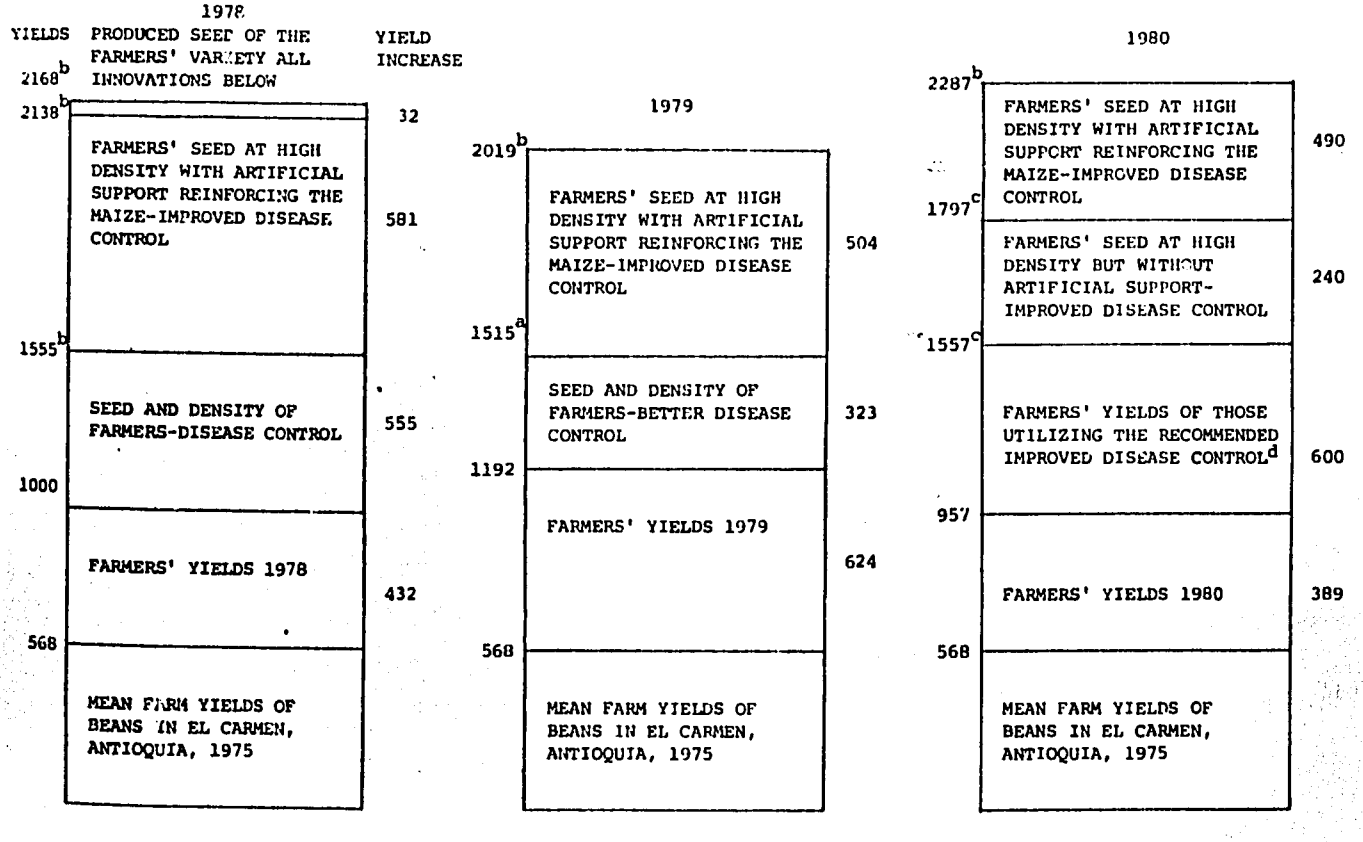
Colombian Andes. The three areas are also representative of the typical small farmer environment of sloping lands and less than optimal soil conditions, with the added uncertainty due to unreliable monthly rainfall in the marginal coffee region.

In El Carmen, Antioquia, the principal production area of the Oriente, bean production by small farmers is in combination with maize, as in most of the northern Andean region. In eastern Antioquia beans have a preferred market and are the major cash crop (Ruthenberg, 1980). Four innovations for climbing beans were identified: (1) higher planting density; (2) improved disease control; (3) new varieties; (4) inoculation with *Rhizobium* for improved nitrogen fixation.

