AGRICULTURAL ECONOMICS

Agricultural Economics 40 (2009) 535–550

The economic and poverty impacts of maize research in West and Central Africa

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Received 31 July 2008; received in revised form 19 January 2009; accepted 8 March 2009

Abstract

This article assembles the results of three multicountry surveys on variety performance and adoption patterns to measure the impacts of maize research in West and Central Africa from 1981 to 2005, and uses cost data since 1971 to compute social rates of return on public investments in maize research in the region. Adoption of modern varieties increased from less than 5% of the maize area in the 1970s to about 60% in 2005, yielding an aggregate rate of return on research and development (R&D) investment of 43%. The estimated number of people moved out of poverty through adoption of new maize varieties rose gradually in the 1980s to more than one million people per year since the mid 1990s. Over half of these impacts can be attributed to international maize research at IITA and CIMMYT. The article concludes with a discussion of strategic options to enhance the impacts of maize research in the region.

JEL classification: I32, O33, Q16

Keywords: Maize research; Economic surplus; Poverty reduction; West Africa

1. Introduction

A lot of empirical work has documented the key contributions of agricultural research to productivity growth and poverty reduction in the developing world, especially in Asia (e.g., Byerlee and Traxler, 1995; Datt and Ravallion, 1998; David and Otsuka, 1994; Fan et al., 2000, 2005; Lipton and Longhurst, 1989). In sub-Saharan Africa (SSA), there have been several key successes in agricultural research (Gabre-Madhin and Haggblade, 2004; Maredia et al., 2000). For example, the generation and diffusion of modern maize varieties has been cited as one of the outstanding success stories of technological change in food crop production in SSA (Maredia et al., 2000). However, success has largely been measured in terms of intermediate indicators such as variety release and single-year adoption (e.g., Manyong et al., 2003; Morris, 2002), with little rigorous assessment of the returns on maize research investments and the impacts on poverty. Concern has been expressed, for example, that substantial likely impacts of agricultural research in SSA realized from technology adoption over longer time periods and wider geographic areas have escaped assessment (Maredia and Raitzer, 2006).

Despite considerable international and national research investments, the evidence of impact is particularly limited for maize research in West and Central Africa. International maize research is conducted by the International Institute of Tropical Agriculture (IITA) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) and the national agricultural research systems (NARS). IITA initiated maize research around 1970 and has had a regional mandate

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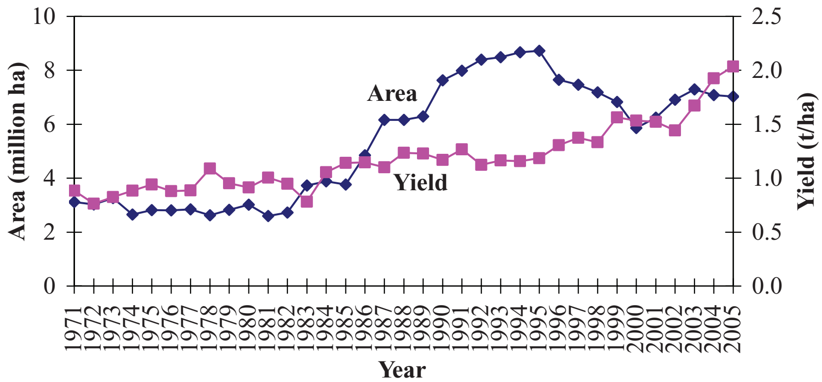
Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell, Inc. is not responsible for the content or functionality of any supporting information supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

DOI: 10.1111/j.1574-0862.2009.00396.x



Source: FAOSTAT database (FAO, 2007).

Fig. 1. Trends in maize area and yields in West and Central Africa, 1971–2005.

for maize improvement in West and Central Africa since 1980 (Manyong et al., 2003). In collaboration with NARS and CIMMYT, IITA has since made significant progress in developing modern varieties (MVs) with high yield potential and increased tolerance to multiple biotic and abiotic stresses.[1] The availability of maize MVs adapted to the savanna zone (e.g., TZB in Nigeria), coupled with fertilizer subsidies and improved infrastructure and support services, changed the status of maize from a minor crop in the 1970s to one of the most important food as well as cash crops in the 1980s (Smith et al., 1994). However, there is little empirical evidence on the rate of diffusion and impacts of maize MVs in the region. Using data on variety release, adoption, and yield gains as well as research investments, this article estimates the economic and poverty reduction impacts of maize research in West and Central Africa over the period 1971–2005.

