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CIMMYT/CRI/CIDA adoption case study

prepared for the Impacts Assessment and Evaluation Group (IAEG),

Consultative Group on International Agricultural Research (CGIAR)

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CIMMYT (www.cimmyt.mx or www.cimmyt.cgiar.org) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center works with agricultural research institutions worldwide to improve the productivity, profitability, and sustainability of maize and wheat systems for poor farmers in developing countries. It is one of 16 similar centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR comprises over 55 partner countries, international and regional organizations, and private foundations. It is co-sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP). Financial support for CIMMYT's research agenda also comes from many other sources, including foundations, development banks, and public and private agencies.

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Executive Summary

This report, one of a series of adoption case studies coordinated by the Impacts Assessment and Evaluation Group (IAEG) of the Consultative Group on International Agricultural Research (CGIAR), examines the adoption by Ghanaian maize farmers of improved production technologies developed through the Ghana Grains Development Project (GGDP). The GGDP, which ran from 1979 to1997, was an agricultural research and extension project implemented primarily by the Ghanaian Crops Research Institute (CRI), with technical assistance from the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA), and funding from the Canadian International Development Agency (CIDA).

The objectives of the case study were to (1) evaluate the success of the GGDP in developing improved maize production technologies and in transferring those technologies to farmers, and (2) assess the impacts of adoption at the farm level.

Data on the adoption of three GGDP-generated maize technologies—modern varieties (MVs), fertilizer recommendations, and plant configuration recommendations—were collected through a national survey of maize growers conducted between November 1997 and March 1998. A three-stage, clustered, randomized procedure was used to select a representative sample of 420 maize farmers. These farmers were questioned at length about their maize production, consumption, and marketing practices; their preferences for different maize varietal characteristics; and their knowledge of and access to improved inputs, such as seed and fertilizer.

The survey revealed that adoption of GGDP-generated maize technologies has been extensive. During 1997, more than half of the sample farmers (54%) planted MVs on at least one of their maize fields, and a similar proportion (53%) implemented the plant configuration recommendations. The rate of fertilizer use on maize, however, was lower, as less than one-quarter of the sample farmers (21%) reported having applied fertilizer to their maize fields. Adoption rates varied by agro-ecological zone, with adoption of all three technologies lowest in the forest zone. Adoption rates were higher among male farmers than among female farmers, except in the case of fertilizer, in which no significant difference was found.

What have been the impacts of the GGDP-generated maize technologies? In the absence of reliable baseline data, it was not possible to calculate quantitative measures of project impact. Based on farmers' qualitative judgments, however, it is clear that adoption of the GGDP-generated technologies has been associated with significant farm-level productivity gains (measured in terms of maize yields) and noticeable increases in the income earned from sales of maize. Impacts on the nutritional status of rural households, however, appear to have been less pronounced. Even though the latest MVs have been extensively promoted for their improved nutritional status, relatively few of the survey respondents were aware of this. Those who were aware said they rarely seek out nutritionally enhanced MVs to prepare weaning foods for infants and young children.

In addition to documenting the uptake and diffusion of the three GGDP-generated maize technologies, this case study provides valuable insights about the many factors that can affect the adoption of agricultural innovations in general. The survey results show that adoption of improved production technology is directly influenced by three sets of factors: (1) *characteristics of the technology* (e.g., complexity, profitability, riskiness, divisibility, compatibility with other technologies); (2) *characteristics of the farming environment* (e.g., agro-climatic conditions, prevailing cropping systems, degree of commercialization of agriculture, factor availabilities, farmer knowledge, availability of physical inputs); and (3) *characteristics of the farmer* (e.g., ethnicity and culture, wealth, education, gender). The survey results also make clear that technology adoption may be affected indirectly by factors beyond the control of researchers, including the agricultural extension service, the inputs distribution system, and the economic policy environment.

Acknowledgments

Many organizations and individuals played a role in the preparation of this report, and although it is not possible to cite all of them, several deserve particular mention.

O. B. Hemeng and Baffour Asafo-Adjei of the Crops Research Institute (CRI) embraced the proposal to carry out the study and offered the use of CRI staff and facilities. Nana Koranteng and Mark Mostovac of the Canadian International Development Agency (CIDA-Ghana) were instrumental in mobilizing financial support from CIDA. The Impacts Assessment and Evaluation Group (IAEG) of the Consultative Group on International Agricultural Research (CGIAR) contributed significant financial resources to help cover the expenses of the principal researchers.

Numerous CRI staff participated in the producer survey. The enumeration teams were supervised by A.A. Dankyi, A.O. Apau, Vincent Anchirinah, Kofi Boa, and Joe Manu. Augustine Suglo, Jerome Nyakorong, Kwaku Ansong, Gyamera Antwi, Philip Sam, Samuel Nyarko, R.K. Owusu Asare, Jones Addai, B. Ameho, and Martin Brantuo served as enumerators. Data entry and cleaning activities were carried out at CRI under the supervision of P.P. Frimpong Manso. Joyce Larbi-Siaw provided valuable administrative and secretarial support.

The manuscript was reviewed by O.B. Hemeng, Baffour Asafo-Adjei, and Kofi Marfo of CRI; Greg Edmeades, R.W. Wedderburn, Shivaji Pandey, Prabhu Pingali, Walter Falcon, and David Poland of CIMMYT; and Nana Koranteng and Mark Mostovac of CIDA-Ghana. Helpful comments were also contributed by Diana McLean of CIDA-Canada and S. Twumasi-Afriyie of CIMMYT. Adriana Rodríguez and David Hodson of CIMMYT's Natural Resources Group prepared the maps. The cover photo was provided courtesy of the Sasakawa Africa Foundation.

Last, but not least, we would like to express our appreciation to the many farmers and their families who took the time to participate in the survey.

Introduction and Objectives

As funding for agricultural research becomes increasingly scarce in many countries, research administrators have come under heightened pressure to ensure that available resources are used efficiently. The need to demonstrate accountability has generated increased interest in research impacts assessment methods and motivated a large number of empirical studies designed to determine whether agricultural research programs are having their intended effects. Many of these studies have used some type of benefit-cost framework to calculate economic rates of return to research investments. Benefit-cost analysis typically involves measuring the diffusion of innovations produced by a research program and calculating the economic benefits resulting from their adoption.

Although the results of many recent research impacts studies support the view that investments in agricultural research continue to generate attractive rates of return, some people are uncomfortable with the limitations of the economic framework. Their concern is understandable, because economic rate-of-returns analysis is, in some ways, poorly suited for evaluating an activity (agricultural research) whose primary outputs (technological innovations) are essentially a means of achieving broader welfare goals that cannot easily be measured, much less valued. The realization that traditional economic approaches are not always well-suited for dealing with changes in the quality of human lives has fueled interest in alternative research impacts assessment methods that are less dependent on the dry calculus of monetary costs and benefits.

One alternative approach to understanding the impacts of agricultural research involves adoption case studies. Well conceived, intelligently planned, and carefully executed case studies can generate valuable insights into understanding how rural households adopt agricultural innovations and are affected by them (Sechrest et al. 1998). Such insights are useful in devising ways to increase the adoption of agricultural innovations, hopefully with favorable effects on sustainable food production, poverty reduction, and environmental protection. Case studies are not necessarily inexpensive to conduct, but they are easier to execute than controlled experimentation involving large groups of test subjects and are sufficiently flexible to accommodate a wide range of research questions.

This report summarizes the findings of a recent case study that focused on the adoption by Ghanaian farmers of improved maize production technologies developed through the Ghana Grains Development Project (GGDP). The overall objective of the case study was to assess the success of the GGDP in achieving its stated goals of developing improved maize production technologies and transferring those technologies to the farm level in order to improve the welfare of maize producers and consumers.

Specific sub-objectives of the case study included the following:

a) to summarize the achievements of the GGDP and to describe its principal outputs;

b) to document adoption at the farm level of improved maize production technologies developed by the GGDP and to shed light on the factors affecting adoption;

c) to assess—qualitatively and, if possible, quantitatively—the impacts of GGDP-generated technologies on the welfare of maize-producing households; and

d) to draw lessons from the GGDP that may be useful in the design and implementation of future projects of a similar nature.

The Ghana maize technology adoption study was one in a series of similarly structured case studies carried out under the aegis of the Impacts Assessment and Evaluation Group (IAEG) of the Consultative Group on International Agricultural Research (CGIAR). An additional objective of the Ghana study was to generate information that could be used by the IAEG to compare the experiences of several CGIAR research centers in working with their national program partners to develop and disseminate improved production technologies for the benefit of the developing world's poor people.

The Ghana Grains Development Project

The Ghana Grains Development Project (GGDP) was launched in 1979 with funding from the Government of Ghana and the Canadian International Development Agency (CIDA). The purpose of the project was to develop and diffuse improved technology for maize and grain legumes (initially only cowpea, but in later phases also soybean and groundnut). The Crops Research Institute (CRI) and the International Maize and Wheat Improvement Center (CIMMYT) served as the project's primary executing bodies, while three other organizations provided ancillary support. The Grains and Legumes Development Board (GLDB) and the Ministry of Food and Agriculture (MOFA) assumed major responsibility for technology transfer activities, and the International Institute of Tropical Agriculture (IITA) supported technology development efforts for grain legumes.

The GGDP operated for 18 years before concluding in 1997 following the termination of CIDA funding. The project had three distinguishing features. First, it placed particular emphasis on training and capacity building for CRI, GLDB, and MOFA. Young scientists were provided with short-term training and opportunities for post-graduate studies. Second, the GGDP helped organize an integrated, national level strategy for technology generation, testing, and diffusion that involved the participation of several institutions. Third, the project established strong links in the continuum from station-based research to adaptive research to extension.

The GGDP represented a true partnership between national and international research organizations. The CRI plant breeders participated in international networks of germplasm exchange and testing managed by CIMMYT and IITA, and CRI agronomists and economists worked side by side with their counterparts from CIMMYT and IITA in developing crop management recommendations that were tailored to local production conditions. Because of the collaborative nature of the research effort, none of the participating institutions can claim sole credit for any of the improved technologies generated through the project. The maize technologies were joint products of CRI and CIMMYT, and the grain legume technologies were joint products of CRI and IITA.

The GGDP can take credit for several important accomplishments. It contributed significantly to strengthening CRI by supporting numerous staff training activities. It also helped to establish methods and procedures for organizing adaptive agricultural research and linking it to extension programs. Finally, it helped to develop technology recommendations for maize and grain legumes. The diffusion and impact of the GGDP maize recommendations is the subject of this report.

The Maize Economy of Ghana

Maize has been cultivated in Ghana for several hundred years. After being introduced in the late 16th century, it soon established itself as an important food crop in the southern part of the country. Very early on, maize also attracted the attention of commercial farmers, although it never achieved the economic importance of traditional plantation crops, such as oil palm and cocoa. Over time, the eroding profitability of many plantation crops (attributable mainly to increasing disease problems in cocoa, deforestation and natural resource degradation, and falling world commodity prices) served to strengthen interest in commercial food crops, including maize.

Today, maize is Ghana's most important cereal crop. It is grown by the vast majority of rural households in all parts of the country except for the Sudan savannah zone of the far north (Figures 1, 2). As in other African countries, in Ghana maize is cultivated by both men and women. What distinguishes Ghana from many other countries, however, is that in Ghana women frequently manage their own maize fields, contribute an important proportion of the overall labor requirements, and exercise complete discretion over the disposal of the harvest.

Maize cropping systems and production technologies

Maize cropping systems and production technologies vary between the four agro-ecological zones in which significant amounts of maize are cultivated.

(1) Coastal savannah zone. As the name suggests, the coastal savannah zone includes a narrow belt of savannah that runs along the coast, widening toward the east of the country. Farmers in this zone grow maize and cassava, often intercropped, as their principal staples. Annual rainfall, which is bimodally distributed, totals only 800 mm, so most maize is planted following the onset of the major rains that begin in March or April. Soils are generally light in texture and low in fertility, so productivity is low.

(2) Forest zone. Immediately inland from the coastal savannah lies the forest zone. Most of Ghana's forest is semi-deciduous, with a small proportion of high rain forest remaining only in the southwestern part of the country near the border with Côte d'Ivoire. Maize in the forest zone is grown in scattered plots, usually intercropped with cassava, plantain, and/or cocoyam as part of a bush fallow system. Although some maize is consumed in the forest zone, it is not a leading food staple and much of the crop is sold. The major cash crop in the forest is cocoa. Annual rainfall in the forest zone averages about 1,500 mm; maize is planted both in the major rainy season (beginning in March) and in the minor rainy season (beginning in September).

(3) Transition zone. Moving further north, the forest zone gradually gives way to the transition zone. The exact boundary between the two zones is subject to dispute, which is not surprising considering that the boundary area is characterized by a constantly changing patchwork of savannah and forest plots. What is certain, however, is that the transition zone is an important region for commercial grain production. Much of the transition zone has deep, friable soils, and the relatively sparse tree cover allows for more continuous cultivation (and greater use of

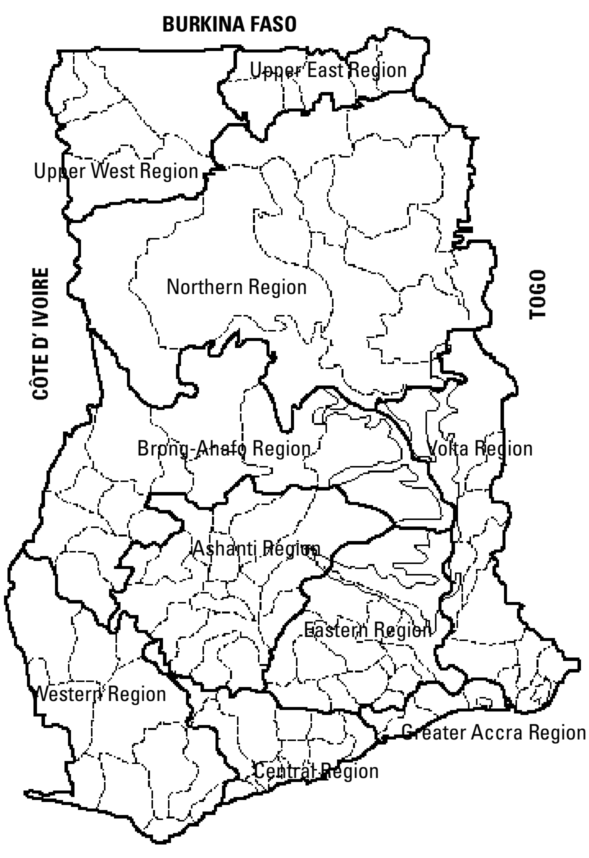

Figure 1. Regional and district boundaries, Ghana.

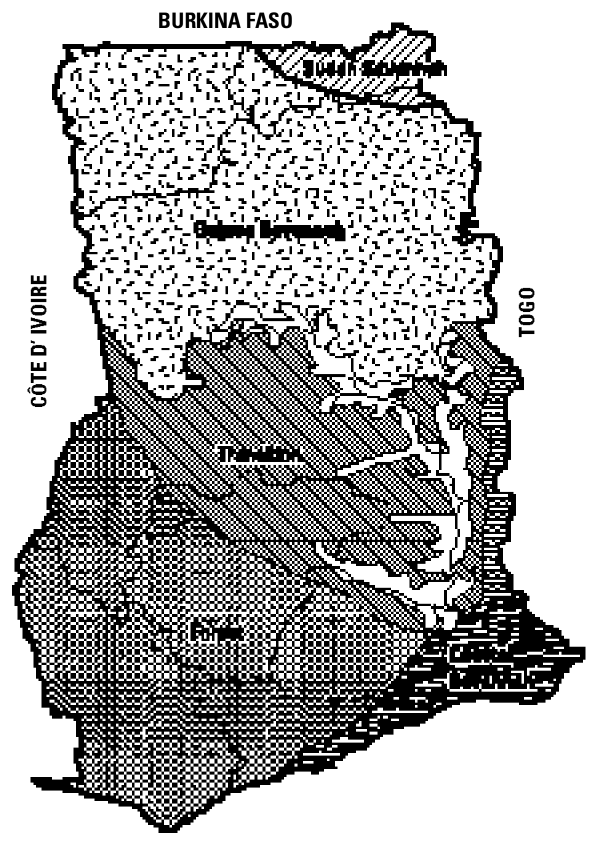

Figure 2. Agro-ecological zones, Ghana.

mechanized equipment). Rainfall is bimodally distributed and averages about 1,300 mm per year. Maize in the transition zone is planted in both the major and minor seasons, usually as a monocrop or in association with yam and/or cassava.