After clearing the land, the initial agricultural activity is to plant two rotations of potatoes with very high levels of organic and inorganic fertilizers. Maize follows and is planted in December–January with three or four seeds per hole, and climbing beans are planted alongside each hill in May–June, using two or three seeds. This is the relay system common in intensively cropped regions with overlapping rainy seasons (Ruthenberg, 1980). In July–August the mature maize plants are bent over and interwoven for increased support or partially cut; in both cases the maize is stored in the field for gradual harvest as required for food and feed. When the stalks are bent or cut, most of the maize leaves are stripped off to give more light to the rapidly growing climbing beans. Bean densities are very low in this system, 22,000 plants/ha. On the experiment station with different varieties of beans and maize, an economically optimum density of 120,000 plants/ha of climbing beans was estimated (CIAT, 1977). The densities utilized in the farm trials were two levels between these extremes, i.e., 66,000 and 90,000 plants/ha.

Historically the price of beans in Antioquia ranges from a ratio of 3:1 to 7:1 compared with the price of maize. Maize yields are low (1–2 t/ha) and the attempted introduction of a shorter, higher yielding maize was recently rejected by Antioquian farmers due to the increased lodging caused by the very aggressive Cargamanto bean variety. The farmers' primary objective for the maize is to provide an adequate, low cost support for the beans.

Losses of 80–90 percent have been reported from the anthracnose fungus (*Collectotrichum lindemufhianum*) in Colombia, and it is widespread in Antioquia. Anthracnose chemical control with benomyl instead of maneb has been shown to be more effective on the experiment station by both CIAT and the Colombian national research service (Schwartz and Galvez, 1980). Antioquian bean producers generally utilize maneb; however, in recent years the effec-



a: significantly different from the farmers' yields at the 85% probability level.
b: significantly different from the farmers' yields at the 95% probability level.
c: significantly different from the farmers' yields at the 99% probability level. In 1980 the base comparison is farm yields of those farmers not utilizing benomyl.
d: the use of benomyl was actively promoted by the National Extension Agency in el Oriente, Antioquia beginning in 1979.

FIGURE 3. Farmers' and best treatment yields, El Carmen, Antioquia, 1978–1980.

tiveness of this control has declined and farmers have had to increase substantially the number of applications to a frequency of every ten days. In spite of the low cost of family labour in this small farming system, the growth cycle of Cargamanto is so long (six and one-half months) that the costs of frequent fungicide application are high.

Earlier breeding efforts by ICA and its predecessor agency concentrated on bush beans. Several excellent new cultivars were produced, including Diacol-Calima, a kidney, mottled red, and ICA-Pijão, and Tui, small black beans for export to Venezuela. These breeding efforts were principally directed at the large farmers of the Cauca Valley; however, sugar-cane, soybeans, sorghum, and cotton have been more profitable and have displaced field beans from this prime agricultural region of Colombia since the mid-1970s when the Venezuelan export market for black beans closed (Ruiz de Londoño *et al.*, 1978). This represents the typical bias of national research stations toward large farmers, prime agricultural regions, and export activities. Since most previous research has been with bush beans, the potential for obtaining an improved climbing variety was believed to be higher. Selection among climbing varieties at CIAT is for high yielding, less aggressive varieties with resistance to anthracnose.

Another way to reduce production costs is to substitute nitrogen-fixing *Rhizobium* bacteria for nitrogen fertilizer. With the same bean variety at almost the same elevation as in Antioquia, inoculation with *Rhizobium* gave yields equivalent to 50–70 kg/ha of nitrogen on the experiment station (CIAT, 1978).

Average farm yields of Cargamanto were estimated in a field survey in 1975 as 568 kg/ha in the El Oriente region. Yields in El Carmen were substantially higher, approximately 1 t/ha in 1978–1980 (Figure 3). Utilizing only the improved chemical control of anthracnose resulted in an approximate 50 percent increase in farm yields in 1978 and 1979 and was highly profitable (Figures 3 and 4). The one-input change was highly effective. This chemical substitution of benomyl for maneb was a type of maintenance research since the effectiveness of maneb was declining. In 1980, following the promotion efforts of the previous year by the national extension service of ICA, 40 percent of the farmers in the on-farm trials were utilizing benomyl and obtaining yields equivalent to those of the 1979 farm experiments. This single input change was very profitable in spite of the high cost of benomyl, much higher than maneb, and was being rapidly adopted by farmers.