2. Maize area and yields in West and Central Africa

Maize area and yields in West and Central Africa stagnated during the 1970s, but increased substantially after the 1980s (Fig. 1). Maize yields increased from as low as 0.88 tons per hectare (t/ha) in 1971 to over 2 t/ha in 2005, with an average growth rate of 2% per year. Maize yield increases accounted for over a third of the observed growth of maize production. The steady growth of maize yields since the 1980s coincides with several national and international maize research initiatives in the 1970s that led to the development of important technologies in the 1980s. On the other hand, maize area increased by over 3% annually. In Nigeria, increased availability of MVs adapted to the savanna zone, coupled with heavy fertilizer subsidies (usually above 80%), improved infrastructure and support services, and established product markets favored maize production and led to area expansion (Smith et al., 1994). Overall, maize area increased in the 1980s and early 1990s, but declined thereafter due mainly to subsidy removal or reduction in several countries in the region.

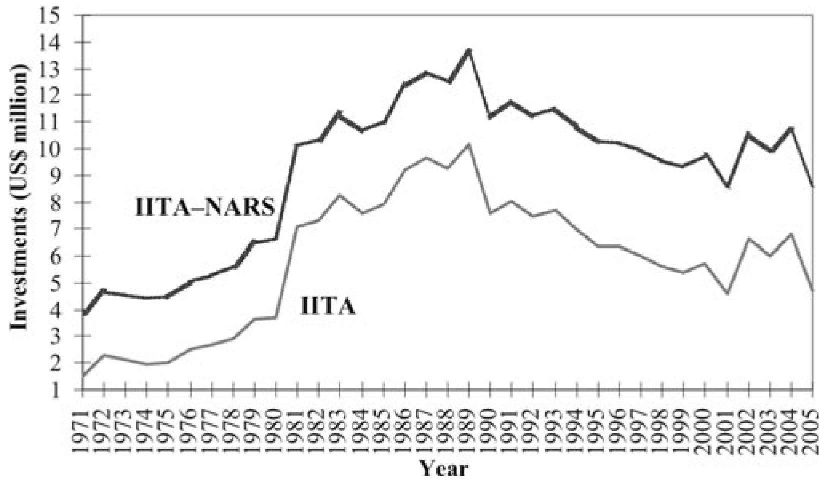
3. Data sources and overview of technology generation and adoption

3.1. Data sources

The data for this study come from three regional maize research impact assessment surveys conducted in 2007 (our survey), 1998 (Manyong et al., 2003), and 1990 (Byerlee and Heisey, 1996). The 2007 survey was carried out in nine countries, including Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria, Senegal, and Togo, which together account for about 85% of maize production in West and Central Africa. Each country was visited by a member of the research team who led the data collection process. Survey questionnaires were developed to guide the data collection through extensive discussions and consultations with the main respondents of the survey—managers, breeders, economists, and extensionists of public as well as private maize research institutes and seed production agencies.

Given that the data on MV releases and adoption prior to 1998 were available from an earlier impact assessment survey conducted in 1998 (Manyong et al., 2003), our survey gathered the names and origins of the maize MVs released over the period 1998–2005. Survey respondents were also asked to estimate the percentage of total national maize area planted to MVs in 2005. Adoption surveys are rarely carried out at the national level because of their high cost, but many national programs have socioeconomic research units undertaking adoption and impact studies in major growing areas. Available adoption estimates from these and other micro studies were thus used to validate expert estimates. The adoption profiles of MVs over the period 1981–2005 were then estimated based on adoption

[1] The term "modern varieties" is used in this article to refer to improved open-pollinated varieties (OPVs) and hybrids developed by national and international maize breeding programs, whereas the term "traditional varieties" refers to farmers' own varieties or landraces.



Source: Own survey; IITA financial reports.