(4) Guinea savannah zone. The Guinea savannah zone occupies most of the northern part of the country. Annual rainfall totals about 1,100 mm, falling in a single rainy season beginning in April or May. Sorghum and millet are the dominant cereals in the Guinea savannah, but maize grown in association with small grains, groundnut, and/or cowpea is also important. Some fields are prepared by tractor, but most are prepared by hand. Maize is grown in permanently cultivated fields located close to homesteads, as well as in more distant plots under shifting cultivation.

Production trends

According to official statistics, the area annually planted to maize in Ghana currently averages about 650,000 ha (Table 1). Most of the maize grown in Ghana is cultivated in association with other crops, particularly in the coastal savannah and forest zones, so planting densities are generally low. Average grain yields of maize are correspondingly modest when expressed per unit land area, averaging less than 2 t/ha. Total annual maize production is currently estimated at just over 1 million tons. Both of the two key determinants of production (area planted and yield) have increased over the longer term, although the upward trends have been characterized by high year-to-year variability typical of rainfed crops (Figure 3).

Following a pattern that has been observed throughout West Africa, the transition zone has become increasingly important for maize production (Smith et al. 1994). The rising importance of the transition zone as a source of maize supply can be attributed to a combination of factors, including the presence of favorable agro-ecological conditions, availability of improved production technology, a relative abundance of underutilized land, and a well-developed road transport system. The relative abundance of arable land in the transition zone has attracted many migrant farmers, particularly from the north of the country, who have moved to the zone to pursue commercial food farming.

Consumption trends

Maize is the most widely consumed staple food in Ghana. A nationwide survey carried out in 1990 revealed that 94% of all households had consumed maize during an arbitrarily selected two-week period (Alderman and Higgins 1992). An analysis based on 1987 data showed that maize and maize-based foods accounted for 10.8% of household food expenditures by the poor, and 10.3% of food expenditures by all income groups. (Boateng et al. 1990).

Table 1. Maize production indicators, Ghana, 1965–1997

	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
1965	173	1.21	209
1966	251	1.60	402
1967	295	0.86	343
1968	272	0.90	301
1969	275	0.90	304
1970	453	1.06	482
1971	433	1.07	465
1972	389	1.03	402
1973	406	1.05	427
1974	425	1.14	486
1975	320	1.07	343
1976	274	1.04	286
1977	256	1.07	274
1978	205	1.06	218
1979	358	1.06	380
1980	440	0.87	382
1981	372	1.02	378
1982	373	0.93	346
1983	400	0.43	172
1984	724	0.96	696
1985	579	1.01	584
1986	472	1.18	559
1987	548	1.09	598
1988	540	1.39	751
1989	567	1.26	715
1990	465	1.19	553
1991	610	1.53	932
1992	607	1.20	731
1993	637	1.51	961
1994	629	1.49	940
1995	686	1.51	1,034
1996	665	1.52	1,008
1997	650	1.54	1,000

Source: FAO Agrostat database.

Despite its widespread popularity as a staple food, maize is rarely if ever predominant in human diets. In both rural and urban households, maize contributes less than 20% of calories to the diet, falling far behind the contribution of root and tuber crops (Alderman and Higgins 1992). Even in areas where maize is a leading staple (for example, southern Central and Volta Regions and parts of the Northern Region), it would be highly unusual to find maize contributing more than 35% to household calorie supply.

Maize in Ghana is consumed in a variety of forms. In the north, it is commonly eaten as a thick gruel, similar to the way that sorghum and millet are consumed. In the south, it is frequently used to prepare porridges and more solid dishes made from fermented or unfermented dough. Many of these foods require considerable time and skill to prepare, which explains why a significant proportion of all maize consumed in Ghana as human food is purchased from specialized food sellers as prepared food, rather than as grain. Prepared foods are particularly important in urban areas, but they are also important in rural areas. A survey conducted in 1987/88 showed that, depending on the month, between 62% and 86% of all households that produced maize for their own consumption needs also purchased some maize products (Alderman 1992).

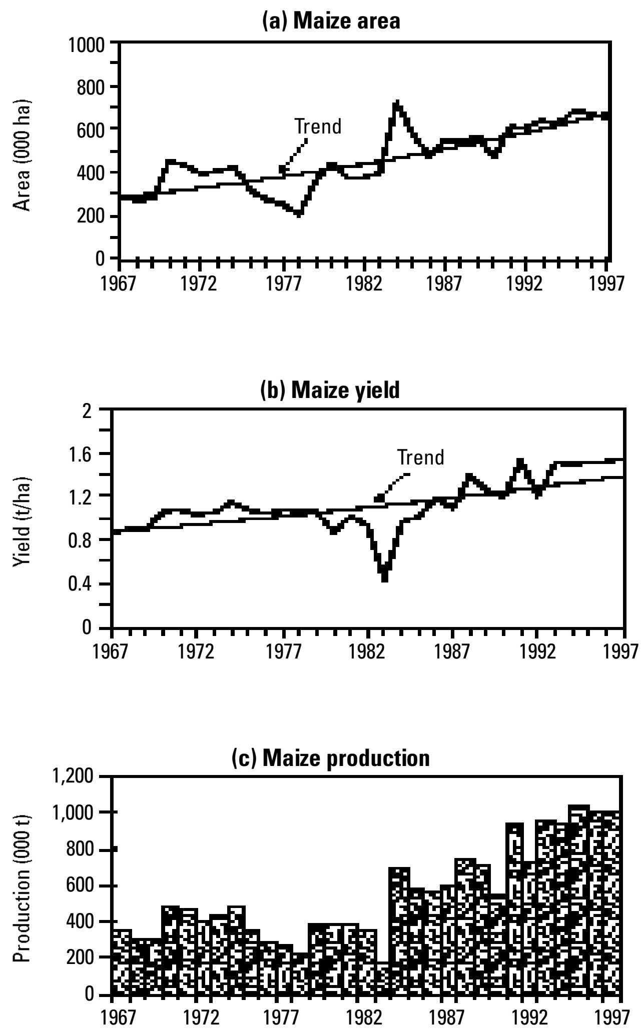

Figure 3. Maize production trends, Ghana, 1967–97.
Source: Unpublished MOFA data.

Maize in Ghana is extensively traded. Miracle (1966) estimated that in the mid-1960s, fully one-third of Ghana's maize crop was being marketed—at the time an unusually high proportion for a subsistence crop in sub-Saharan Africa. The proportion has increased over the years with the rise of commercial farming. Today, at least half of the national maize crop is believed to enter the market (GGDP 1991; Alderman 1991). The extensive marketing of maize has important welfare implications because revenues from maize sales represent an important source of income for many households, even households that grow maize primarily to satisfy their own consumption requirements. Nationwide, maize accounts for 16.8% of the revenues from crop sales earned by poor households and 18.5% of revenues from crop sales earned by "hard-core poor households" (Boateng et al. 1990).

Maize research

As previously noted, the main objective of the GGDP was to stimulate the development and dissemination of improved production technologies for maize and grain legumes. The current study focuses on the adoption of three specific products of the GGDP maize research program: (1) improved germplasm, (2) fertilizer recommendations, and (3) plant configuration recommendations. Although these three technologies were not the only ones developed by the GGDP, they were among the most important.[1]

1 For a detailed description of the improved crop production technologies developed by the GGDP, see the *Maize and Legumes Production Guide* (GGDP, undated).

Improved germplasm

Prior to the inception of the GGDP in 1979, plant breeders working at CRI had developed and released several modern varieties (MVs) of maize.[2] These early MVs generated little interest among farmers, however, and they were not widely adopted.

Under the GGDP, the Ghanaian national maize breeding program was reorganized, and the links between CRI and CIMMYT were greatly strengthened. For a relatively small national breeding program such as Ghana's, this strategy made good sense. In accordance with its global mandate for maize improvement, CIMMYT has established a worldwide system for testing and evaluating promising germplasm. Each year, CIMMYT maize breeders distribute hundreds of experimental varieties, hybrids, and inbred lines to collaborators in dozens of countries throughout the world. The collaborators grow out the experimental materials under carefully controlled conditions and report performance data back to CIMMYT. By analyzing performance data collected across a wide range of locations, the CIMMYT breeders are able to identify superior materials for distribution to national breeding programs.

The GGDP maize breeding program was successful, in part, because it was able to capture "spillover benefits" generated by CIMMYT's global breeding efforts. Each year of the project, CIMMYT breeders provided their CRI counterparts with a selection of experimental materials that were known to be well adapted to lowland tropical and subtropical production environments similar to those found in Ghana. Researcher-managed trials were first conducted at CRI to identify which CIMMYT varieties were best adapted to Ghanaian conditions. Seed of the most promising CIMMYT varieties was then distributed to farmers for on-farm testing throughout the country. Working hand-in-hand with farmers, GGDP scientists identified truly outstanding materials, which were then taken back to CRI for several additional cycles of selection and improvement. This collaborative process involving CIMMYT breeders, CRI breeders, and Ghanaian farmers led eventually to the release, beginning in 1984, of a series of maize varieties and hybrids, virtually all of which contained germplasm whose origin can be traced back to the CIMMYT Maize Program (Table 2).

Through time, the GGDP maize breeding program steadily gained strength. This was demonstrated by the fact that each new generation of MVs developed by the CRI

Table 2. Maize varieties and hybrids developed by the Ghana Grains Development Project

Name	Year of release	Grain color	Grain texture	Maturity (days to flowering)	Yield (t/ha)	Streak resistant?	Nutritionally enhanced?	CIMMYT germplasm
Aburotia	1984	White	Dent	105	4.6	No	No	Tuxpeño PBC16
Dobidi	1984	White	Dent	120	5.5	No	No	Ejura (1) 7843
Kawanzie	1984	Yellow	Flint	95	3.6	No	No	Tocumen (1) 7931
Golden Crystal	1984	Yellow	Dent	110	4.6	No	No	——
Safita-2	1984	White	Dent	95	3.8	No	No	Pool 16
Okomasa	1988	White	Dent	120	5.5	Yes	No	EV8343-SR[a]
Abeleehi	1990	White	Dent	105	4.6	Yes	No	Ikenne 8149-SR[a]
Dorke SR	1990	White	Dent	95	3.8	Yes	No	Pool 16-SR[a]
Obatanpa	1992	White	Dent	105	4.6	Yes	Yes	Pop 63-SR[a]
Mamaba[b]	1996	White	Flint	110	6.0	Yes	Yes	Pop. 62, Pop. 63-SR[a]
Dadaba[b]	1996	White	Dent/flint	110	6.0	Yes	Yes	Pop. 62, Pop. 63-SR[a]
Cidaba[b]	1996	White	Dent	110	6.0	Yes	Yes	Pop. 62, Pop. 63-SR[a]

Source: GGDP.

a Developed jointly with IITA. SR= resistant to maize streak virus.

b Three-way cross hybrid.

2 As used here, the term *modern varieties* (MVs) refers to improved open-pollinated varieties (OPVs) and hybrids developed since 1960 by any formal plant breeding program. *Local varieties* refers to farmers' traditional varieties (also known as landraces) that have never been worked on by a formal breeding program, as well as older improved OPVs and hybrids. The term *modern variety* is something of a misnomer, since some MVs are now more than 30 years old, but the term is used to maintain consistency with other publications. The term *high-yielding varieties* (HYVs), which is often used to refer to the modern varieties, is equally inaccurate, because many MVs were bred for characteristics other than yield potential.

breeders incorporated an increasing number of desirable characteristics. The initial generation of MVs featured mainly improved yield potential and acceptable grain characteristics (e.g., Aburotia, Dobidi). The next generation of MVs additionally offered farmers resistance to maize streak virus, a potentially devastating disease that in years of severe infection is capable of causing crop losses of up to 100% in selected areas (e.g., Abeleehi, Okomasa). The release of streak-resistant MVs was followed in 1992 by the release of Obatanpa, a "quality protein maize" (QPM) variety featuring enhanced nutritional quality in the form of higher levels of lysine and tryptophan, two amino acids that are known to play a key role in human and animal development. In the field, Obatanpa was indistinguishable from other recently released MVs, but its higher lysine and tryptophan content made it the focus of a number of nutritional promotion campaigns. It also was extensively promoted for use in feeding poultry and pigs. The final MVs developed under the project were three QPM hybrids (Mamaba, Dadaba, and Cidaba) released in 1997; all three were medium-duration materials with moderate levels of resistance to maize streak virus.

Fertilizer management

In spite of numerous government-sponsored projects designed to promote the use of fertilizer on food crops, few farmers in Ghana applied fertilizer to their maize fields when the GGDP was launched in 1979. The low level of fertilizer use on maize was quickly identified as a priority problem for research, because experimental evidence showed clearly that poor soil fertility was severely constraining yields in many areas.

Although the relative unpopularity of fertilizer among Ghanaian maize farmers could be attributed to a number of causes, a big part of the problem was that there were no consolidated, widely accessible recommendations for applying fertilizer to maize. In an attempt to rectify this problem, GGDP researchers organized an on-farm testing program aimed at developing fertilizer recommendations for maize. The challenge was to formulate recommendations that would be flexible enough to accommodate the wide range of soil fertility conditions found in farmers' fields, yet at the same time be simple enough to be incorporated into existing extension programs.

In contrast to the GGDP plant breeding effort, GGDP research on crop management practices (fertilizer use and planting practices) did not involve direct introduction of CIMMYT-generated technologies. Unlike improved germplasm, which can be developed at CIMMYT headquarters in Mexico and distributed to many different countries around the world, crop management recommendations are by nature location-specific. Thus, they must be developed on a country-by-country basis, taking into account local agro-climatic conditions, planting materials, crop management practices, and prices.

CIMMYT's contribution to the GGDP crop management research effort took two forms: (1) training of researchers and (2) provision of technical assistance. During the life of the project, more than one thousand CRI researchers and local collaborators received training in the design and management of crop management trials. In addition, CIMMYT scientists were based in Ghana throughout the project's duration and actively participated in planning and implementing the GGDP crop management research program.

Following several years of extensive on-farm trials, GGDP researchers developed a set of fertilizer recommendations that distinguished between agro-ecological zones and took into account field cropping histories. Recommended fertilizer application rates varied widely, ranging from no fertilizer application (in the case of forest-zone fields that had been fallow for five or more years) to application of compound NPK fertilizer at a rate of 90-40-40 (in the case of transition- and savannah-zone fields that had been continuously cropped for two or more years). The recommendations were periodically adjusted to take into account changes in the relative prices of fertilizer and maize grain.

Plant configuration

In most parts of Ghana, maize traditionally has been planted in a random pattern, with a relatively large number of seeds (3–5) placed in holes at least one meter apart. Although this strategy is appropriate for tall-statured local varieties grown under low levels of soil fertility, GGDP researchers determined that the plant configurations produced using traditional random planting practices are less than optimal for short-statured MVs, especially when these are grown with chemical fertilizer. Experiments conducted at CRI during the early stages of the project established that the Ghanaian MVs tolerated a significantly higher planting density than the tall-statured local varieties commonly grown by farmers.

Like the fertilizer recommendations, the GGDP plant configuration recommendations were developed in Ghana based on extensive on-station and on-farm trials. Several years of on-farm experiments were conducted to explore the relationship between plant configuration and grain yield. The results of these experiments were then used to formulate crop management recommendations that could be communicated easily to farmers. The recommendations emphasized planting in rows to help farmers calibrate plant population densities and achieve plant spatial arrangements that facilitate subsequent crop management operations, such as weeding and fertilizer application. In addition to stressing the importance of row planting, the recommendations also focused on reducing the distance between holes and on reducing the number of seeds planted per hole. Recommended distances between rows and between holes were expressed in terms of the length of the cutlass that most farmers use for planting, and alternative methods of row planting (using sighting poles or ropes) were made part of the extension program.

Maize technology transfer

In addition to its research component, the GGDP also supported a number of activities designed to improve the transfer of improved technologies generated through the project to farmers. The strong emphasis on technology transfer issues was reflected in three types of activities:
(1) building linkages between research and extension,
(2) providing support to extension activities, and
(3) strengthening seed production capacity.