From this 1.5 t/ha yield level achieved with benomyl use, farm yields can be further increased by another 0.5 t/ha with higher planting density (Figure 3). However, to achieve this higher density, stakes to reinforce the maize stalks were also necessary and these stakes increased production costs by U.S. $592 dollars/ha (1980 dollars) including increased labour expenditures. The introduction of stakes was economically viable as indicated by the upward slope of the curves BC in Figure 4.

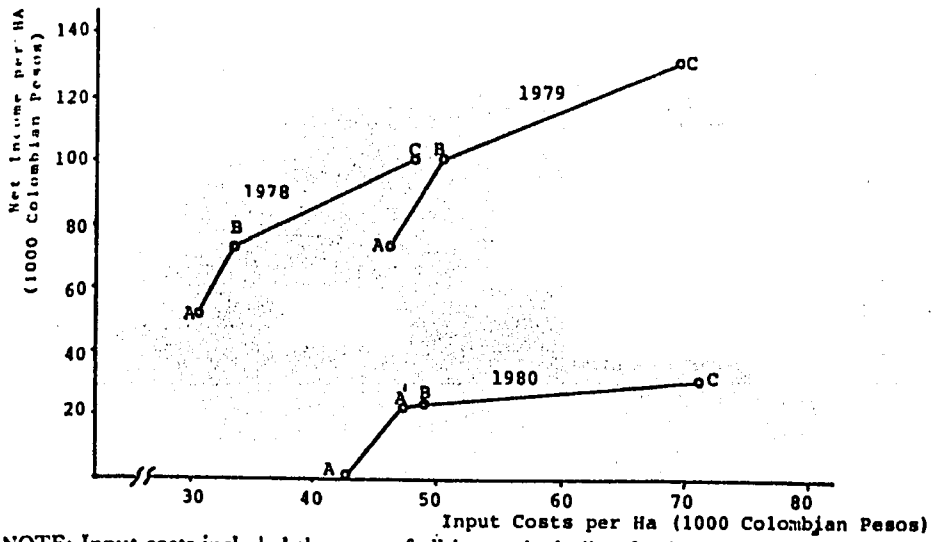
During the farm trials the abrupt decline of the bean price from U.S. $1.67 to $1.00 per kg from 1979 to 1980 had a dramatic effect on the returns to the new technology. The decreased slope of BC from 1979 to 1980 indicates a decline of the incremental return on each dollar of investment from 1.50 to 0.40 in this two-year period. Forty percent is still a very reasonable rate of return on investment; however, the initial investment is considerable for a small farmer. In summary, with a large increase in input costs, yields of 2 t/ha of field beans can be obtained. Flagging the high input costs to reach these yield levels indicates research areas with high potential pay-offs. A less aggressive bean variety, a maize variety with a stronger stem, or a different maize planting system, are all potential alternatives to attain 2 t/ha bean yields with a lower production cost than with a system requiring stakes.

The effect of technological innovation on income compared with changes in the bean price received by farmers is indicated in Figure 4. Both the absolute returns and the incremental returns from higher planting density were substantially decreased by the abrupt decline of the bean price in 1980. To facilitate technological change, economic policy support may often be necessary. For example, in 1980 a price support to maintain the 1979 price for beans would have had much more impact on farm income than any of the technologies evaluated, and would have been expected to facilitate the introduction of new technology.

In the design of new technology, failures are as important as successes. With both *Rhizobium* inoculation and the new selections of climbing beans, there were yield reversals when the technology moved from the experiment station to farm trials. On the farms, the farmers' varieties and practices were not only more profitable but also gave better yields than the new technologies. These technology failures on the farms helped identify a series of problems for future research on the experiment station, such as the demand for a fungicide effective against fusarium root rot but not lethal to *Rhizobium*. Moreover, in the farm trials, valuable characteristics of the farmers' varieties were discovered which were previously unknown (Sanders and Lynam, 1981a). Several of these characteristics, for example a tolerance to nematodes and to heavy insect attack in the early stages of growth and resistance to storage insects, will be important in future breeding work.