Fig. 2. Real maize research investments in West and Central Africa, 1971–2005.

rates at three points in time: 1990 (Byerlee and Heisey, 1996), 1998 (Manyong et al., 2003), and 2005 (our survey). The survey also collected yield data from regional and on-farm variety evaluation trials—conducted by national maize programs and coordinated by the West and Central Africa Maize Network (WECAMAN)—to estimate the genetic yield gains attributable to maize research.

Data on international maize research investments were obtained from IITA financial reports. The real maize research expenditure series for the period 1971–2005 was constructed by converting the nominal expenditures to constant 2000 U.S. dollars. National maize research investments included financial expenditures as well as human resources, measured in full-time equivalent (FTE) scientist years (BS degree and above). While the financial investments data represented an aggregate of personnel salary, operational and capital expenditures, and overheads, the human resource investments data represented an aggregate of different category of staff expressed in full time equivalent scientist years (FTEs). The NARS real maize research expenditure series for the period 1971–2004 was constructed by projecting the 2005 real expenditures backward to 1971 using Beintema and Stads (2006, p. 39) data on country-specific annual growth rates of agricultural research expenditures, assuming that maize research expenditures increased at the same rate as total research expenditures. To the extent that annual program budgets depend on the total national agricultural research budgets, it is reasonable to expect that program budgets grow at the same rate as total budgets (Byerlee and Traxler, 1995).

Secondary time-series data relating to maize area, yields, and production were accessed from FAOSTAT database (FAO, 2007). Similarly, international maize prices were obtained from FAOSTAT international commodity prices database. The price series was constructed by adding representative international transport and handling costs to the main international reference price of maize (#2 yellow, Free On Board [FOB] U.S. Gulf ports). Time-series data on absolute and relative poverty for the countries surveyed were obtained from the World Bank PovcalNet database (Chen and Ravallion, 2007).

3.2. Maize research investments

Fig. 2 shows the evolution of international and national maize research investments. Clearly, international maize research investments account for much of the overall investments in maize research in the region.[2] IITA investments in maize research rose steadily from only a little over US$2 million in the early 1970s to a maximum of over US$10 million in 1988, but then declined thereafter throughout the 1990s, falling to less than US$5 million in 2000 before beginning to rise again to over US$6 million in 2001. National maize research investments generally declined throughout the 1990s and beyond, due mainly to declining donor funding. Despite funding instabilities, considerable national and international maize research investments have been made in West and Central Africa. Ghana has made the largest maize research investments, followed by Nigeria, Burkina Faso, and Cameroon. Ghana's maize program enjoyed continued funding throughout the 1980s and 1990s largely through the Ghana Grains Development Project (Morris et al., 1999). A total of US$308 million had been invested in maize research over the period 1971–2005, with international maize research accounting for about 66% (US$204 million) of this investment.

[2] Data were not available on CIMMYT's maize research investments in the region, such as the costs incurred in Ghana during the implementation of the Ghana Grains Development Project over the period 1979–1997 (Morris et al., 1999). Nonetheless, national maize program costs reflect much of such investments, as do overall NARS research expenditures (Beintema and Stads, 2006).

Table 1
Number of modern maize varieties released in West and Central Africa, 1965–2006

Country	Source		Type		Total
	Public sector	Private sector	OPVs	Hybrids	
Nigeria	34	48	70	12	82
Burkina Faso	33	26	54	5	59
Benin	22	7	26	3	29
Cameroon	27	0	22	5	27
Ghana	22	14	31	5	36
Togo	19	8	24	3	27
Senegal	31	16	44	3	47
Mali	14	4	18	0	18
Côte d'Ivoire	8	0	6	2	8
Chad	14	0	14	0	14
D.R. Congo	20	0	20	0	20
Guinea	12	0	12	0	12
Total	256	123	341	38	379