Research-extension linkages

From the outset, great care was taken to ensure that GGDP research activities were closely linked to extension activities. An important contribution of the project was the development of an extensive network of adaptive experimentation that served both research and extension functions. Centrally planned and administered on-farm experiments were conducted jointly by researchers working with extension agents in every agro-ecological zone. Between 100 and 150 replicated on-farm experiments were planted each year, the results of which were used to plan further experiments and to move promising technologies into demonstration trials. The extension agents who participated in the on-farm experimentation program often took responsibility for the demonstrations, providing important continuity and experience. Links between researchers and extension agents were further strengthened through annual National Maize and Cowpea Workshops, which brought researchers, extension agents, policymakers, and farmers into a forum where ideas and information could be shared.

Extension activities

In addition to involving extension agents directly in the research program, the GGDP sponsored a number of extension activities, some of which were quite innovative at the time. For example, regular planning meetings were held from the outset of the project to discuss strategies for transferring GGDP-generated technologies to farmers' fields. These planning meetings were attended by researchers, extension specialists, and, notably, by local farmers; in this respect, the meetings provided a vehicle for testing novel participatory research and extension methods. The GGDP also developed its own Training, Communications, and Publications Unit (TCPU), which produced an extensive array of printed extension materials (e.g., flip charts, handbooks, fact sheets). These materials were used to train thousands of extension agents, researchers, seed growers, farmers, and students.

A particularly noteworthy feature of the GGDP was its efforts to make extension activities more gender-neutral, including the recruitment and training of female extension agents, the hiring of rural sociologists to address gender issues in technology development and technology transfer, and the provision of gender analysis training for agricultural policymakers. The TCPU also made a strong effort to develop more gender-sensitive materials; gender analysis modules were incorporated into most training activities.

These innovative approaches to the problem of technology transfer were supported by substantial investment in more traditional extension activities. The effectiveness of the GGDP extension division was increased by inviting the participation of GLDP and MOFA extension agents. Beginning in 1987, links were also established with the Sasakawa-Global 2000 Project in an effort to develop a combined demonstration-promotion strategy that would carry the GGDP recommendations to many more farmers.

Seed production

At the time the GGDP was launched, responsibility for commercial maize seed production in Ghana lay in the hands of the Ghana Seed Company, a government organization. Handicapped by recurring shortages of funds and a lack of trained personnel, the Ghana Seed Company chronically failed to perform up to expectations. Consequently, improved maize seed often remained unavailable to many farmers.

Concerned by the limited capacity of the Ghana Seed Company to satisfy demand for seed, the GGDP management, in consultation with the research staff, decided to concentrate on developing open-pollinated varieties (OPVs) rather than hybrids, on the theory that OPVs are more appropriate for farmers who may not always be able to obtain fresh commercial seed. One advantage of OPVs compared to hybrids is that farmers who grow OPVs can save seed from their own harvest for re-planting the following season; in contrast, farmers who grow hybrids must purchase fresh seed every cropping season, making them dependent on a functional seed industry.

Although the rationale for developing OPVs was undoubtedly sound, over time it became evident that the uptake of MVs was being discouraged by the unavailability of high-quality seed. By the late 1980s, it had become clear that if the GGDP was to have any success in promoting the adoption of maize MVs, action would have to be taken to strengthen local seed production capacity. During its later phases, the project responded with a number of initiatives to strengthen the maize seed industry. The GGDP arranged and offered contract seed grower training, helped develop the MOFA seed regulatory group, and supported foundation seed production activities within the GLDB.

Methodology and Data Collection Activities

To assess the success of the GGDP, it is necessary to know the extent to which the three GGDP-generated maize technologies (MVs, fertilizer, plant configuration) have disseminated throughout Ghana. Data on the adoption and impacts of the GGDP maize technologies were collected in early 1998 through a national survey of maize farmers.

Sampling procedure

Unlike earlier studies that examined maize technology adoption patterns in selected regions of Ghana (Tripp et al. 1987; GGDP 1991), this study's goal was to develop an accurate picture of adoption patterns throughout the entire country. Thus it was extremely important to draw a sample that would accurately represent the national population of maize farmers. Considerable effort, therefore, was invested in planning and implementing the sampling procedure.

After several alternative approaches had been considered and rejected as unsuitable, the decision was made to use a three-stage, clustered, randomized sampling procedure. The three stages involved selection of (1) districts, (2) enumeration areas, and (3) maize farmers (Table 3). Given the resources available for the survey, it was considered feasible to interview approximately 400–450 maize farmers. Partly for statistical reasons, and partly out of logistical considerations, the decision was taken to interview seven maize farmers in each of 60 enumeration areas (EAs), giving a total of 420 maize farmers. These farmers were selected as follows.

Stage 1: Twenty (20) districts were randomly selected from all of the districts found in the country, with each district's probability of selection made proportional to the area planted to maize in that district. This self-weighting sampling procedure resulted in the selection

Table 3. Sampling procedure, Ghana maize technology adoption survey

Sampling stage	Sampling unit	Selection criterion	Units at this level	Cumulative units
1	District	Randomly selected, with probability of selection proportional to the maize area found in district	20	20
2	Enumeration area	Randomly selected from among enumeration areas classified as semi-urban or rural	3	60
3	Farmer	Randomly selected from among all maize farmers in the enumeration area	7	420

Source: Compiled by the authors.

Table 4. Location of survey districts

Region	District	Ecological zone
Upper West	Wa	Guinea savannah
Northern	Salaga	Guinea savannah
	Damongo	Guinea savannah
	Walewale	Guinea savannah
Brong Ahafo	Nkoranza	Transition
Ashanti	Sekyere West	Transition
	Adansi East	Forest
	Amansie West	Forest
Western	Dorma-Ahenkro	Forest
	Sefwi Wiaso	Forest
	Mpohor-Wassa	Forest
Central	Gomua-Assin-Ajumako	Coastal savannah
	Agona	Coastal savannah
Eastern	Suhum Kraboa	Forest
	Yilo Krobo	Transition
	West Akim	Forest
	Fanteakwa	Forest
Greater Accra	Tema	Coastal savannah
Volta	Adidome	Coastal savannah
	Jasikan	Forest

Source: Compiled by the authors.

of districts located in nine of the country's ten regions (Table 4, Figure 4). No districts were selected from the Upper East Region, which is not surprising considering that the area planted to maize in this region is extremely small.[3]

Stage 2: Within each of the 20 selected districts, three enumeration areas (EAs) were selected at random from among all EAs classified as *rural* or *semi-urban*, giving a total of 60 different enumeration areas. Following the initial drawing, several EAs were rejected because they were found to contain few or no maize farmers; these EAs were replaced with other randomly selected EAs. The EAs that formed the sampling frame were the same as those used by the Statistical Services Department (SS) and the Project Planning, Monitoring, and Evaluation Division (PPMED) of the Ministry of Agriculture for their statistical reporting

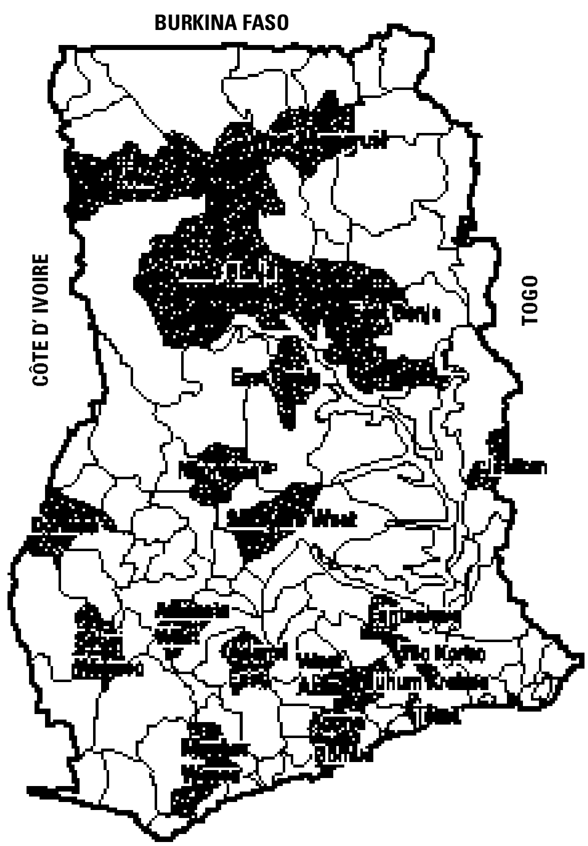

Figure 4. Distribution of survey districts.

3 At the time the survey was conducted, Ghana's ten regions were subdivided into 109 administrative districts, of which 82 contained 3,000 ha or more planted to maize. The sample thus included 25% of all districts in the country in which significant amounts of maize were cultivated.

activities. The advantage of using EAs as sampling units is that each EA is approximately equal in size. This helps ensure that all farmers have an equal probability of being selected, which is not the case when sampling units consist of towns or villages of unequal size.

Stage 3: Initial visits were made to the 60 selected EAs, and a complete list of maize farmers was compiled for each EA. These farmer lists were compiled based on information provided by local authorities. Seven names were then randomly selected in each EA from the list of maize farmers.

Because of the self-weighting nature of the random sampling procedure (and assuming the farmer lists compiled for each EA were complete), the sample can be considered to be highly representative of the overall population of maize farmers. Hence, the adoption experience of the sample respondents can be extrapolated directly to the national level.

Data collection activities

Data collection activities commenced in January 1998 when survey participants convened at CRI in Kumasi to attend a three-day training course. The participants were organized into five teams; each team consisted of one supervisor and two enumerators. All of the supervisors were CRI research officers with graduate degrees in agricultural economics or agronomy. Most of the enumerators were CRI staff with prior experience in survey work, although several enumerators were recruited for the survey from outside CRI. The training course included a discussion of the objectives of the survey, a detailed question-by-question review of the survey instrument, instructional sessions on interviewing techniques, role playing exercises, and practice interviews with local farmers.

The survey was carried out from January to March 1998. Interviews were conducted with the help of a formal questionnaire; in addition, illustrated cards were used to help elicit farmers' preferences for different varietal characteristics. Most of the interviews were conducted jointly by two enumerators, with one enumerator interviewing the respondent and the other recording the responses. Depending on the complexity of the respondent's farming activities and/or the respondent's familiarity with the GGDP technologies, the time required to complete each interview varied from 45 minutes to 2 hours.

The enumeration teams spent an average of 2–3 days at each site before completing the seven scheduled interviews. Many respondents could not be located on the first visit, so it was often necessary to return several times to the same house before an interview could be conducted. When it was not possible to locate a farmer even after repeated visits, replacements were selected at random from the farmer list.

After each interview was concluded, the completed questionnaire was reviewed by the supervisor for accuracy and completeness. The questionnaires were then delivered to the data processing staff at CRI in Kumasi for entry and verification.

Characteristics of the survey respondents

Basic demographic information about the survey respondents appears in Table 5. The data have been disaggregated by agro-ecological zones to highlight geographical differences in demographic factors that might influence farmers' willingness or ability to adopt improved maize technologies.

Noteworthy among the data appearing in Table 5 is that exactly one-quarter (25%) of the survey respondents were women. This aggregate figure, calculated across the entire sample, conceals considerable variability between agro-ecological zones, with the proportion of women respondents ranging from a low of 2% in the Guinea savannah zone to a high of 35% in the transition zone. Casual observation suggests that roughly the same number of women as men work in maize fields in Ghana, so at first glance the number of women farmers in the sample seems rather low. However, the relatively low proportion of women farmers probably stems from the

Table 5. Demographic characteristics of survey respondents

Zone	Farmers interviewed (n)	Gender: Men (%)	Gender: Women (%)	Average age (years)	Average schooling (years)	Marital status: Married (%)	Marital status: Other [a] (%)	Residence status: Native (%)	Residence status: Settler (%)	Average household size
Guinea savannah	84	98	2	41	2.3	81	19	74	26	15.4
Transition	63	65	35	45	6.5	73	27	90	10	9.8
Forest	189	70	30	44	6.7	84	16	55	45	8.0
Coastal savannah	84	71	29	47	6.3	83	17	73	27	9.7
All zones	420	75	25	44	5.7	82	18	68	32	10.1

Source: 1998 CRI/CIMMYT survey.
a Includes single, widowed, and divorced.

fact that in parts of Ghana, women do not enjoy independent access to land and other resources equal to that of men, so many women end up working in the fields of their husbands or male relatives.[4] In drawing up the lists of maize farmers used to select the sample, local authorities would have included the names of men and women known to manage their own maize fields. The lists, therefore, would not have included farmers—men and especially women—whose participation in maize production activities was restricted to selling their labor services. The proportion of women farmers in the sample is quite consistent with previous estimates, which indicated that approximately 30% of all rural households in Ghana are headed by women (Bumb et al. 1994; Doss, personal communication).[5]

Information on the survey respondents' access to infrastructure, education, and health services appears in Table 6. This information is potentially important, because infrastructure-related factors affect flows of goods, services, and information and are therefore frequently linked to the uptake of agricultural innovations. The data in Table 6 support the view that farmers in the Guinea savannah zone tend to live in remote locations without electricity and that they have only limited access to health services. Accessibility can also be a problem for forest zone farmers because of the difficulty of building and maintaining good roads there. Infrastructure, education, and health services are generally somewhat better in the transition zone, but they are best in the densely populated coastal savannah zone.

Table 6. Access to infrastructure by survey households

	Percent of survey respondents who live in a village with:						
Zone	Electricity	Pipeborne water	Tarred road	Easy transportation	Market	Health post	Elementary school
Guinea savannah	0%	50%	17%	33%	46%	8%	83%
Transition	22%	44%	44%	56%	22%	44%	100%
Forest	19%	41%	15%	41%	33%	30%	100%
Coastal savannah	50%	67%	58%	92%	46%	33%	100%
All zones	22%	48%	28%	52%	34%	28%	97%

Source: 1998 CRI/CIMMYT survey.

4 Restrictions on women's access to land are particularly common in the north of Ghana, where resource ownership and inheritance is patrilinearly determined. However, restrictions also are found in the south, especially in areas with high numbers of northern migrants.

5 Randomly selected samples of maize farmers drawn for past surveys have also included about 30% women respondents (see Tripp et al. 1987; GGDP 1991).

Table 7 presents selected data showing the importance to the survey households of agriculture in general and maize farming in particular. In all four zones, the majority of respondents indicated that agriculture is the main source of household income; the proportion was lowest in the coastal savannah zone, reflecting the greater availability of off-farm employment there. Consistent with their dependence on agriculture, survey respondents reported having access to significant quantities of land. The average land area available to each household (through ownership, sharecropping, rental, or other means) ranged from a high of 11.2 acres in the sparsely populated Guinea savannah to a low of 5.1 acres in the densely populated coastal savannah. Considering that average household size is much larger in the Guinea savannah, land availability per capita is quite similar to that found elsewhere in Ghana.

Finally, the data in Table 7 demonstrates that maize is an important cash crop for the majority of Ghana's maize farmers. Nearly one-half (49.0%) of the survey respondents identified maize as their most important source of agricultural income, and almost one-third more (32.9%) identified maize as the second most important source.

Adoption of Improved Maize Technologies

How widely have the GGDP-generated maize technologies been adopted by Ghanaian farmers? Have all three technologies been adopted at the same rate and to the same extent? What factors are associated with successful adoption? Are there discernible differences between adopters and non-adopters? These and other questions related to the adoption experience are addressed in the following sections of the report.

Before discussing the survey results, it is worth noting that the rate of adoption of any agricultural innovation can be measured in two ways: (1) in terms of the number of farmers who adopt the innovation, or (2) in terms of the total area on which the innovation is adopted. These two measures will yield equivalent results when farm sizes are roughly the same and/or the rate of adoption is constant across farm sizes, but often this is not the case. Frequently farm sizes vary and adoption rates differ with farm size, meaning that a particular innovation is taken up with greater frequency by large-scale farmers than by small-scale farmers, or vice versa. Under these circumstances, the proportion of farmers adopting the innovation can differ significantly from the proportion of the total cultivated area that is affected by the innovation.

Which of the two measures is better? The correct answer is that neither measure is inherently better; the choice depends on the issue being addressed. If the goal is to determine how many people have been affected by an innovation, it makes sense to ask what proportion of farmers have adopted the innovation. But if the goal is to calculate the economic benefits attributable to adoption, it makes sense to ask how much area is affected. Given the multiple objectives of our study, we made use of both measures, as appropriate.