After eastern Antioquia, southern Huila is the next most important bean production region of Colombia. Most of the production comes from the mountain valleys and less steeply sloping mountainsides. Approximately 80 percent of the bean production in these areas is in direct association (simultaneous or near-simultaneous planting) with maize, and the other 20 percent is bush beans in monoculture. Below 1,500 m bush beans predominate whereas above 1,500 m on the hillsides, climbing beans in direct association with maize is the principal planting system.

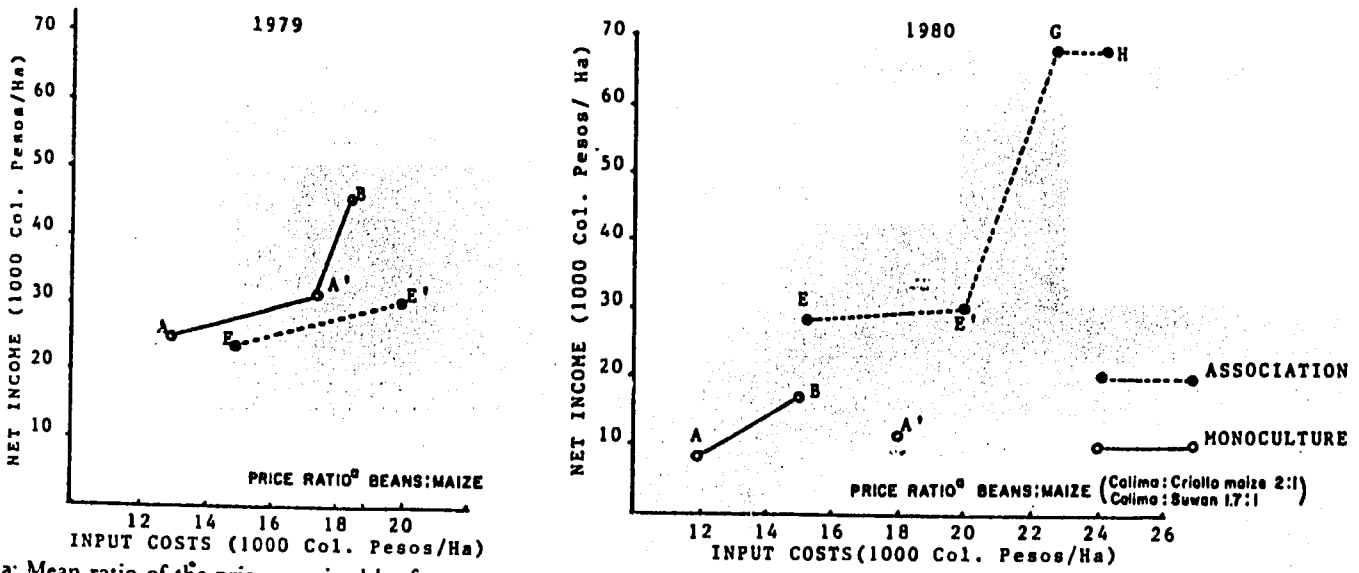
In the 1978 and 1979 Huila farm trials a simple, low-cost combination of improved agronomic practices including higher density planting, improved chemical control of disease and insects, and weed control increased bush bean yields over the best farmers' monoculture practices (1.2 t/ha to 1.5 t/ha). As in Antioquia, these yield increases did not greatly raise input costs and they were highly profitable (CIAT, 1979; 1980c). However, adoption of improved agronomic practices for field beans in Huila has been much less rapid than in Antioquia. Linear programming analysis of a Huila model farm showed a poor 11 percent rate of return to the introduction of this new agronomy. The effect of new technology is obscured by the abrupt price decline at harvest. In Huila the bean price received by farmers declined from U.S. $0.89 to $0.56 per kg (1980 dollars) during the three weeks of the 1978 harvest, and recovered



A: Farmers' technology. In 1978 farmers were asked their yields. In 1979 and 1980 parcels, the same size as the experimental treatments, were harvested from farmers' fields.
A': Farmers' technology using improved disease control. In 1980 40% of the farm trial sample were utilizing benomyl, the principal component of the treatment in the 1978 and 1979 trials of improved disease control (B).
B: Farmers' seed and cultural practices with improved chemical control of diseases.
C: Farmers' seed but higher density with artificial support to reinforce the maize in the relay system. Also improved disease control.