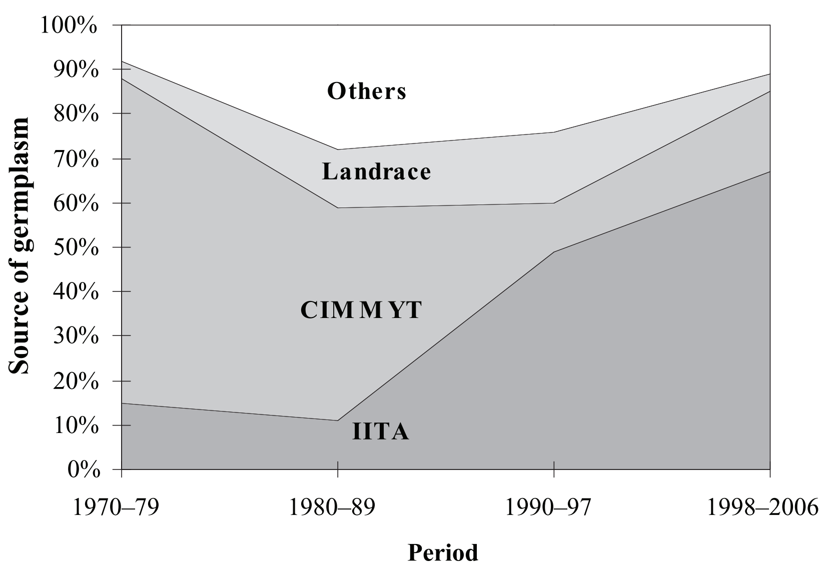
Source: Own survey; Manyong et al. (2003).

3.3. Maize variety development and release

An important first step in assessing the impacts of maize research is to document the number of maize variety releases. A total of 379 maize MVs have been released in West and Central Africa over the period 1965–2006, with 267 varieties released during 1965–1998 and 112 varieties over the period 1998–2006 (Table 1). The public and private sectors released a total of 256 and 123 maize MVs, respectively. Nigeria had the highest number of releases (82), with private seed companies accounting for over 58% of all releases, followed by Burkina Faso, Senegal, and Ghana. Open-pollinated varieties (OPVs) account for about 90% of all variety releases, which is thought to be consistent with a focus on small-scale farmers (Byerlee and Heisey, 1996); the rest are hybrids, including quality-protein maize (QPM). The emphasis on OPVs aims to reflect the idea that farmers cannot afford to purchase fresh seed every cropping season to maintain the yield advantages of hybrids, whereas they can recycle OPV seed for three or four seasons.

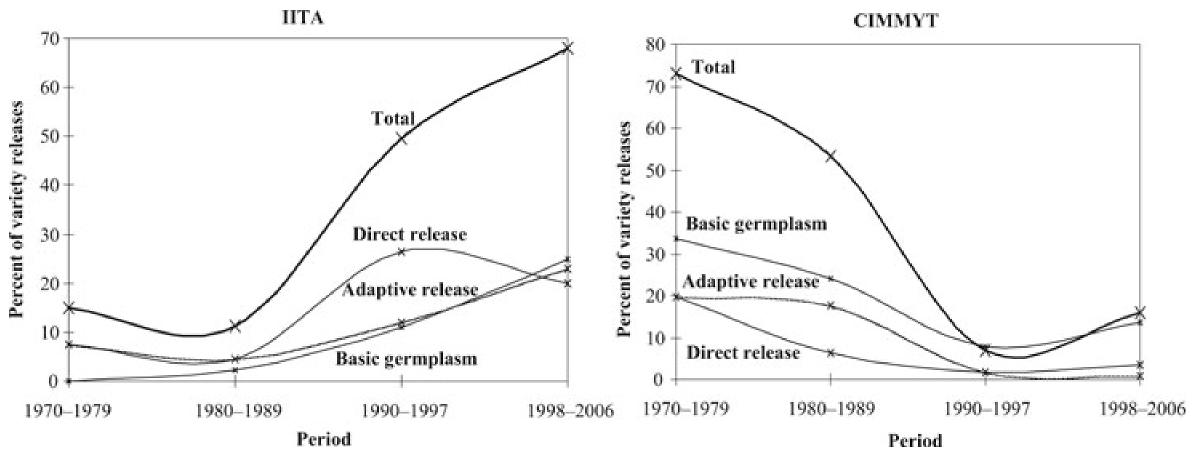
The annual release of MVs increased markedly from less than a single variety in the 1970s to about five varieties during the 1980s and 1990s (Manyong et al., 2003) and over 12 varieties since the late 1990s. With international maize research playing an increasing role since the 1980s, national programs currently release more than twice as many MVs per year as in the 1980s. IITA and CIMMYT breeding programs have been the major sources of germplasm for the released varieties and together supplied nearly 90% of the germplasm in the 1970s, 60% in the 1980s and 1990s, and 85% since the late 1990s (Fig. 3). CIMMYT was the major source of germplasm in the earlier periods, particularly in the 1970s. However, varieties released in the 1970s were not only much fewer but were also more prone to diseases and pests, whereas more promising varieties such as maize streak virus-resistant varieties have been released since the 1980s. IITA has become an important source of germplasm since the 1980s and currently supplies nearly 70% of the germplasm in the region. More importantly, most of the IITA materials needed little or no further improvement, given the strategy to support weak national programs by supplying nearly finished products (Manyong et al., 2003).