Table 7. Agricultural activities of survey households

	Main income source (%)		Land resources (acres)					Households in which maize is (%):	
Zone	Agriculture	Non-agriculture	Owned	Share-cropped	Rented	Other	Total	1st income source	2nd income source
Guinea savannah	96%	4%	9.5	0.4	0.1	1.2	11.2	45.2%	21.4%
Transition	97%	3%	4.1	1.9	0.4	0.2	6.6	66.7%	19.0%
Forest	94%	6%	3.7	1.2	0.6	0.4	5.9	49.2%	34.9%
Coastal savannah	83%	17%	2.8	0.5	1.1	0.7	5.1	39.3%	50.0%
All zones	93%	7%	4.7	1.0	0.6	0.6	6.9	49.0%	32.9%

Source: 1998 CRI/CIMMYT survey.

Table 8 presents data on the percentage of farmers that used one or more of the GGDP-generated maize technologies on at least part of their farm during the 1997 season. Over one-half of the sample farmers (54%) planted MVs, and a similar proportion (53%) planted at least part of their maize crop in rows. The rate of fertilizer use on maize was much lower, however, as less than one-quarter of the sample farmers (21%) applied fertilizer to their maize fields. Adoption rates varied considerably across agro-ecological zones, with adoption of all three technologies lowest in the forest zone.

Table 9 shows interactions among the three GGDP-generated technologies, again expressed as the percentage of adopting farmers. More than one-third of the sample farmers (37.5%) failed to use any of the three recommended technologies; these farmers grew only local varieties, planted their entire maize crop in a random pattern, and applied no fertilizer to their maize fields. The remaining farmers all adopted one, two, or all three of the recommended technologies. The most common combination involved adoption of MVs and row planting, without application of fertilizer; nearly one-quarter of the sample farmers (22.7%) opted for this strategy. About one in eight sample farmers (12.3%) practiced all three of the recommended technologies.

The data in Tables 8 and 9 provide clear evidence that the GGDP-generated maize technologies have diffused widely. In 1997, two-thirds of Ghana's maize farmers used at least one of the three improved technologies—an impressive number, especially considering that maize in Ghana is grown mostly by small-scale farmers living in isolated communities. These results show that the GGDP made very good progress in achieving its objectives of developing and disseminating improved maize technologies.

Although these findings are encouraging, they do not provide grounds for complacency. The data presented in Tables 8 and 9 raise at least two questions. First, why hasn't the rate of adoption of the GGDP-generated maize technologies been even higher? And second, what explains the observed differences in adoption between technologies and across agro-ecological zones? To answer these questions, it is necessary to examine more closely the characteristics of the technologies, their diffusion patterns, and the factors associated with successful adoption.

Modern varieties (MVs)

Characteristics of MV technology

Of all the inputs used in agriculture, none has the ability to affect productivity more than improved seed. If farmers can obtain seed of MVs that perform well under local conditions, the efficiency with which other inputs are converted into economically valuable outputs increases and productivity rises. For this reason, adoption of MVs often serves as the catalyst for adoption of improved crop management practices—which is precisely why the GGDP placed such a heavy emphasis on plant breeding research.

Table 8. Adoption of GGDP-generated maize technologies, 1997

	Percent of farmers that on at least part of their farm used:		
	Modern variety	Fertilizer	Row planting [a]
Guinea savannah	66%	36%	73%
Transition	68%	29%	59%
Forest	38%	9%	39%
Coastal savannah	69%	29%	65%
All zones	54%	21%	53%

Source: 1998 CRI/CIMMYT survey.
a n = 392 (excludes ridge planting).

Table 9. Interactions among GGDP-generated maize technologies, 1997

	Farmers that on their primary maize field, jointly (%):			
	Planted improved variety		Planted local variety	
	Applied fertilizer	Applied no fertilizer	Applied fertilizer	Applied no fertilizer
Row planted	12.3%	22.7%	4.5%	11.1%
Random planted	1.0%	10.3%	0.5%	37.5%

Source: 1998 CRI/CIMMYT survey.
Note: n = 392 (excludes ridge planting).

One important feature of MVs is that they are an "embodied technology," which makes them relatively easy for farmers to adopt. Improved seed can contribute to productivity independent of other inputs, so farmers generally do not have to alter their current practices to realize benefits from adopting the technology. Of course, the benefits of MVs can be greatly enhanced if farmers also adopt complementary management practices that allow their higher yield potential to be fully realized (e.g., application of chemical fertilizer, adjustment of plant population densities), but in most cases, even if the complementary management practices are not adopted, simple replacement of seed will prove remunerative.

MV diffusion patterns

Table 10 shows the areas planted to specific maize varieties during the 1997 major and minor cropping seasons. During 1997, over one-half of Ghana's maize area (53.8%) was planted to MVs. Although few reliable data exist that would allow comparisons with neighboring countries, this rate of MV adoption is high compared to other countries in which maize is grown mostly by subsistence-oriented farmers. For example, throughout most of southern Mexico and Central America, MV use currently averages around 20% (Morris and López-Pereira 1998).

Table 10. Area planted to specific maize varieties, 1997

Variety (year of release)	Major season (acres)	Minor season (acres)	Total (acres)	Total (%)
Local varieties	617.3	127.5	744.8	46.1%
Modern varieties:				
La Posta (pre-1980)	49.0	1.0	50.0	3.1%
Aburotia (1984)	44.0	13.5	57.5	3.6%
Dobidi (1984)	84.0	18.7	102.7	6.4%
Golden Crystal (1984)	2.0	2.0	4.0	0.2%
Okomasa (1988)	41.5	6.0	47.5	2.9%
Abeleehi (1990)	32.5	19.5	52.0	3.2%
Dorke (1990)	0.5	0.0	0.5	0.0%
Obatanpa (1992)	200.3	56.3	256.6	15.9%
"Agric" (unknown)	257.5	41.5	299.0	18.5%
All MVs	711.1	158.5	869.7	53.8 %
Total	**1,328.6**	**286.0**	**1614.5**	**100.0%**

Source: 1998 CRI/CIMMYT survey.

Interestingly, the proportion of Ghana's maize area planted to MVs is virtually identical to the proportion of Ghana's maize farmers that have adopted MVs.

The adoption of maize MVs has varied between agro-ecological zones (Table 11), with considerably lower adoption in the forest zone than elsewhere.

Efforts to track the popularity of individual MVs were confounded by the fact that slightly more than one-third of the area planted to MVs in 1997 was planted to varieties identified only as "Agric." Agric is a generic name used by many farmers in Ghana to identify an improved variety that originally came from the Ministry of Agriculture. This phenomenon is quite surprising, because usually in countries where maize is a leading food crop grown by the majority of rural households, a detailed and exact nomenclature exists for precisely identifying local and improved varieties.[6]

In 1997, GGDP-developed MVs accounted for virtually the entire area planted to identifiable MVs. The only MV grown in 1997 that pre-dated the inception of the project was La Posta, a CIMMYT variety that was directly introduced from Mexico in the mid-1970s.

Among GGDP-generated MVs, by far the most popular was Obatanpa, which in 1997 accounted for at least 16% of Ghana's total maize area (or at least 30% of the area planted to MVs). It is important to remember that these

Table 11. Adoption of maize MVs, by agro-ecological zone, 1997

	Percent of maize area planted to MVs		
	Major season	Minor season	Total
Guinea savannah	59.7%	NA	59.7%
Transition	70.4%	64.9%	68.3%
Forest	29.5%	46.6%	33.1%
Coastal savannah	76.3%	62.7%	74.2%
All zones	53.3%	55.9%	53.7%

Source: 1998 CRI/CIMMYT survey.

6 Significant exceptions include Malawi, where local maize varieties are referred to collectively as *chimanga cha makolo*, or "maize of the ancestors" (Smale 1991).

figures are conservative, because in all likelihood some of the area planted to "Agric" was actually planted to Obatanpa.

A significant proportion of the area planted in 1997 to identifiable MVs was planted to older MVs released ten or more years ago (e.g., Dobidi, Aburotia).

Factors associated with MV adoption

Descriptive information about technology diffusion patterns (such as the information on the spread of MVs presented in the previous section) is important because it allows researchers and extensionists to assess the success of their efforts, and because it provides the vital quantitative information needed for formal economic rate-of-returns analysis. Descriptive information in and of itself, however, does not always provide insight into the nature of the technology adoption process. For that, it is necessary to dig a bit deeper.

What do the survey results indicate about the MV adoption process? Table 12 presents data on factors that are often associated with the adoption of MVs. The data are presented in the form of a series of quantitative indicators that were calculated for two sub-groups within the survey sample: MV adopters and MV non-adopters. Standard t-tests were performed to determine the level of statistical significance, if any, between observed differences in the indicators between the two groups.

Table 12. Factors associated with adoption of MVs

Factor	Plant MVs	Do not plant MVs	Significance level of difference
Farmer characteristics:			
Age (years)	45.1	43.3	NS*
Years of schooling	6.3	5.0	< .01*
Resource ownership:			
Total land owned (acres)	5.8	3.4	< .001*
Major season maize area (acres)	3.5	2.6	< .001*
Commercial orientation:			
Maize sales (bags)	7.6	6.8	NS*
Access to technology:			
Extension contacts (no.)	3.3	1.1	< .001*

Source: 1998 CRI/CIMMYT survey.
* = t-test.

Farmer characteristics: The mean age of MV adopters does not differ significantly from that of non-adopters. MV adopters are slightly better educated than non-adopters, however, having 1.3 more years of schooling on average. The latter finding may indicate a link between farmers' level of education and their tendency to try new technologies.

Resource ownership: MV adopters own significantly more land than non-adopters and plant a significantly greater area to maize, suggesting that MV adoption may be positively correlated with wealth. This finding is not surprising, because farmers who have a greater stake in agriculture in general, and in maize farming in particular, have greater incentives to learn about and adopt MVs.

At first glance, the positive correlation between MV adoption and farm size seems inconsistent with the findings reported earlier that the proportion of farmers who have adopted MVs is virtually identical to the proportion of total maize area that is planted to MVs (suggesting that MVs have been adopted at an equal rate across all farm sizes). It is important to recall, however, that here the "adopters" category includes farmers who have adopted MVs on only part of their farms; the "adopters" figure thus fails to reflect that many farmers—particularly small-scale farmers—continue to grow local varieties in addition to MVs. The finding that the proportion of farmers who have adopted MVs is virtually identical to the proportion of total maize area that is planted to MVs masks the fact that MV adoption (measured in terms of area, rather than in percentage of farmers) has been slightly higher on larger farms.

Commercial orientation: MV adopters sell slightly more maize than non-adopters, but the difference is not statistically significant. This finding fails to support the hypothesis that market-oriented farmers are more likely to invest in MVs and other productivity-enhancing technologies.

Access to technology: MV adopters had three times more contacts with extension officers during the 12-month period immediately prior to the survey than non-adopters. This finding is important, because it is through contacts with extension officers that many farmers learned about MVs and acquired improved seed. During the life of the GGDP, the government mounted numerous campaigns to increase maize production. The campaigns varied in philosophy and approach, but they typically included the distribution of MV seed samples and fertilizer by extension agents, the planting of numerous demonstration plots, and the organization of field days designed to educate farmers about improved maize production practices. Based on the survey results, there can be little doubt that these efforts had a noticeable impact and that the extension service has played a critical role in promoting the adoption of MVs.

The finding that extension officers have played an important role in distributing MV seed to farmers in Ghana is strongly supported by data on sources of MV seed (Table 13).

Almost half (46.7%) of the survey respondents who grew MVs in 1997 reported that the seed was originally acquired from an extension officer. In earlier years, this proportion was even higher. Although inputs dealers seem to be playing an increasingly important role in distributing improved seed, the extension service remains, by far, the single most important source of seed for maize MVs.

Table 13. Sources of improved maize seed (% of farmers who plant MVs)

Seed source	MV seed acquired in 1997	MV seed acquired previously
Extension agent	46.7%	48.3%
Another farmer	19.2%	30.0%
Input dealer	26.3%	5.8%
Grain market	5.4%	11.7%
Other/unknown	2.4%	4.2%
Total	100.0%	100.0%

Source: 1998 CRI/CIMMYT survey.

Fertilizer

Characteristics of fertilizer technology

Compared to MVs, chemical fertilizer is an extremely complex technology. Chemical fertilizer comes in many different formulations, some of which are not well-suited to addressing a given soil nutrient deficiency. In addition, chemical fertilizer can be applied at different rates, using different methods, and at different points in the cropping cycle. Furthermore, soil nutrient deficiencies tend to be location specific, so the optimal fertilizer treatment often varies between neighboring farms, between different fields located within the same farm, and even between plots within the same field. Finally, fertilizer tends to be costly, and the economically optimal application rate varies with changes in the relative prices of fertilizer and grain. Efficient management of chemical fertilizer requires a sophisticated understanding of the complex relationship between soil nutrient status, plant growth habits, and economics. Fertilizer, therefore, is often characterized as a "disembodied technology," indicating that considerable knowledge is required on the part of the farmer for the potential benefits to be fully realized.

In recognition of the complexity of fertilizer management, considerable effort was devoted to making the GGDP-generated fertilizer recommendations readily accessible to farmers. Recommendations were expressed in terms of the number of bags of fertilizer to be applied per acre (the measurement units most commonly used by farmers) and in terms of the number of maize plants to be treated with the amount of fertilizer that fits in a milk tin (the most common application method). In addition, suggested application schedules balanced the need for timely application with farmer concerns about the risks associated with early fertilizer application.

By simplifying the recommendations, the GGDP made the management of fertilizer-based technologies more accessible to farmers. But the GGDP could not, in and of itself, remove another major potential obstacle to fertilizer adoption: the cost. Chemical fertilizer is expensive in Ghana, and for many rural households, purchasing even the modest quantities required to treat maize fields at the GGDP-recommended rates requires a significant out-of-pocket investment. At various times in the past, the government of Ghana introduced production credit programs to facilitate purchases of fertilizer and other inputs for maize and other food crops, but these programs generally foundered because of poor loan repayment rates. To the extent that investment in fertilizer exceeds the resources that are available to most rural households, one would expect fertilizer use on maize to be discouraged in the absence of an effective credit system.

Fertilizer diffusion patterns

Table 14 shows the use of fertilizer on maize during the 1997 major and minor cropping seasons. Combining the data for both seasons, slightly more than one-quarter of Ghana's maize area (25.9%) received some form of chemical fertilizer. As with MVs, the rate of adoption of fertilizer varied between agro-ecological zones, being significantly lower in the forest zone than elsewhere.

In interpreting these results, it is important to note an important difference between the data reported earlier on MV adoption rates and these data on the incidence of fertilizer use. In the case of MVs, the causal link between research recommendations and farmer behavior is easily established. For example, if a farmer is observed growing Obatanpa, it must be because of the GGDP, because Obatanpa was developed through the GGDP and could not have reached the farmer from any other source. But in the case of crop management practices (including fertilizer use), the causal link between researcher-generated recommendations and farmer behavior is much more difficult to establish. Just because a farmer uses chemical fertilizer, it does not necessarily mean that he or she learned about chemical fertilizer through the GGDP. Farmers often experiment on their own, and it is conceivable that the farmer in question independently decided on a practice that closely resembles the GGDP recommendation.

Table 14. Adoption of fertilizer, by agro-ecological zone, 1997

	Percent of maize area that was fertilized:		
	Major season	Minor season	Total
Guinea savannah	32.2%	NA	32.2%
Transition	37.0%	49.5%	41.7%
Forest	8.7%	10.4%	9.1%
Coastal savannah	41.6%	18.2%	38.0%
All zones	26.0%	25.2%	25.9%

Source: 1998 CRI/CIMMYT survey.

Establishing a causal link between researcher-generated recommendations and farmer practices is further complicated by the fact that it is usually very costly to assess the degree to which farmers' fertilizer application practices precisely reflect the official recommendations. The GGDP fertilizer recommendations span a wide range of fertilizer types, application rates, and application schedules. They vary by agro-ecological zone and also take into account the cropping history of the field to be fertilized. This means that a lot of detailed information must be collected to establish whether a given farmer is precisely following the official recommendation.