NOTE: Input costs included the costs of all inputs including family labour priced at the average wage rate. No rental charge was placed on land, nor was depreciation calculated on simple implements utilized. 1978 and 1979 income and cost estimates were inflated to 1980 estimates based upon the cost of living index.

FIGURE 4. Income and input costs for farmers' fields and new technology, El Carmen, Antioquia, 1978–1980. (in 1980 pesos)



a: Mean ratio of the prices received by farmers.
A: Practices of average farmer in monoculture.
A': Best farmer practices in monoculture. Better farmers utilize fertilizer and spraying for disease and insect control.
B: Farmers' variety (Calima) with improved agronomy including higher density, weed control and curative spraying.
E: Average farmer practices in association. Calima × local ("Criollo") maize variety.
E': Better farmer practices in association. Calima × hybrid maize variety with fertilizer and pesticide on the maize.
G: Calima × Suwan I without chemicals at high bean density.
H: Calima × Suwan I with chemicals at high bean density.
NOTE: Bean Density was 162,425 pl/ha of beans and 42,000 pl/ha of maize. For 1980 the exchange rate of 45 Colombian pesos per dollar was utilized.

FIGURE 5. Income and input costs for farmers' fields and new technology treatments in monoculture and association, Pitalito, Huila, 1979 and 1980. Correction: 1979 graph lacks caption "Calima: Criollo Maize 3:1."

to the former price after several months. If the model farm combined the introduction of improved agronomy with storage for four months, the rate of return on investment increased to a respectable 69 percent (Sanders and Lynam, 1981a). A government policy to encourage on-farm storage through longer-term credit financing, or active extension promotion of the simple storage technology could hasten the introduction of this change (Arcia, 1980; Arcia and Sanders, 1980).

In 1980 the improved monoculture bush bean agronomy was compared with an associated system of simultaneous planting with maize (Figure 5). At the 1979 relative prices, the improved agronomic technology in monoculture beans was substantially more profitable than either of the farmers'

associated systems. From 1979 to 1980 the ratio of the bean-maize price in Huila declined from 3:1 to 2:1. In 1980 all the monoculture bean systems were inferior to association. The importance of not arriving at conclusions about particular farming systems on the basis of one year's data is obvious.

The more dramatic result of the 1980 farm trials in southern Huila was the large increase in income with the introduction of the CIMMYT (International Maize and Wheat Improvement Center) maize variety, Suwan I, and improved agronomy. Maize yields on the farms were increased from 2.4 to 4.3 t/ha, and there was a 17 percent price premium for Suwan I, apparently due to its earlier harvest date. Net farmer income was more than doubled with a small increase in input costs as indicated by the steep slope of the line, E'G in Figure 5. The further increase of improved agronomy on the beans in association (H) had little additional effect on income compared with this new variety of maize. This is a classic case of a substantial increase in yields and income based upon the introduction into the farmers' system of a new variety combined with improved agronomic practices. However, these are only one-season results and should, therefore, be interpreted with caution. The 1980 farm trials emphasize the importance of systems analysis as both the introduction of the new maize variety and the post-harvest bean price collapse had much more effect on farmers' income than the improved bean agronomy.

As in the Antioquia case, two of the innovations which were successful on the experiment station failed completely in the southern Huila farm trials. In experiment station results, improved bean seed quality increased yields by 85 percent (CIAT, 1975). Since many bean diseases are seed-transmitted and clean seed production is commercially profitable in the United States, substantial effort was invested in improving seed quality for these trials. There was either no yield effect or the yield increase was so small that it was not economical. At the present time improved seed quality is unlikely to substitute for new varieties (Sanders and Lynam, 1981a). In 80 percent of the Huila farm trials the initial soil fertility was not a problem as beans frequently followed heavily fertilized tomatoes, and the fertility of the volcanic and alluvial soils in mountain valleys is often high. Hence, there was either no yield effect from fertilization or a small uneconomic return in contrast to the dramatic response in one regional fertilization trial where the initial phosphorous level was negligible (CIAT, 1979; Sanders and Lynam, 1981a).