One of the objectives of international maize research is to help transform the scientific capacity of the national programs from mere acceptance of nearly finished technologies, to the ability to screen and adapt technologies, to a final stage in which full scientific capabilities have been transferred. In this context of technology and capacity transfer, the contribution of international maize research to maize variety release involves



Source: Own survey; Manyong et al. (2003).

Fig. 3. Source of germplasm for maize varieties released in West and Central Africa.



Source: Own survey; Manyong et al. (2003).

Fig. 4. IITA and CIMMYT content of maize variety releases in West and Central Africa.

three modes: (1) direct release—materials released directly as varieties by the national programs without any further improvement; (2) adaptive release—varieties developed by international programs but selected by the national programs for release after in-country testing and evaluation for local adaptation; and (3) basic germplasm—varieties developed by national programs through substantial improvement of basic germplasm from international programs.

Fig. 4 presents the evolution and relative importance of the three modes of utilization of maize germplasm from IITA and CIMMYT by the NARS in West and Central Africa. Important observations emerge from the analysis of variety release by mode of germplasm use. First, direct and adaptive releases were the dominant modes of IITA contribution in the 1970s and 1980s when many NARS were at an early stage of capacity development. By contrast, basic germplasm transfer has been the dominant mode of CIMMYT contribution since the 1970s. Second, basic germplasm transfer from IITA has gained importance since the 1990s, indicating the beginning of efforts toward the full transfer of scientific capacity to NARS for sustainable technology development. Indeed, the proportion of released varieties developed by national breeding programs using basic germplasm from IITA increased sharply from zero in the 1970s to 25% after late 1990s.

3.4. Adoption of modern varieties

The size of the impact of research generating new crop varieties depends on whether and to what extent—in terms of area planted, for example—MVs have been taken up and grown by farmers. However, measuring the size of the area planted to MVs constitutes one of the practical challenges in estimating benefits from crop breeding research. For open-pollinated crops such as maize, the difficulty arises from the fact that the characteristics of successive generations of MVs grown from recycled seed may be too different from the original generation to be readily identifiable in the field and the yield gains attributable to the MVs could possibly be lost over time (Morris and Heisey, 2003). The approach adopted in this study to estimate area under maize MVs in the surveyed countries was thus to exclude very old OPVs and hybrids, which neither breeders nor farmers would consider as MVs after several years of seed recycling and mixing with other varieties. Assuming the cumulative proportion of the area planted to MVs over time follows the logistic pattern (Griliches, 1957), the cumulative adoption rates were predicted by estimating the parameters of the logistic function using survey data on MV adoption for 1990, 1998, and 2005.

In SSA, there was very little adoption of modern varieties during the period prior to the 1980s (Evenson and Gollin, 2003). First, there were very few variety releases—less than one per year in the case of maize (Manyong et al., 2003). Second, there were lags between release and beginning of adoption due to several constraints relating mainly to seed production and distribution. Griliches (1958, p. 507) described this as the "lag between technical and commercial availability," which in the United States was two years on average but would obviously be much longer in SSA. Third, more suitable varieties became available only after the 1980s—based on research targeted specifically for African conditions (Evenson and Gollin, 2003). Therefore, research-induced benefits from adoption of maize MVs were assumed to accrue from the early 1980s.