To simplify matters, we assumed that all observed use of chemical fertilizer on maize in Ghana is at least indirectly attributable to the GGDP. This assumption, as noted, almost certainly overstates the impact of the GGDP in promoting efficient fertilizer use.[7]

Factors associated with fertilizer adoption

Table 15 presents data on factors that are often associated with the use of chemical fertilizer on maize. As with the earlier data on factors associated with MV adoption, these data are presented in the form of a series of quantitative indicators calculated for two sub-groups within the survey sample: fertilizer adopters and fertilizer non-adopters. T-tests or chi-square tests were performed to determine the level of statistical significance, if any, between observed differences in the indicators of the two groups.

Farmer characteristics: The mean age of fertilizer adopters does not differ significantly from that of non-adopters. The level of education (measured in mean number of years of formal schooling) does not differ significantly between the two groups.

7 On the other hand, estimating the adoption of the GGDP fertilizer recommendations on the basis of observed fertilizer use may understate the impact of the GGDP in promoting efficient fertilizer use, because the GGDP recommendation for recently cleared forest soils is not to apply any fertilizer. For this reason, at least some farmers who do not apply fertilizer to maize should not be considered "non-adopters."

Resource ownership: Fertilizer adopters own significantly more land than non-adopters and plant a significantly greater area to maize, suggesting that fertilizer use may be positively correlated with wealth. This is not surprising, since farmers who have a greater stake in agriculture in general, and in maize farming in particular, have greater incentives to learn about and apply fertilizer.

Land tenure: Fertilizer use is significantly correlated with land tenancy arrangements. Fertilizer use is highest on owned land (23.3%), next highest on rented land (9.3%), and lowest on sharecropped land (4.3%). These results lend themselves to at least two interpretations. Most obviously, they suggest that farmers are more likely to invest in fertilizer if they believe they will be able to capture the benefits generated by the investment—in this instance, yield increases resulting from enhanced soil fertility, including yield increases realized in future cropping seasons because of residual effects of fertilizer in the soil. This likelihood is greatest in the case of owned land, to which farmers have long-term claims, and lower in the case of rented and sharecropped land. The incentives for applying fertilizer are particularly low with sharecropped land, because production from sharecropped fields must be divided up with the owner. An alternative explanation for the observed association between fertilizer use and land tenancy status is that farmers may rely on rental and/or sharecropping agreements to gain access to land that is especially fertile (Marfo 1997). In this case, the lower incidence of fertilizer use on rented and sharecropped fields would be attributable to the greater fertility of these fields, rather than to tenancy status *per se*.

Table 15. Factors associated with adoption of fertilizer

Factor	Apply fertilizer	Do not apply fertilizer	Significance level of difference
Farmer characteristics:			
Age (years)	42.4	44.7	NS*
Years of schooling	5.7	5.7	NS*
Resource ownership:			
Total land owned (acres)	6.5	4.2	< .001*
Major season maize area (acres)	3.8	2.9	< .01*
Land tenure (% farmers):			< .01**
Owned land	23.3	76.7	
Rented land	9.3	90.7	
Sharecropped land	4.3	95.7	
Cropping intensity:			
Average period cropped (years)	4.1	1.7	< .001*
Cropping history (% farmers):			< .01**
> 5 years fallow	8.5	91.5	
0–5 years fallow	14.2	85.8	
1–5 years cropped	19.7	80.3	
> 5 years cropped	45.1	54.9	
Commercial orientation:			
Maize sales (bags)	8.8	6.9	NS*
Access to technology:			
Extension contacts (no.)	4.0	1.9	< .001*

Source: 1998 CRI/CIMMYT survey.
* t-test.
** chi-square test.

Cropping intensity: Fertilizer use on maize is positively associated with high levels of cropping intensity. Maize fields that receive applications of chemical fertilizer have been continuously cropped for 4.1 years on average, compared to only 1.7 years for fields that do not receive chemical fertilizer. Nearly one-half of fields that have been continuously cropped for more than five years receive chemical fertilizer, compared to less than one-tenth of fields that have been left fallow for more than five years. These results suggest that maize farmers in Ghana understand that fertilizer response increases as soil nutrient levels become depleted through continuous cropping and that they adapt their fertilizer application practices on a field-by-field basis, taking into account the cropping history of each field. Thus, fertilizer management practices appear to be driven by technical considerations.

Commercial orientation: Fertilizer adopters sell slightly more maize than non-adopters, but the difference is not statistically significant. This finding fails to support the hypothesis that commercially oriented farmers are more likely to invest in fertilizer and other productivity-enhancing technologies.

Access to technology: Fertilizer adopters had twice as many contacts with extension officers during the 12 months immediately prior to the survey as non-adopters. The difference is statistically highly significant. This finding suggests that extension officers play a crucial role in educating farmers about the benefits of fertilizer use.

Plant configuration

Characteristics of row planting technology

Even though it is a disembodied technology, row planting is fairly easy to adopt, because farmers who take up row planting do not have to make drastic changes to their traditional management practices. Row planting requires only minimally more resources—a planting rope or sighting poles, and a little additional labor—than traditional random planting. Most maize in Ghana is planted using unremunerated family labor, so farmers who adopt row planting generally do not incur substantial out-of-pocket expenditures (as they do when they adopt fertilizer, for example).

If the costs of adopting row planting are modest, the potential benefits are substantial, especially when the farmer has also adopted MVs. The benefits of row planting are enhanced through its strong complementarity with MVs; when farmers row plant in accordance with the GGDP recommendation, plant population densities increase significantly. Adopted individually, either of the two technologies is capable of boosting productivity, but only when they are adopted jointly do productivity gains become really substantial. For this reason, the diffusion of row planting is usually closely linked to the diffusion of MVs.

Row planting diffusion patterns

Table 16 shows the incidence of row planting in maize during the 1997 major and minor cropping seasons. During 1997, over one-half of Ghana's maize area (55.4%) was planted in rows. As with the other GGDP technologies, the incidence of row planting varied between agro-ecological zones, being lower in the forest zone than elsewhere.

Table 16. Adoption of row planting, by agro-ecological zone, 1997

	Percent of maize area that was row planted:		
	Major season	Minor season	Total
Guinea savannah	67.9%	NA	67.9%
Transition	59.4%	76.0%	65.7%
Forest	43.4%	45.5%	43.8%
Coastal savannah	56.4%	73.1%	58.8%
All zones	54.2%	60.6%	55.4%

Source: 1998 CRI/CIMMYT survey.

To what extent can the observed incidence of row planting of maize be attributed to the efforts of the GGDP to promote this practice? As with fertilizer use, the causal link between researcher-generated recommendations for row planting and farmer practices is to some extent implicit; because farmers are observed to be row planting does not necessarily mean they learned the practice from researchers. It is unlikely, however, that farmers would independently discover the benefits of row planting through experimentation, because these advantages are not obvious, especially when farmers grow local varieties. Given that increased plant population densities are beneficial only with short-statured plants, adoption of MVs and adoption of row planting are strongly complementary, and in reality, the two often occur together. Therefore, it is fairly safe to assume that all observed incidences of row planting of maize can be attributed to the GGDP recommendation.

Factors associated with adoption of row planting

Table 17 presents data on factors that are often associated with row planting of maize. Once again, the data are presented in the form of a series of quantitative indicators that were calculated for two sub-groups within the survey

Table 17. Factors associated with adoption of row planting

Factor	Row plant	Do not row plant	Significance level of difference
Farmer characteristics:			
Age (years)	44.5	44.3	NS*
Years of schooling	6.3	5.3	< .05*
Resource ownership:			
Total land owned (acres)	5.3	3.5	< .001*
Major season maize area (acres)	3.5	2.6	< .001*
Land preparation method (% farmers):			< .001**
Manual	43.9	56.1	
Animal or tractor	81.0	19.0	
Cropping intensity:			
Average period cropped (years)	2.7	1.2	< .001*
Commercial orientation:			
Maize sales (bags)	8.4	6.6	NS*
Access to technology:			
Extension contacts (no.)	3.3	1.2	< .001*

Source: 1998 CRI/CIMMYT survey.
* t-test.
** chi-square test.

sample: farmers who plant in rows and farmers who plant randomly.[8] T-tests or chi-square tests were performed to determine the level of statistical significance, if any, between observed differences in the indicators between the two groups.

Farmer characteristics: The mean age of farmers who plant in rows does not differ significantly from that of farmers who plant randomly. Farmers who plant in rows are significantly better educated, however, having one additional year of schooling on average. The latter finding may indicate a link between farmers' level of education and their ability and/or willingness to try new technologies.

Resource ownership: Farmers who plant in rows own significantly more land than those who plant randomly and plant a significantly greater area to maize. Once again, this finding is consistent with the idea that farmers who have a greater stake in agriculture in general, and in maize farming in particular, have greater incentives to learn about and adopt improved technologies.

Land preparation method: Plant population management strategies are strongly linked to land preparation methods. Of the many farmers who cultivate their fields by hand, well more than half (56.1%) plant their maize in a random pattern. In contrast, of the few farmers who cultivate their fields using animals or tractors, more than four-fifths (81.0%) plant their maize in rows.

Cropping intensity: Row planting of maize is positively associated with cropping intensity. Maize fields that are planted in rows have been continuously cropped for 2.7 years on average, compared to only 1.2 years for fields that are randomly planted. Undoubtedly, the association between continuous cropping and row planting is explained in part by the fact that continuous cropping results in the removal of greater numbers of stumps, making row planting (and mechanized plowing) easier.

Commercial orientation: Farmers who plant in rows sell slightly more maize than farmers who plant randomly, but the difference is not statistically significant. Again, this finding fails to support the hypothesis that commercially oriented farmers are more likely to invest in productivity-enhancing technologies.

Access to technology: Farmers who plant in rows had nearly three times as many contacts with extension officers during the 12-month period immediately prior to the survey as farmers who plant randomly. The difference is statistically highly significant. This finding suggests that extension officers play a crucial role in educating farmers about the benefits of row planting.

Disadoption of GGDP maize technologies

In seeking to understand technology diffusion processes, it is important to remember that adoption decisions vary in their degree of reversibility. Some technologies are quickly and easily abandoned (disadopted) if they do not prove profitable, while other technologies can be abandoned only at considerable expense to the farmer.

Knowing about disadoption rates can be useful for several reasons. Most obviously, technologies that are easily reversible will tend to be seen by farmers as less risky, because if the technology turns out to be unprofitable, it can easily be abandoned. Somewhat less obviously, knowing about disadoption can also provide important information about why a new technology may not be diffusing as rapidly as expected. When determining why farmers may have failed to adopt a new technology, it is important to distinguish between cases in which farmers tried the technology and later abandoned it (which suggests that there is a problem with the technology itself) and cases in which farmers never tried the technology at all (which may simply indicate that the technology transfer mechanism is ineffective). Knowledge of disadoption rates can help researchers distinguish between these two cases.

8 The analysis of plant population management practices was based on 392 farmers who reported planting maize in rows or randomly. The analysis excluded 28 farmers who reported planting maize on ridges. Ridge planting is unique to the Guinea savannah and has important implications for water conservation and soil fertility management.

Table 18. Disadoption of GGDP-generated maize technologies, Ghana

	Modern variety	Fertilizer	Row planting [a]
Farmers using in 1997 on at least part of their farm	227 (54.0%)	88 (21.0%)	208 (53.1%)
Farmers who have ever used on at least part of their farm	250 (60.4%)	128 (31.0%)	239 (57.3%)
Gross difference	23 (6.4%)	40 (9.5%)	31 (4.2%)
Proportion of adopters who subsequently disadopted	9.2%	31.3%	13.0%

Source: 1998 CRI/CIMMYT survey.
a n = 392 (excludes ridge planting).

In this context, it is useful to examine the extent to which the GGDP-generated maize technologies may have been taken up and subsequently abandoned. Table 18 presents data on the disadoption of the three GGDP maize technologies. In absolute terms, disadoption has been relatively uncommon; among the sample farmers, less than one-tenth reported having disadopted MVs, fertilizer, or row planting. However, when the number of disadopters is expressed as a proportion of farmers who have actually tried each technology, the disadoption rates increase and clear differences appear between the three technologies. For MVs and row planting, disadoption remains a relatively minor problem; only 9.2% of sample farmers who had actually tried MVs were no longer growing them in 1997, and only 13.0% of the farmers who had tried row planting were no longer row planting in 1997. In the case of fertilizer, however, the story is different: nearly one-third (31.3%) of the sample farmers who at some point in the past had used fertilizer on maize were no longer applying it to maize in 1997. Because most of the farmers who have given up using fertilizer indicated that they had done so voluntarily (rather than because fertilizer had become unavailable), these findings suggest that at current prices, fertilizer is unprofitable for many maize farmers.

Impacts of Improved Maize Technologies

In assessing the performance of any agricultural research project, it is important to know the extent to which technologies generated by the project have spread throughout the target population and to understand the factors that have influenced the adoption process. For this reason, adoption rates are a valid criterion for measuring the success of the GGDP, whose objectives centered around the development and dissemination of improved technologies. But simply knowing about adoption is not enough, because adoption is only a means to an end. The immediate objectives of the GGDP may have been to develop and disseminate improved technology for maize and grain legumes, but the ultimate goal of the project was to improve the well-being of poor people in Ghana. In that context, it is necessary to look beyond the question of adoption and to focus on the question of impacts.

How has the adoption of GGDP-generated maize technologies affected the well-being of poor people in Ghana? The question is not easily answered, both for conceptual and practical reasons. From a theoretical point of view, *well-being* is a slippery concept that can be measured in many different ways (e.g., in terms of wealth, disposable income, living standards, health, life expectancy, political freedom, social status, economic opportunity, or gender equality). What one person or group considers indispensable to well-being may be quite unimportant to another person or group, so attempts to define well-being are always somewhat subjective. From a practical point of view, even if agreement can be reached on suitable indicators of well-being, these indicators are often difficult and/or expensive to measure empirically. In a world of limited resources, investing more in impacts assessment activities usually means having to invest less in other types of activities, and it is not always obvious that the tradeoff is worthwhile. On the theory that impacts must first be generated before they can be assessed, project planners frequently channel the lion's share of available resources into production-oriented activities, leaving monitoring and evaluation activities to take care of themselves at some unspecified future date. Unfortunately, this often means that the resources needed for impacts assessment work are lacking.

Attempts to assess the impacts of the GGDP encountered both types of problems, i.e., conceptual and practical. To begin with, what sorts of indicators should be used to assess the well-being of poor people in Ghana? Should well-being be measured in terms of per capita income levels? Health indicators? Nutritional status? Employment opportunities? Since there is no "objective" way to come up with indicators of well-being, we somewhat arbitrarily decided to examine four indicators that presumably would be affected by an agricultural research project such as the GGDP: (1) agricultural productivity, (2) farmer incomes, (3) nutritional status, and (4) gender equality.

But having agreed on a set of impacts indicators, we faced a practical problem: What should be the standard of comparison? Unfortunately, when the GGDP was initiated in 1979, no baseline survey was conducted to collect descriptive data about the target population. Without such baseline data, it is difficult to assess the impacts of the project in precise, quantitative terms. Consequently, the evidence on project impacts presented below relies mainly on qualitative assessments made by sample farmers.

Agricultural productivity

Agricultural productivity is a valid indicator of GGDP impacts because of the tremendous importance of agriculture in rural Ghana. Considering the large number of Ghanaians who grow maize, any technology that succeeds in increasing the productivity of resources devoted to maize production will bring about real income gains for the vast majority of the rural population by freeing up resources for use in other activities. To the extent that increases in productivity are translated into lower prices for maize, the income gains will also be passed on to urban dwellers.

How can productivity gains attributable to the GGDP be measured? The purpose of the GGDP was to generate and disseminate improved maize technology, so the obvious place to look for productivity gains is in maize fields. Empirically measuring changes in total factor productivity is difficult, so a simpler measure, partial factor productivity, was used in this study, specifically grain yield per unit land area.

How have average maize yields in Ghana been affected by the GGDP? This relatively straightforward question turns out to be extremely difficult to answer. Ghanaian farmers themselves do not calculate maize yields, and they are rarely able to provide enumerators with the detailed area and production data needed to calculate yields in terms of standard measurement units. Under these circumstances, the only way to obtain accurate yield data is to go out and make crop yield cuts in farmers' fields, which is prohibitively expensive on a large scale.