Besides the principal bean production areas of Antioquia and Huila, beans are also produced, principally for home consumption, in many highland areas of Colombia including the coffee regions. In a sample of farm trials in Restrepo, a marginal coffee region, average initial phosphorous levels were 2–4 ppm compared with over 20 ppm in Huila. When diseases were controlled in the Restrepo farm trials there was an excellent response to fertilizer. With an application of 150 kg/ha of 10-30-10 (N.P.K.), a yield of 1.5 t/ha was reached consistently; and with 500 kg/ha of 10-30-10 it was possible to attain 2 t/ha. As in Antioquia it was not difficult or expensive to raise yields from 1 t/ha, which is the farmers' best yields, to 1.5 t/ha, but this yield increase required the simultaneous introduction of a series of agronomic practices including increased planting density, improved weed control, macro- and micro-nutrients (CIAT, 1980d). Another 0.5 t/ha yield increase, to reach 2 t/ha, was technically possible by tripling the fertilizer use but this would require much higher input costs (Sanders and Lynam, 1981a). In spite of the high input costs needed to manage the soil fertility problem, farmers in Restrepo are expanding their bean production, utilizing more chemical fertilizer, shifting from organic to inorganic fertilizers, and increasing planting densities. Once again the external economic factor, in this case the world coffee price, is expected to be the most important determinant in the introduction of new bean technology (Stabile, 1979).

The results for the three regions of Colombian farm trials are summarized in the yield gap comparisons of Figure 6. The 2.9 t/ha experiment station yield is the approximate ceiling. The better bean producers in all three regions are already obtaining 1 t/ha, in relay in El Carmen, and with moderate input use in monoculture in southern Huila and Restrepo; thus there is a yield gap of 1.9 t/ha. Yields of 1.5 t/ha were attained consistently without high input levels in all three regions. These yield levels with improved agronomy are higher than mean farm yields in the United States (Figure 6). With high input levels, such as with stakes in Antioquia or high fertilizer levels in Restrepo, 2 t/ha yields have been achieved regularly in the farm trials. A higher bean price or lower input cost innovations are probably necessary for adoption of the 2 t/ha technology, but these absolute yields are now technically feasible on the farm. Breeding may reduce the need for some of the inputs in the 2 t/ha technology and breeding has shown another 0.9 t/ha potential gap from 2 t/ha to 2.9 t/ha.

In summary, 25 percent of the 2 t/ha yield gap is easy to close with new agronomic technology and is presently in a rapid adoption process on Colombian farms. Another 25 percent is now technically, but not economically, viable. The other 50 percent of the yield gap is attributed to: 1) the potential value of new varieties once characteristics achieved on the experiment station are put into varieties acceptable to consumers; and 2) the differences between experiment station and farms in resources and management (Davidson and Martin, 1965). Finally, breeders will undoubtedly raise the 2.9 t/ha yield ceiling in the future.

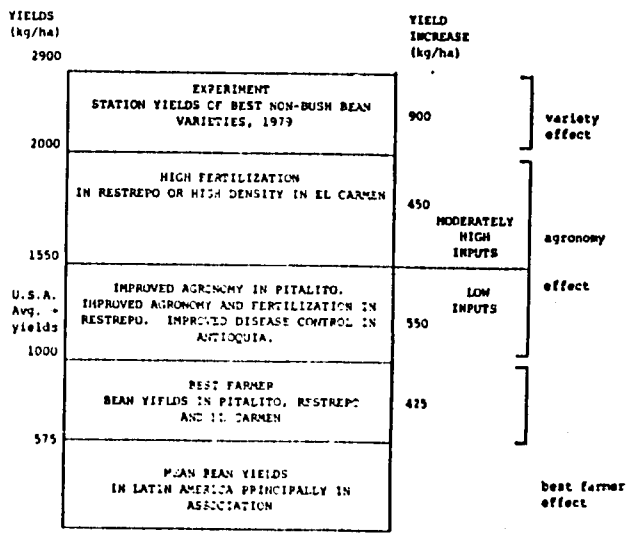


FIGURE 6. Experimental and farmer bean yields.

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The direct linking of plant breeding and the related disciplines into research evaluation will lead to the production of new varieties to overcome specific regional yield constraints identified in the farm trials. This is the second stage of technology development. The incorporation of this element is the principal difference between the Cáqueza and CIAT experiences.