Adoption grew steadily from low levels in the early 1980s to high levels through the 1990s and beyond in all countries (Fig. 5). The aggregate adoption curve shows that, in 2005, 60% of the maize area in the region was planted to MVs and the pattern closely follows that of the adoption pattern in Nigeria, which accounts for nearly half of the maize area in the region. In Senegal, adoption of maize MVs increased sharply from less than 1% in the early 1980s to over 40% after 1990 until it reached 95% in 2005. In Ghana and Burkina Faso, adoption grew very slowly in the 1980s, but increased markedly after

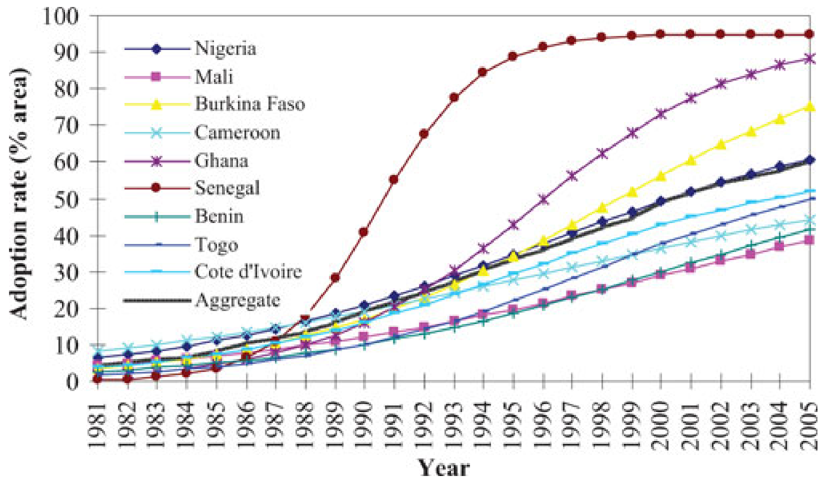


Fig. 5. Cumulative adoption rates of modern maize varieties in West and Central Africa.

1990. In other countries, adoption has similarly increased, albeit much more slowly, since the 1980s.

As the maize area varies across countries, the adoption rates alone may not indicate the relative sizes of the impacts of maize research in the different countries. Table 2 presents the total maize area and area under MVs at the beginning of the benefit period in 1981 and at the end of the benefit period in 2005. Total maize area as well as the area planted to MVs increased in all countries except in Côte d'Ivoire where total maize area declined. Overall, maize area tripled from 2.6 million hectares in 1981 to over 7 million hectares in 2005, whereas area under MVs increased from 111,000 hectares to 4.2 million hectares. In 2005, adoption rates were the highest in Senegal, but the maize area was one of the smallest (143,000 hectares) and hence the area under MVs was also small (136,000 hectares). Hybrid maize accounts for less than 5% of the area under MVs due largely to the lack of a viable seed industry in the region. The share of hybrid maize in total MV adoption is thus much smaller than the share in total MV releases.

Table 2
Maize area planted to modern varieties in West and Central Africa

Country	Maize area ('000 hectares)		Area planted to modern varieties ('000 hectares)	
	1981	2005	1981	2005
Nigeria	438	3,589	27	2,180
Mali	70	425	2	163
Burkina Faso	143	442	5	333
Cameroon	442	550	36	244
Ghana	372	750	5	664
Senegal	78	143	3	136
Benin	367	569	10	236
Togo	164	430	3	213
Côte d'Ivoire	530	133	20	69
Total	2,604	7,031	111	4,238

Source: Own survey 2007; FAOSTAT database (FAO, 2007).

The most widely cultivated varieties by country include: TZB (1980s) and TZB-SR (since 1990s) in Nigeria; TZPB (1980s) and TZPB-SR (since 1990s) in Benin; SR22 in Burkina Faso; CMS8806 in Cameroon; Obatanpa in Ghana; AB11 in Togo; DMR-ESR-W in Senegal; Sotubaka in Mali; and DMR-ESR-Y in Côte d'Ivoire. In Nigeria, the variety TZB was developed by IITA in collaboration with the national programs and was released during the mid 1970s. IITA, the Institute of Agricultural Research (IAR), and the Institute for Agricultural Research and Training (IAR&T) have been responsible for most maize research in Nigeria. By the late 1980s, it was estimated that 90% of the maize area was planted to high-yielding OPVs, such as TZB and TZPB (Smith et al., 1994). The varieties combined higher yields with resistance to lowland rust and blight, which had previously plagued Nigerian maize, particularly in the forest zone. In the drier northern savannah, farmers largely adopted the drought-tolerant variety TZB, whereas in the more humid south, farmers adopted TZPB. Years of breeding work at IITA in collaboration with IAR&T to address maize streak virus (MSV) culminated in the release during the mid 1980s of the MSV-resistant variety TZB-SR. By the late 1980s, TZB-SR already accounted for an estimated 12% of the area under maize and has since been the most widely cultivated variety in Nigeria, with yield advantages over local varieties ranging from 50% to 100% (Gilbert et al., 1994).