For this study, we adopted the approach of asking farmers to estimate how many bags of maize they would expect to harvest from their largest maize field using each of the following technology combinations (which are equivalent to experimental "treatments"):

(1) local variety without fertilizer,
(2) local variety with fertilizer,
(3) former MV without fertilizer,
(4) former MV with fertilizer,
(5) current MV without fertilizer,
(6) current MV with fertilizer.

Farmers were asked to make estimates only for technology combinations they had actually used, so our results are based on farmers' direct experience. By making pairwise comparisons between each technology combination, we were able to calculate the percentage yield increase attributed by farmers to each technology or combination of technologies. In addition to focusing on productivity gains achieved under actual farming conditions (as opposed to experimental conditions), this

Table 19. Estimated maize yield increases attributable to adoption of MVs, fertilizer

	Farmers' estimated yield increase (%)	
	Both varieties without fertilizer	Both varieties with fertilizer
Switch from local variety to current MV	88	102
Switch from former MV to current MV	18	32
Addition of fertilizer to current MV	86	
Addition of fertilizer to local variety	81	

Source: 1998 CRI/CIMMYT survey.

approach allowed us to avoid the problem of having to convert non-standard local measurement units for land and production into standard measurement units.

Table 19 (p. 23) shows farmers' estimates of the percentage gains in maize yields attributable to the adoption of MVs and fertilizer. Several aspects of the estimates are noteworthy.

First, switching from a local variety to an MV results in a significant yield increase, even in the absence of fertilizer. This finding is consistent with experimental data showing that well-adapted maize MVs outperform local varieties even under unfavorable production conditions.

Second, when fertilizer is applied (to both varieties), the size of the yield increase achieved by switching from a local variety to an MV is significantly larger. This is not surprising, because most MVs have been bred to respond to favorable production conditions.

Third, newer MVs outperform older MVs. As expected, however, the yield increase achieved by switching from an older MV to a newer MV is not nearly as large as the yield increase associated with the initial switch from a local variety to an MV.

Fourth, the size of the yield increase achieved by switching from an older MV to a newer MV varies depending on whether fertilizer is applied, indicating that newer MVs respond better to fertilizer than older MVs.

Fifth, adoption of fertilizer only (i.e., with no change in variety) significantly increases maize yields. As expected, the yield response is greater in MVs than in local varieties.

These results suggest that the GGDP-generated maize technologies have brought about significant productivity increases on farms where they have been adopted. Since the data on maize yield increases were based on farmer's estimates, rather than on direct measurements, we are reluctant to read too much into the actual figures. Nevertheless, the figures are plausible and consistent with experimental data.

Another way to determine whether the GGDP has had a positive impact on agricultural productivity is simply to ask farmers if their maize yields have changed during the course of the project. This approach, admittedly, has its shortcomings, because yield changes attributable to the adoption of GGDP-generated technologies could have been confounded (enhanced or offset) by other factors, such as changes in agro-climatic conditions, cropping systems, agricultural support policies, economic incentives, and so forth. With this caveat, Figure 5 shows the distribution of valid responses to the question: "During the past 10 years, have your maize yields increased, remained the same, or decreased?" Due to the phrasing of the question, responses were provided only by farmers with 10 or more years experience growing maize. Nearly 60% of those who responded indicated that their maize yields have increased, providing further evidence (admittedly somewhat circumstantial) that the GGDP has helped raise productivity.

Farmer incomes

Income is widely used as a welfare measure because it is strongly correlated with the capacity to acquire many things that are associated with an improved standard of living, such as food, clothing, shelter, health care, education, and recreation. Income gains are a valid indicator of GGDP impacts because the productivity gains attributable to the adoption of improved maize technologies logically should be reflected in income gains

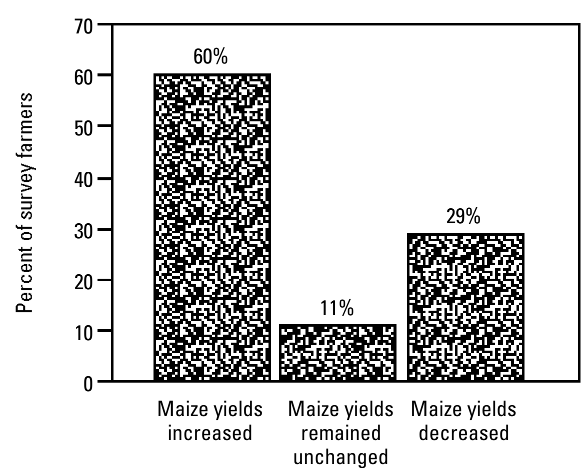

Figure 5. Farmers' estimates of changes in maize yields during the past 10 years.
Source: CRI/CIMMYT survey.

(either directly through increased sales of maize, or indirectly through increased earnings from resources that have been released from maize production).

How can income gains attributable to the GGDP be measured? In the absence of baseline data on farmers' maize marketing activities prior to the initiation of the project, we could think of no reliable way to measure income gains directly. Indirect methods based on farmers' recollections must be ruled out as too unreliable; when questioned about the distant past, few farmers are able to recall detailed information about amounts of maize they sold and the prices they received.

Lacking any aproach to measure income gains directly, we simply asked farmers whether during the previous ten years they had noticed any changes in (1) the quantity of maize they produced each year, (2) the quantity of maize they sold each year, and (3) their total annual income from maize sales. The distributions of responses are shown in Figures 6, 7, and 8. In response to all three questions, more than half of the respondents indicated that they had noticed increases. Interestingly, the proportion of farmers reporting an increase in the quantity of maize sold was lower than the proportion of farmers reporting an increase in income from maize sales. This discrepancy can be explained by the fact that maize prices strengthened considerably during the past ten years, so that total income from maize sales could indeed have increased even if the physical quantity of maize sold remained the same or even decreased. Taken together, the responses to these three questions provide additional evidence (again, admittedly circumstantial) that the GGDP has had a positive effect on the incomes of many rural households throughout Ghana.

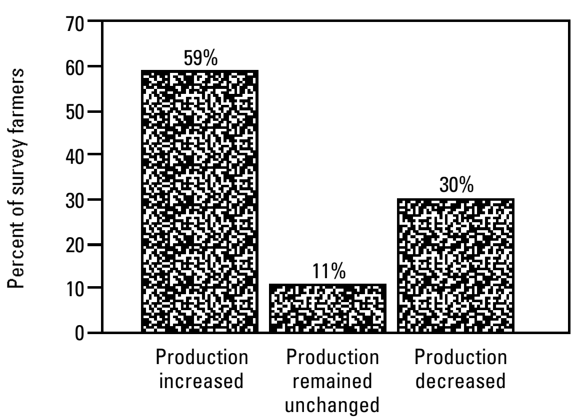

Figure 6. Farmers' estimates of changes in maize production during the past ten years.
Source: CRI/CIMMYT survey.

If rural incomes have increased because of the GGDP, how have the income gains benefited rural households? Farmers who reported increased income from maize sales were asked to describe how the additional income was spent. By far the most common reported use was to pay children's school fees. The next most common reported uses included purchasing building materials to expand or renovate the farmer's house, investing in merchandise for a family-owned retail trading business, and purchasing additional agricultural land. The additional income earned through maize farming (much of which presumably can be attributed to the adoption of GGDP-generated technologies) for the most part seems to have been invested productively, rather than spent on short-term consumption.

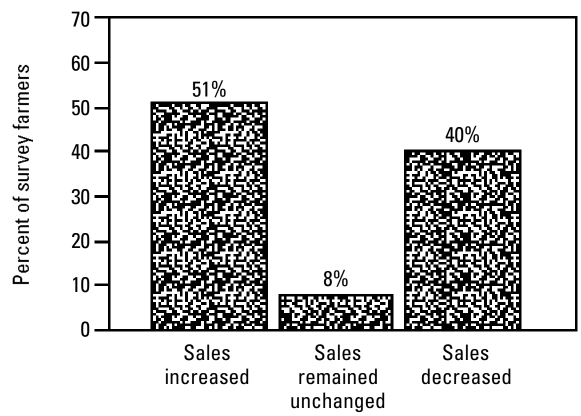

Figure 7. Farmers' estimates of changes in maize sales during the past ten years.
Source: CRI/CIMMYT survey.

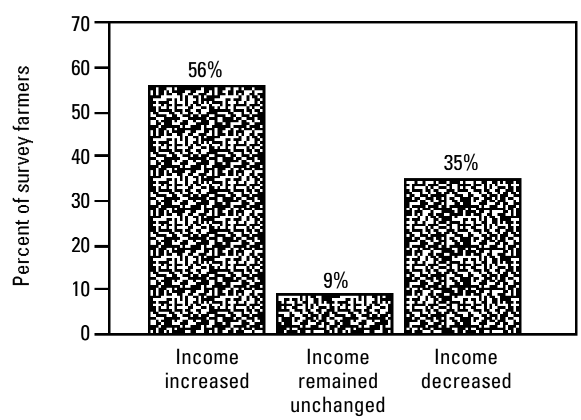

Figure 8. Farmers' estimates of changes in income from maize sales during the past ten years.
Source: CRI/CIMMYT survey.

Nutrition

One objective of the GGDP was to improve nutrition in rural households. The focus on nutrition was understandable, because improvements in nutrition are associated with numerous measures of well-being, including improved health, increased life expectancy, enhanced intellectual capacity, and increased ability to perform physical work. The nutritional status of maize-growing households is thus a valid indicator of GGDP impacts, because by increasing maize production, the GGDP would be expected to improve food consumption levels in these households.

In addition to its importance as a widely consumed food staple, maize is particularly important in Ghana from a nutritional point of view because many popular weaning foods for infants are made from maize. Mainly for this reason, during the latter stages of the GGDP considerable effort was invested in breeding MVs with enhanced nutritional quality. Obatanpa, released in 1992, is a so-called quality protein maize (QPM) containing the opaque-2 gene, which confers unusually high levels of the amino acids lysine and tryptophan. Studies have shown that feeding with QPM significantly accelerates growth in some species of livestock, notably pigs and chickens. The evidence from studies involving humans, however, is less conclusive. Beneficial effects have been documented in controlled feeding trials involving specialized populations (e.g., school children, soldiers, prisoners), but more definitive trials involving large segments of a "normal" population are only now being organized.

How can the nutritional impacts of GGDP-generated maize technologies be measured? Lacking baseline data on the nutritional status of maize-growing households prior to the initiation of the project, we could think of no reliable way to measure nutritional gains directly. What we could and did do, however, was: (1) determine whether the survey respondents have noticed changes in total household maize consumption, (2) assess their awareness of nutritional issues, and (3) establish whether maize-growing households are making an effort to use nutritionally enhanced varieties to prepare weaning foods.

First, we asked each respondent whether the quantity of maize consumed in their household had changed during the previous ten years. More than three-quarters indicated that maize consumption in their household had increased (Figure 9). Next, we asked each respondent whether they were aware of any maize variety that was particularly good for feeding to infants and children. Of the entire sample, slightly more than one-quarter answered affirmatively. The rate of positive responses varied considerably by region, however, ranging from a high of nearly one-half of the farmers in Ashanti region to a low of less than one-tenth of the farmers in the Upper West region. Somewhat surprisingly, a lower proportion of women than men reported being aware that certain maize varieties have enhanced nutritional properties. Finally, we asked each respondent to name specific maize varieties that are particularly good for feeding to infants and young children. To the extent that they are recognized, enhanced nutritional qualities are associated with MVs, rather than local varieties. Obatanpa was named by slightly more than half of the nutritionally aware farmers (51%), followed by "Agric" (30%).

Where do Ghanaian farmers obtain information about nutritionally enhanced maize? Among the relatively few farmers who know that certain maize varieties have enhanced nutritional qualities, the majority acquired this information from a researcher or extension officer. Farmers

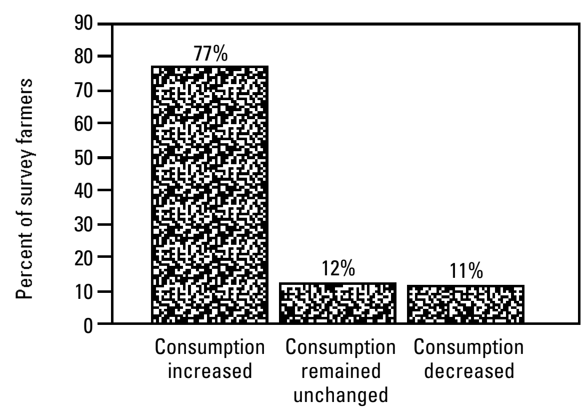

Figure 9. Farmers' estimates of changes in maize consumption during the past ten years.
Source: CRI/CIMMYT survey.

themselves also serve as an important conduit for nutritional information, as one-quarter of those expressing knowledge of the enhanced nutritional quality of specific varieties received the information from other farmers.

Unfortunately, knowledge that certain maize varieties have enhanced nutritional qualities does not necessarily mean that farmers make an effort to use those varieties. Among those farmers who indicated an awareness that certain varieties are particularly good for feeding infants and young children, only slightly more than one-third reported using those varieties to prepare weaning foods. Although our study did not investigate why nutritionally aware farmers often fail to act upon their knowledge, it would be interesting to know why the use of nutritionally enhanced varieties to prepare weaning foods is so low. Possible explanations include lack of access to QPM materials, non-suitability of QPM varieties for preparing weaning foods, or simply a belief that infants and young children are adequately nourished and therefore do not require nutritional supplements.

On the whole, these findings suggest that the level of nutritional awareness among rural households is still quite low in many parts of Ghana. Researchers and extension officers clearly have had some impact in educating farmers about the enhanced nutritional qualities of Obatanpa, but the information has not penetrated equally into all regions, and even where it has penetrated, it is not always acted upon.

Gender effects

In assessing the achievements of the GGDP, it is important to examine not only the nature and size of project-generated impacts, but also their distribution among different groups within the population. Particularly important is whether the improved maize technologies generated by the GGDP have been accessible to women as well as to men. Accessibility for women is important because women often represent a relatively disadvantaged group within society and also because women tend to make household-level resource allocation decisions that directly influence the welfare of children.

Have the GGDP-generated maize technologies been taken up equally by women farmers and men farmers? Table 20 disaggregates the adoption results by gender. (The data in Table 20 refer to the proportion of men and women who have adopted each technology, not the proportion of the maize area cultivated by men and women, respectively.) Although there is no statistically significant difference between the rates at which men and women apply chemical fertilizer to their maize fields, adoption of MVs and row planting has been significantly higher among men farmers than among women farmers.

This discrepancy is curious because there is no obvious reason why MVs and row planting should be more difficult for women to adopt than men. So what explains the difference? What is it about men farmers and women farmers that leads men to take up MVs and row planting with significantly greater frequency?

Table 21 disaggregates by gender some of the factors that were shown to be associated with the adoption of the GGDP-generated technologies. In terms of farmer characteristics, there seem to be few gender-linked differences that would explain differential rates of adoption; the mean ages of men and women in the sample were very similar, and women farmers even had slightly more maize growing experience than men. Nor are there any obvious gender-linked differences in cropping systems and/or farming practices that would explain differential rates of adoption; men and women in the sample owned land in similar proportions, relied to a similar degree on maize as their primary source of agricultural income, and used similar land preparation practices.

Table 20. Gender and technology adoption

Technology	Male adopters (%)	Female adopters (%)	Significance level of difference
Modern varieties (MVs)	59.0%	39.0%	<.001
Fertilizer	22.5%	16.2%	NS
Row planting	58.7%	37.5%	<.001

Source: 1998 CRI/CIMMYT survey.

But if men and women farmers in Ghana are alike in many respects, the data in Table 21 highlight a number of gender-linked differences that may be affecting the uptake of improved technologies:

- Men farmers on average cultivated a significantly larger maize area than women farmers. Although the GGDP-generated maize technologies appear to be scale neutral (in the sense that MVs, fertilizer, and row planting can be adopted just as easily on small farms as on large farms), the adoption of any new and unfamiliar technology involves certain fixed start-up costs associated with learning about the technology, acquiring inputs, etc. These start-up costs diminish in importance when they are spread over a large production enterprise, meaning they are relatively less significant for large-scale farmers than for small-scale farmers. Expressed another way, large-scale farmers (who tend to be men) have greater economic incentives to invest in learning about new technologies than small-scale farmers (who tend to be women).