CONCLUSIONS

The comparison of the Cáqueza and CIAT projects illustrates the need for a strong linkage to the primary instrument of technology generation, the research station. The CIAT programme was able to respond to the field problems identified on a continuing basis as the technology was evaluated on the farms. Agronomic innovations can increase farmers' yields and incomes but the significant gains are expected to come from new varieties plus improved agronomy. The Cáqueza Project indicated the difficulty of transferring new varieties from the experiment station to the farm since there are often more yield constraints on the farms than are theorized on the experiment station. Suwan I maize demonstrated the substantial potential gains when a new variety is appropriate to the environment and the economic system.

Since farming systems have interrelated components and are complex, changes of a single component are unlikely to be successful, with the important exception of maintenance research in filling a specific emerging need. Higher planting densities is an excellent example of an apparently simple change which then requires a series of other changes; the substitution of benomyl for maneb to control anthracnose is an example of maintenance research applied as the effectiveness of maneb decreased over time.

Technology associated with an approximate, farm level, yield increase of 50 percent to 1.5 t/ha of beans is presently being adopted on Colombian farms, and a 2 t/ha yield is technically feasible. Hence, new technology can have a substantial effect on productivity and can be developed for small farmers by experiment stations. Some surprising results were that much of the technology borrowed from developed countries was unsuccessful at the farm level; this included improved seed quality, fertilizer application in most sites in southern Huila, and inoculation. The yield reversals in moving from the experiment station to the farm indicate the critical role of farm trials in providing feedback to researchers and the importance of developing the second stage of technology production in response to regional yield constraints.

In the international agricultural research centres there has been a concentration on new varieties. It has been suggested that for small farmers only new varieties be introduced. However, to obtain improved yields, which the farmer can see in the field, the new varieties often will need to be combined with a series of improved agronomic practices, such as higher planting density, increased fertilizer application, and possibly some defensive chemicals for insect and disease control. The yield and income effects of Suwan I maize introduction are a dramatic example of the potential of a new variety which, combined with improved agronomic practices, can fit into the farmers' production system.

Technological change in agriculture is a process requiring the interaction between farmers and researchers. Farm trials provide feedback to the experiment station on design requirements. Breeders and other plant scientists are thereby provided with more information to make decisions on their selection and crossing criteria. Research costs will be higher when the number of breeding objectives is increased. However, breeding for small farmers and less favourable agricultural areas apparently requires that input cost increases, associated with the new technology, be moderate at least at the start of the adoption process. Nevertheless, the impact of new varieties generally requires an increase in input costs (Evans, 1980).

Technological change is not a panacea and should not be regarded as the solution to all small farmer problems. To the extent that small farmers have been relegated to the steep slopes and the less fertile soils, the probability of a technological change being viable and profitable decreases (Ruthenberg, 1980). Rather than searching for new technology in very adverse conditions, it may be more efficient to move the small farmers down into the valleys through land reform and there to utilize their comparative advantage in labour-intensive crop activities, such as bean production. Steeply sloping areas and marginal soils can be reforested or left undisturbed as natural vegetation, if production increases sufficiently in the areas with a better natural resource base (Ruthenberg, 1977).

Much of the food crop production in the Andean countries is presently encountered on mountain plateaus and less steeply sloping mountain sides. Technological change can increase productivity and income in these areas as demonstrated in the CIAT and Cáqueza farm results. However, economic factors, such as price changes, can dwarf the technological innovations; hence, other economic policy measures also are necessary to complement the impact of technological change. These measures could include price supports, longer term credit for the farmer to wait out the post-harvest price decline, and extension and credit support for coffee diversification.

A bias of most crop scientists towards the "engineering" solution of the more sophisticated and mechanized agricultural technology, regardless of its social costs, is expected to be a constant of crop technology development. Hence, it is important that economists and other social scientists actively participate in the design as well as the evaluation of new crop technology. Otherwise, even the production of new varieties could be excessively oriented toward mechanization rather than resolving problems more important to small farmers, such as increased tolerance to various stress conditions. The most important conclusion here, however, is that programmes to promote new agricultural technology for farmers need to be well integrated with the crop scientists at the experiment station. This is necessary to ensure the most rapid movement possible into stage two of technology development, the scientific response to region-specific problems constraining food crop yield increase in the Northern Andes.

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