Table 21. Gender and farmers' circumstances

	Male farmers	Women farmers	Significance level of difference
Farmer characteristics:			
Age (years)	44.1	44.5	NS*
Years of schooling	6.3	4.1	< .001*
Years growing maize	13.6	16.3	< .05*
Access to land (% farmers):			NS**
Own land	77.6	76.0	
Rent land	11.9	8.0	
Sharecrop land	10.5	15.0	
Importance of maize (% farmers):			
Primary source of income	47.3	54.3	NS*
Major season maize area (acres)	3.4	2.1	< .001*
Land preparation method (% farmers):			NS**
Manual	79.2	83.8	
Animal or tractor	20.8	16.2	
Access to technology:			
Extension contacts (no.)	2.6	1.4	< .05*
Field days attended (no.)	0.6	0.3	< .10*
Access to capital (% farmers):			
Used credit for maize	6.3	2.9	< .001*

Source: 1998 CRI/CIMMYT survey.
* t-test.
** chi-square test.

- Men farmers reported a significantly higher number of personal contacts with extension officers during the three years prior to the survey than did women farmers, and they attended twice as many farmer field days on average. As we have seen, extension officers served as the principal source of information about the GGDP-generated maize technologies and, furthermore, played a key role in distributing MV seed to farmers, so the differential rate of extension contacts would appear to have been extremely important in explaining the observed differences in adoption rates.

- Men farmers made greater use of credit to finance maize production activities. Although relatively few farmers of either gender used credit to finance maize production activities, men were more than twice as likely than women to use credit for maize. If adoption of MVs and/or fertilizer requires expenditures that are beyond the means of most maize farmers, then access to credit may be an important determinant of adoption.

- Men farmers on average had two more years of formal schooling than women farmers. Although small in absolute terms, this difference could be important. Farmers' average level of education often plays a crucial explanatory role in technology adoption, because better-educated farmers have greater ability to understand and manage complex technologies.

To what extent do these gender-linked differences influence technology adoption behavior? Doss and Morris (1998) examined whether adoption of MVs and/or fertilizer among the survey respondents was systematically linked with access to key resources and/or demographic and institutional factors. After controlling for access to land, labor, and capital (credit); farmer's age and level of education; contact with the extension service; and proximity to markets, they found no significant association between the gender of the farmer and the probability of adopting. Doss and Morris concluded that technology adoption decisions depend primarily on access to resources and institutional factors, rather than gender *per se*.

This finding should be interpreted with caution, however, because it does not necessarily mean that MVs and fertilizer are gender-neutral technologies. If adoption of MVs and/or fertilizer depends on the availability of land, labor, credit, or other resources, and if in a particular context men tend to have better access to these resources than women, then in that context the technologies will not benefit men and women equally. Policy changes may be needed to increase women's access to the key resources. Alternatively, it may be desirable to modify research efforts by deliberately targeting technologies that are particularly suited for the resources that are available to women. The bottom line is that it is important to examine both the technology itself and the physical and institutional context in which that technology is implemented in order to predict whether it will be adopted successfully by both women and men.

Discussion and Implications

This report has presented selected findings of a recent study that examined the adoption by Ghanaian farmers of improved maize production technologies developed through the Ghana Grains Development Project (GGDP). Data collected in early 1998 through a national survey of maize farmers show that GGDP-generated maize technologies have disseminated widely throughout Ghana's maize-growing areas. Based on this evidence, it is clear that the project has succeeded in meeting its main objectives of raising productivity, increasing incomes, and improving nutrition for resource-poor households. In the process, an additional goal of the project has also been realized: the capacity of CRI to carry out effective commodity-focused research has been greatly strengthened.

In retrospect, the success of the GGDP can be attributed to four main factors:

First, the objectives of the GGDP were well chosen. Maize (and to a lesser extent grain legumes, which have not been discussed extensively in this report) is produced and consumed throughout Ghana, so improved technologies that succeeded in increasing the productivity of resources devoted to maize production were bound to have significant and widely felt impacts.

Second, the GGDP adopted an extremely effective research strategy. By extensively testing experimental technologies at the farm level, researchers were able to foster the active participation of farmers in the technology development process; this helped ensure that the recommendations developed through the project were appropriate for farmers' circumstances.

Third, the GGDP was able to link its research component with an effective extension strategy. During the technology development phase, considerable efforts were made to familiarize extension officers with the technologies by involving them in on-farm testing activities. Once farmer recommendations had been formulated, the same extension officers played a key role in implementing a national program of demonstration trials that served to widely publicize the technologies.

Fourth, the project served as a model for collaboration between three groups of key players in the development process: (1) national agricultural research and extension organizations (CRI, MOFA, and the Grains and Legumes Development Board [GLDB]), (2) international agricultural research centers (CIMMYT, IITA), and (3) a committed donor agency (CIDA). These organizations interacted very effectively throughout the duration of the project, allowing the particular strengths of each to be exploited and ensuring that the product of the collaborative effort was far greater than the same organizations could have achieved by acting individually.

Although interesting in its own right, this review of the GGDP experience is also valuable as an illustrative case study, because it provides many useful insights into the nature of the technology development and transfer process. The challenge addressed by the GGDP—how to generate improved agricultural production technologies and deliver them to resource-poor farmers—is one faced by many other countries, so the GGDP's successes and failures can serve as a source of knowledge that can potentially be used to inform and improve future technology development efforts, both within and outside of Ghana.

What broader lessons emerge from this review of the GGDP experience? The final three sections of this report focus on lessons learned about (1) the technology adoption process, (2) the importance of complementary factors in tempering the technology adoption process, and (3) approaches to carrying out effective research impacts evaluation studies.

Factors affecting technology adoption

Although technology diffusion paths are frequently depicted using smooth S-shaped logistic curves, in reality the uptake of agricultural technology is more likely to proceed erratically as individual farmers learn to adapt the technology to their own particular circumstances. In addition to providing a detailed picture of the diffusion of improved maize technologies throughout Ghana, the data generated through the CRI/CIMMYT survey provide important insights about the many factors that can influence the adoption process. These factors may be divided into three general categories: (1) characteristics of the technology; (2) characteristics of the farming environment into which the technology is introduced; and (3) characteristics of the farmer making the adoption decision.

Characteristics of the technology

It has long been recognized that the rate and extent of adoption of any new technology are conditioned by the nature of the technology itself. Important characteristics that can encourage or discourage adoption include the complexity of the technology, its profitability, riskiness, compatibility with other technologies or practices, and divisibility. By themselves, these characteristics do not determine adoption; technologies that are simple, inexpensive, and risk-free may never be taken up, just as technologies that are complex, costly, or risky may find wide acceptance. But the characteristics of the technology do matter, and they deserve careful attention.

The three GGDP-generated maize technologies represented different levels of complexity. MVs were probably the least complex technology, because adopting MVs required relatively few changes to the farmer's current practices. Plant configuration ranked next in terms of complexity, because in order to adopt the row planting recommendation, farmers had to learn how to use planting ropes or sighting poles, and they had to know how to measure row and plant distances. Fertilizer was undoubtedly the most complex technology; managing fertilizer efficiently involved learning the names of different products, their nutrient composition, correct application rates (based on field characteristics), optimal application schedules, and efficient application methods. Judging by complexity alone, one might have predicted that Ghanaian maize farmers would first adopt MVs, then row planting, and finally fertilizer. Past surveys suggest that this adoption sequence has in fact been common (Tripp et al. 1987; GGDP 1991).

The complexity of the technology is only one factor influencing adoption, however, and what actually happens in farmers' fields depends on many other particulars. Another important determinant of adoption is the expected profitability of the technology. Farmers naturally are interested in technologies that give higher returns to scarce factors of production (e.g., labor, cash, land, or some combination of these). Of the three GGDP-generated maize technologies, adopting fertilizer can potentially result in considerably higher yield increases than adopting MVs or row planting alone.[9] But the higher yields that can potentially be achieved with fertilizer must be balanced against the higher cash costs associated with fertilizer use. In economic terms, although the *net benefits* associated with adopting fertilizer are often higher, the *marginal rate of return* to the additional investment required is not necessarily higher (Table 22, 23). MV use and row planting generate lower net benefits, but adopting MVs and planting in rows requires very little cash investment, so the marginal rate of return to the additional investment required is extremely attractive.

Farmers also look at the risks involved in adopting a new technology. Several types of risk can be distinguished. Farmers may be convinced that the new technology works, but they may still be uncertain how it will perform on their own farms. This uncertainty can usually be allayed by observing the technology in a neighbor's field or in a nearby demonstration plot. Another type of risk relates to the technology's performance during periods of unusual

9. The strong agronomic interactions between the three technologies, however, complicates the estimation of independent yield response functions.

climatic stress (e.g., drought), which may be more difficult to assess because such periods do not occur very often. Research has shown that farmers often place a premium on stability, choosing technologies that perform satisfactorily under a wide range of conditions, instead of technologies that perform exceptionally well but only under favorable conditions. Tripp and Marfo (1997) report that many farmers in southern Ghana were particularly attracted to some MVs because they matured earlier than local varieties and thus had a better chance of escaping drought. The short stature of these MVs also protected them from the threat posed by lodging. A third type of risk relates to the possibility of losing the investment made in an improved technology. This risk is particularly relevant in the case of fertilizer; purchasing fertilizer involves a significant cash outlay, and many farmers worry that in years of low rainfall the fertilizer will have little effect.

New technologies stand a better chance of being adopted if they are compatible with current farming practices. Generally speaking, the maize technologies produced by the GGDP were not only compatible with other widely used crop production practices, they were also compatible—and indeed highly complementary—with each other. Aside form switching their seed, farmers who decided to adopt MVs were required to make few changes to their crop management practices. Adopting row planting did involve learning a new planting technique, but the additional time needed for row planting was more than offset later by labor savings in weeding and fertilizer application. Adopting chemical fertilizer did not significantly affect other practices either, although it did create an increased need for labor during certain periods in the cropping cycle.

A final characteristic of the three GGDP-generated maize technologies was that they were divisible, meaning they could be adopted on part of a farm or on all of it.

Table 22. Profitability of adopting maize MVs (average of farmer-managed trials conducted in four agro-ecological zones)

	Local variety	Aburotia	Dobidi
Marginal benefits:			
Average grain yield (t/ha)	1.81	2.26	2.49
Increase in grain yield relative to local variety (t/ha)		0.45	0.68
Farm price of maize grain (cedis/t)	300,000	300,000	300,000
Value of increase in grain yield relative to local variety (cedis/ha)		135,000	204,000
Marginal costs:			
Seed rate (kg/ha)	20	20	20
Seed price (cedis/kg)	1,500	2,000	2,000
Additional seed cost associated with MV use (cedis/ha)		10,000	10,000
Net benefits (cedis/ha)		125,000	194,000
Marginal rate of return to additional investment (%)		1,350	2,040
Benefit/cost ratio		13.5	20.4

Source: Technical coefficients based on *GGDP Annual Report* (1985), updated by the authors using 1998 prices.

Table 23. Profitability of adopting fertilizer on maize (average of farmer-managed trials conducted in four agro-ecological zones)

	Fertilizer effect only		Fertilizer and MV joint effect
	Local variety	Modern variety	
Marginal benefits:			
Average grain yield with no fertilizer (t/ha)	1.71	2.47	1.71 [a]
Average grain yield with NPK 90:60:60 (t/ha)	2.77	3.97	3.97 [b]
Difference (t/ha)	1.06	1.50	2.16
Farm price of maize grain (cedis/t)	300,000	300,000	300,000
Value of grain yield increase due to fertilizer (cedis/ha)	318,000	450,000	648,000
Marginal costs:			
Seed rate (kg/ha)	20	20	20
Seed price (cedis/kg)	1,500	2,000	2,000
Additional seed cost associated with MV use (cedis/ha)			10,000
NPK fertilizer cost (cedis/ha)	75,000	75,000	75,000
Ammonium sulphate cost (cedis/ha)	92,000	92,000	92,000
Fertilizer transport costs (cedi/ha)	10,000	10,000	10,000
Labor for fertilizer application (cedis/ha)	35,000	35,000	35,000
Total costs that vary (cedis/ha)	212,000	212,000	222,000
Net benefits (cedis/ha)	106,000	238,000	426,000
Marginal rate of return to additional investment (%)	50	112	192
Benefit/cost ratio	1.5	2.1	2.9

Source: Technical coefficients based on *GGDP Annual Report* (1985), updated by the authors using 1998 prices.
a Local variety.
b Modern variety (MV).

This reduced the riskiness of the technologies by allowing farmers to adopt each recommendation progressively, in step-wise fashion. Indeed, the survey results make clear that many farmers are partial adopters, who even today use one or more of the three technologies only on a portion of their maize area. In addition to facilitating step-wise adoption, the divisibility of the three technologies made them accessible to both large- and small-scale farmers.

Characteristics of the farming environment

A technology can be simple, profitable, relatively secure, compatible with farmers' current practices, and divisible; but that does not necessarily mean it will be adopted. Adoption decisions depend partly on the characteristics of the technology, but they depend also on the environment in which farmers operate. Important characteristics of the farming environment that can affect technology adoption include agro-climatic conditions, the nature of prevailing cropping systems, the degree of commercialization of the cropping enterprise, factor availabilities, farmers' knowledge and access to technical information, and the availability of physical inputs.

Although maize is grown in most parts of Ghana, some areas are better suited for maize production than others. The most favorable areas for maize are concentrated in the transition zone and in parts of the Guinea savannah; these areas receive more solar radiation, feature lighter soils, and have fewer trees (which means land preparation is easier). Maize can be grown in forest areas, but agro-climatic factors are generally less favorable for maize production, and competition from tree crops is much greater. The observed differences in adoption rates between the forest zone and other zones stem in part from the generally lower profitability of maize in forest areas relative to alternative crops, especially cocoa.[10]

Cropping systems in Ghana are complex and varied, so it is to be expected that improved technologies will be accommodated in different ways, depending on local practices. Although MVs appear to be compatible with most current maize cropping systems, farmers who decide to adopt the recommendations for row planting and fertilizer management may be forced to make adjustments. In the northern part of the country, many maize fields are prepared by ridging up the soil, a practice that improves moisture conservation and facilitates fertility management. Farmers who ridge their fields already plant in rows, so for them the GGDP-generated row planting recommendation has little relevance. In the southern part of the country, particularly in heavily forested regions, soil fertility is periodically replenished through a carefully managed bush fallow system. Farmers who have access to extensively fallowed land may not face soil nutrient deficiencies, so chemical fertilizer may have little relevance for them.

Farmers' technology choices tend to be influenced by the degree to which the crop is marketed. Varietal selection criteria often vary depending on whether the harvest will be consumed at home or sold for cash. If maize is grown mostly to be eaten at home, consumption characteristics assume great importance (e.g., appearance, taste, smell, grain texture, ease of processing, storage quality). But if maize is grown for sale as a cash crop, grain yield and market price tend to be the most important factors. The Ghanaian experience with MVs was quite revealing in this respect. In the north of Ghana, where a lot of maize is retained for home consumption, MVs were generally judged acceptable for food preparation. In the south, initially there were some concerns about the suitability of MVs for preparing local foods, and these concerns were sometimes reflected in lower market prices for MVs. The higher yield of the MVs offset this disadvantage, however, and despite the occasional price differential, MVs soon gained acceptance even among commercial farmers.

Regardless of how attractive a new technology may be, it will probably not be adopted if adoption requires farmers to contribute additional factors of production that they do not have and cannot easily obtain. Of the three GGDP-generated maize technologies, the two that might have been affected by factor scarcities were row planting and fertilizer use, both of which require additional labor to adopt, and one of which (fertilizer use) requires a significant cash investment. Judging from the survey results, the labor constraint does not appear to have been

10 Also, GGDP maize extension efforts did not target the forest zone, since this zone was known to produce mainly tree crops.

binding; few farmers reported that they had not adopted the GGDP technologies because labor was unavailable. The capital constraint may have been more serious, however, with shortages of capital possibly discouraging fertilizer use. Many of the survey farmers reported that they did not use fertilizer because they lacked the cash needed to purchase it.

Since farmers cannot adopt improved technologies unless they have first heard about them, successful adoption is predicated on farmers having access to detailed and accurate technical information. Such information can reach farmers from various sources, but it is likely to reach them most rapidly (and with fewer errors) if there is a well-functioning extension service in place. Regular contact with extension officers clearly has been an important factor in explaining the adoption of all three GGDP-generated maize technologies. Extension resources are scarce in Ghana, and not all farmers have had equal contact. In the past, extension organizations have placed relatively little emphasis on promoting maize in forest areas, which may help explain lower adoption rates in those areas. And although good progress has been achieved in making extension activities gender-neutral, the survey results suggest that women farmers on average still have fewer contacts with the extension service than men farmers.

Finally, even if farmers know about a new technology, they cannot adopt it if adoption requires using an input that is unavailable. Two of three GGDP-generated maize technologies are based on physical inputs (MV seed and chemical fertilizer). Although improved seed theoretically should be available from local inputs supply shops, in practice the seed industry is still very underdeveloped, particularly in more isolated areas. Many farmers manage to procure improved seed from extension officers, who frequently are able to provide seed samples as part of an extension program or sometimes sell seed on a commercial basis as a business sideline. Of course, once a particular MV has appeared in an area, local farmers can usually acquire farm-saved seed from early adopters. Obtaining fertilizer is generally more problematic because it is bulky and must be purchased each season. Fertilizer distribution was recently privatized in Ghana, but the number of agents continues to be constrained by low demand.

Characteristics of the farmer

Two farmers considering exactly the same technology and operating in the exact same farming environment can still end up making very different adoption decisions. A third set of factors that can affect the technology adoption process relates to farmers' personal circumstances, including ethnicity and culture, wealth, education, gender, and security of access to land.

Ghana's maize farmers belong to a large number of different ethnic groups, each with its own language, customs, and forms of social organization. With respect to technology adoption, cultural factors frequently affect individuals' access to resources (especially land, but also labor and capital), their obligations to contribute to different types of agricultural production activities, their ownership claims to crops harvested from communally cultivated fields, their access to external sources of information, and so forth. Cultural factors are particularly evident when comparing the patrilineal societies of the north with the matrilineal societies that dominate much of the south. Women's access to land and capital, their decision-making responsibility in maize farming, and their ability to mobilize labor all differ significantly between these two traditions; those factors directly affect the attractiveness of improved technologies. To further complicate matters, a considerable number of farmers are migrants to other areas; these migrants have to balance their own customs with those of the host culture, which can add additional layers of complexity to technology adoption decisions.

The vast majority of Ghana's maize farmers cultivate only a few hectares or less of maize and can accurately be characterized as small-scale farmers. But despite the relatively restricted range of farm sizes, differences in wealth are evident between farmers, and these differences can affect the technology adoption process. Farmers with higher incomes generally enjoy advantages that facilitate adoption. For example, they may find it easier to make contacts with extension officers or to tap into other sources of technical information. Once they have heard about an improved technology, they may be better able to travel to distant towns in search of agricultural inputs. And, after they have located the inputs, they may experience less difficulty in raising the cash needed to purchase them. Considering these and other advantages associated with wealth, it follows that the rate of technology adoption is slightly higher on larger farms (which presumably tend to be owned by wealthier farmers).

Another farmer-related characteristic that can be important in the adoption process is the farmer's level of education. The survey results show that farmers who have adopted one or more of the GGDP-generated maize technologies have received more formal schooling than those who have not adopted. Since the adoption of improved technologies requires the acquisition and assimilation of new information, this result is perhaps not surprising.

Finally, the survey revealed differences in the extent to which some of the GGDP-generated maize technologies have been adopted by men and women. A number of gender-linked factors appear to be associated with these differences, including the farmer's access to key resources (such as land, labor, and credit), contacts with the extension service, and level of education. Controlling for these factors, there is no difference in the rates at which men and women have adopted the GGDP-generated technologies. This suggests that the observed gender-linked differences in the rates of adoption are not attributable to inherent characteristics of the technologies themselves; rather the differences result from the fact that women in Ghana have less secure access than men to land, labor, and credit, enjoy relatively fewer contacts with the extension service, and receive less formal education.

Importance of complementary factors

As the discussion in the previous section makes clear, the adoption of improved agricultural technology is influenced by many factors, only some of which pertain to the characteristics of the technology itself. For this reason, development planners must be realistic about the ability of research organizations, working on a unilateral basis, to bring about desired changes in farming practices. Improved technology—the principal output of research organizations—is certainly a requirement for changing farming practices, but improved technology by itself is not sufficient. Other elements must also be present. As the GGDP experience illustrates, if improved technology is to make a meaningful impact at the farm level, it must be accompanied by at least three complementary factors: (1) an effective extension service, (2) an efficient inputs distribution system, and (3) appropriate economic incentives.

Extension

One distinguishing feature of the GGDP, and an important component of its eventual success, was its heavy emphasis on extension. Efforts to educate farmers about the potential benefits of the improved technologies began with the establishment of extensive networks for on-farm testing of MVs and crop management practices. The on-farm trials provided researchers with vital feedback about the performance of experimental technologies, while giving farmers an opportunity to observe the technologies and to learn about them. After the optimal technologies had been identified and approved for transfer to farmers, additional effort was invested in devising recommendations that would be easy for farmers to assimilate and implement. Finally, in an effort to see the technology transfer process through to a successful conclusion, the project included a strong extension component, under which thousands of government extension officers were taught about the recommendations.

To further strengthen the GGDP extension effort, external agencies were invited to participate in the technology transfer process. In the late 1970s and early 1980s, the World Bank's Training and Visit (T&V) extension program was incorporated into two regional development projects that included maize production components. Maize technology transfer efforts received a considerable boost in 1987 with the launch of the Sasakawa-Global (SG) 2000 food production project. The SG 2000 strategy revolved around the establishment of large demonstration plots ("production test plots"), delivery of improved seed and fertilizer at low rates of interest, and lobbying for increased policy support to agriculture. Without question, the SG 2000 program helped increase awareness of improved maize technologies; according to a 1990 survey, almost one in four farmers had some form of contact with SG 2000 (managing a demonstration plot, visiting a demonstration, or receiving a loan), and these farmers had significantly greater knowledge of the GGDP recommendations (GGDP 1991; Tripp and Marfo 1997).

The strong link between frequency of extension contacts and adoption of GGDP-generated maize technologies shows that extension continues to play a vital role in promoting adoption. In this respect, while the agencies that participated in the extension effort can justifiably claim partial credit for the widespread dissemination of GGDP maize technologies, there are grounds for concern about the adequacy of the extension effort. The survey results indicate that extension coverage is spotty in many areas and that important groups of farmers, especially women, are regularly being missed. Furthermore, casual observation suggests that too many extension agents lack knowledge about the latest recommendations, indicating that the links between research and extension need to be strengthened.

Inputs delivery

Two of the three GGDP maize technologies are based on the use of purchased inputs that farmers must acquire from external sources (improved MV seed and chemical fertilizer). These purchased inputs must be readily and reliably available if farmers are to adopt the technologies. Unfortunately, often they are not available. Ghana's recently privatized agricultural inputs supply system is struggling to establish itself, and seed and fertilizer distribution outlets are still scarce in many areas.

To what extent has the lack of a well-developed inputs supply system impeded the adoption of the GGDP-generated maize technologies? In the case of MVs, probably quite a lot. When questioned about their choice of variety, many maize farmers who still grow local varieties state that they have not switched to MVs because MV seed is not available. Since most farmers who have adopted MVs say that MVs significantly outperform local varieties (and relatively few farmers who try MVs subsequently abandon them), it seems likely that many more farmers in Ghana would adopt MVs if they had access to improved seed.

The case of fertilizer, however, is different. It is not clear that adoption of fertilizer has been significantly affected by the lack of a well-developed inputs supply system. When asked why they do not use fertilizer, most farmers say that fertilizer is not needed to grow maize (implying that fertility levels in their maize fields are adequate) or that it is too expensive. This suggests that the problem is not availability, but low profitability. Although the price of fertilizer would be lower if a well-functioning fertilizer distribution system were in place, it is not clear that the cost reductions achieved by improving the efficiency of distribution would be great enough to overcome the profitability problem.

Economic incentives

Profitability considerations have also played an important role in influencing the uptake of GGDP technologies. MVs and row planting have been widely adopted in part because the additional costs associated with MV use and row planting are more than paid back by the additional revenue these technologies generate. Fertilizer has been adopted (or adopted and subsequently disadopted) at a much more modest rate, largely because the high cost of fertilizer is not returned in terms of incremental production.

Does this mean that the GGDP fertilizer recommendations were inappropriate? Not at all. In developing the fertilizer recommendations, GGDP researchers were careful to consider the prevailing prices of fertilizer, of the labor required for fertilizer application, and of maize grain. In addition, the fertilizer recommendations were conservatively calculated in order to withstand the effects of possible future unfavorable price changes. During the course of the project, the government of Ghana implemented a number of sweeping policy reforms that among other things removed many long-standing subsidies to the agricultural sector. As a direct result of the reforms, fertilizer prices rose sharply in relation to maize prices, significantly reducing the profitability of fertilizer use on maize (Figure 10, p. 36) (for details, see Bumb et al. 1994).

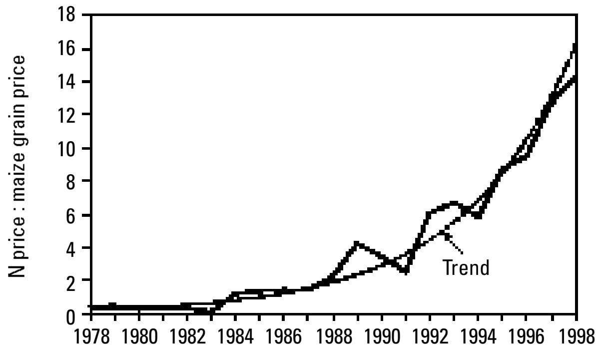

Figure 10. Nitrogen price-to-maize grain price ratio, Ghana, 1978-98.
Source: Unpublished MOFA data.

The conclusion to be drawn from this experience is not that researchers must be clairvoyants to develop technologies that will stand the test of time, but that the success or failure of any technology depends to a large extent on its profitability—which in turn depends on external economic forces beyond the influence of the researchers. In assessing the likely profitability of a new technology, it makes sense to consider possible future changes in economic incentives, but realistically it will never be possible to anticipate all possible changes. In this respect, even the most outstanding agricultural research programs owe at least part of their success to blind luck.

Lessons for research impacts evaluation

It seems appropriate to conclude with a few comments regarding the nature of the impacts evaluation process. One of the biggest challenges we faced in reviewing the performance of the GGDP was the difficulty of identifying and quantifying project-generated impacts. These tasks were made considerably more difficult because measurable performance indicators were not clearly defined at the outset of the project and baseline data on such indicators were not systematically collected. If projects of a similar nature are to be undertaken in future, more consideration should be given during the project design phase to monitoring and evaluation issues, and resources should be invested in collecting baseline data that can be used later to measure the achievements of the project.

Of course, even if measurable performance indicators are defined and baseline data on these indicators are collected prior to the initiation of a project, they will not always readily lend themselves to analysis. Ignoring for a moment the considerable practical difficulties involved in carrying out conventional impacts assessment studies based on standard economic approaches, it is important to remember that most of these studies overlook many of the benefits generated by research projects simply because it is difficult to assign economic value to them. In the case of the GGDP, such benefits include the following:

1. *Strengthened institutional capacity:* Undoubtedly, the GGDP strengthened the capacity of the CRI and other Ghanaian institutions to carry out effective research. The hands-on involvement of CIMMYT and IITA scientists in the day-to-day management of maize and grain legume research, combined with generous external funding from CIDA that provided the resources needed to conduct the research, allowed the GGDP to serve as a model for how effective commodity-focused research should be designed and implemented. The high standards set by the GGDP have "rubbed off" onto other CRI research programs.

2. *Better-trained human capital:* During the life of the GGDP, thousands of Ghanaian researchers and extension officers received training. The effects of this training will long outlive the project, as CRI, MOFA, and the national extension service will continue to benefit from having better-trained personnel.

3. *Improved information:* The GGDP generated a substantial amount of information that can and is being put to good use by many different users. Information generated by the GGDP is being used within CRI for research planning and management purposes and also by extension officials, inputs distributors, grain traders, and others in their day-to-day activities.

We mention these "intangible" benefits in closing to emphasize once again the difficulty of carrying out applied impacts assessment work. Given the indirect nature of the link between investments made today in agricultural research and changes realized tomorrow in the welfare of poor people, any attempt to measure and quantify research impacts is bound to be incomplete in some respect. The results presented in this report provide compelling evidence that the GGDP has succeeded in meeting its primary objectives of raising productivity, increasing incomes, and improving nutrition for resource-poor households throughout Ghana. While this conclusion will be welcomed by many of those who contributed to the success of the project, others will be justified in feeling that important parts of the story have been overlooked.

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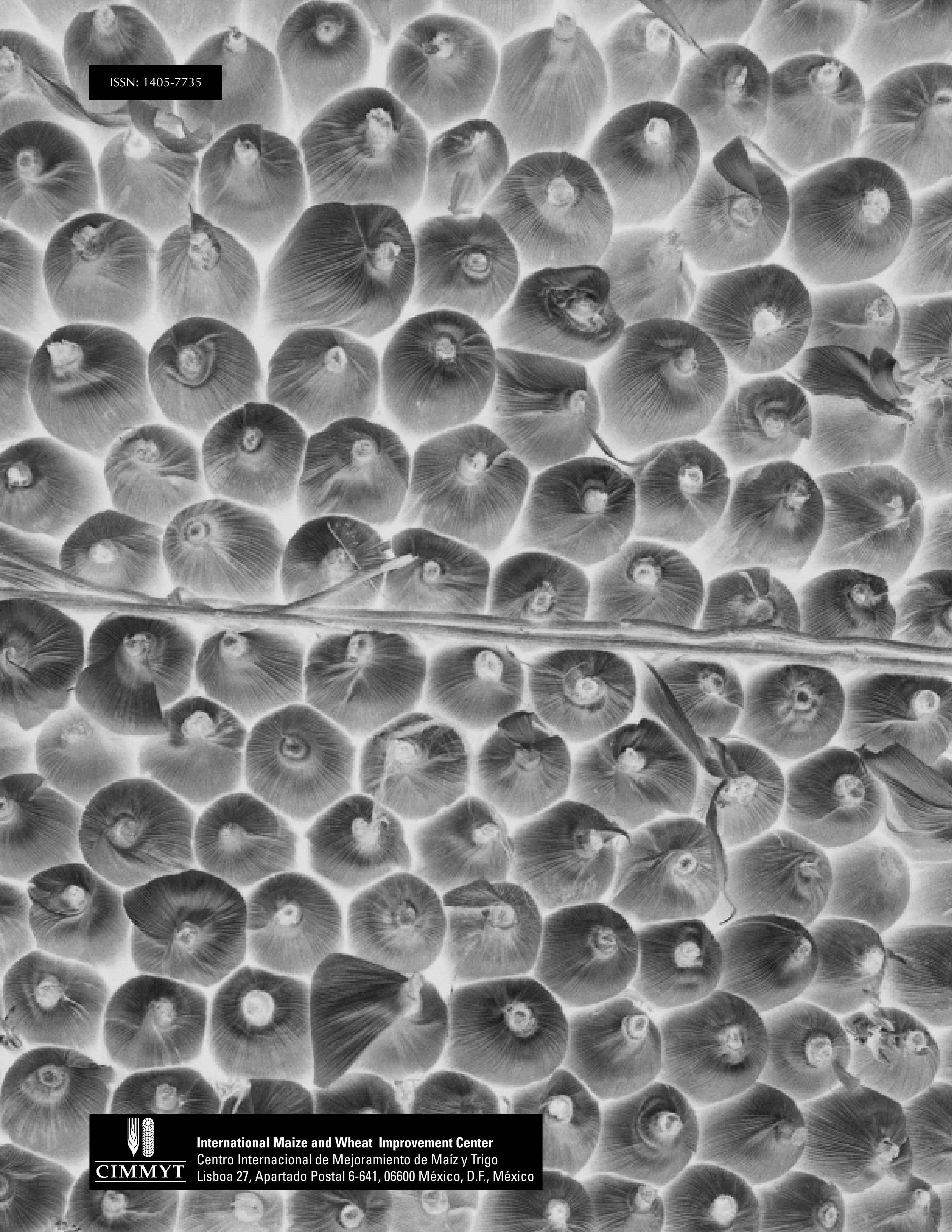

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