4. Empirical procedure

4.1. Economic surplus analysis

The economic surplus model has long been used in assessing the economic impact of agricultural research (Akino and Hayami, 1975; Byerlee and Traxler, 1995; Dalton and Guei, 2003; Griliches, 1958; Pardey et al., 2002, 2006). Alston et al. (1995) discuss several variants of the economic surplus model and present procedures for estimating research benefits for different scenarios in both *ex ante* and *ex post* analysis. Typically, net economic benefits from agricultural research arising from research-induced supply shifts are estimated based on a parallel downward shift in the (linear) supply curve of a commodity. As the supply shift represents the aggregate effect of farm-level yield gains due to MVs, however, the economic surplus model largely accounts for the yield effects of research and not for its effects on planted area. It is worth noting though that the adequacy of the economic surplus model under area expansion depends on how the area expansion has occurred and what would have prevailed had there been no research.

In the savannas of Nigeria, for example, Smith et al. (1994) reported that maize MVs, coupled with fertilizer subsidies, improved infrastructure and support services, and market opportunities, contributed to maize area expansion at the expense of sorghum and millet. However, aggregate national and regional data on cultivated area only show that the area under each of the three crops—maize, sorghum, and millet—grew at the rate of over 2.5% per year over the period 1981–2005. Available data thus suggest that maize area expansion may have occurred as part of a general increase in cropped area due largely to other factors, such as fertilizer subsidies, market opportunities, and infrastructure and support services. Indeed, despite increased availability of MVs, the maize area declined in the later half of the 1990s following removal of fertilizer subsidies in many countries. The economic surplus model was thus assumed to be adequate for evaluating maize research benefits against the counterfactual scenario where the maize area would still have expanded without MVs—in the same way as the sorghum and millet area has increased without notable varietal change. Given the counterfactual maize planting regime, maize research benefits can be conceptualized and measured in the traditional manner as research-induced yield gains resulting from the replacement of traditional varieties with MVs.[3]

Using the economic surplus model, the annual flows of economic benefits from maize research were first estimated for each country and then aggregated to derive the total benefits in the region. The model for the small, open economy (Alston et al., 1995), adapted for an *ex post* impact assessment (Masters et al., 1996), was used to calculate the *ex post* economic benefits in year t from a downward shift in the maize supply curve as

$$ES_t = P_t Q_t K_t (1 - 0.5 K_t \varepsilon), \tag{1}$$

where ES is the change in total economic surplus attributed to maize research, K is the supply shift as a proportion of the price and measures net unit cost reductions resulting from adoption of a modern variety, P is the real world market price of maize, Q is total maize production, and ε is the price elasticity of supply of maize.

4.1.1. Supply shift

The research-induced supply shift parameter, K_t, is the single most important parameter influencing total economic surplus results from unit cost reductions. Following Alston et al. (1995), the supply shift was estimated as

$$K_t = \left(\frac{(\Delta Y/Y)}{\varepsilon} - \frac{(\Delta C/C)}{1 + (\Delta Y/Y)}\right) \times A_t, \tag{2}$$

where $\Delta Y/Y$ is the average proportional maize yield increase per hectare attributable to research, $\Delta C/C$ is the average proportional change in the variable costs required to achieve the yield increase, and A_t is the rate of adoption of MVs at time t. The experimental yield gains associated with MVs are net of the effects of other inputs and thus no additional costs are incurred to realize the gains except improved seed costs. The incremental cost associated with seeds of the predominantly used OPVs is a small fraction of the total cost of production per hectare (i.e., ΔC/C), implying that the second term within the bracket in Eq. (2) would be approximately zero.[4] Therefore, the formula for calculating the supply shift reduces to

$$K_t = \left(\frac{(\Delta Y/Y)}{\varepsilon}\right) \times A_t. \tag{3}$$

4.1.2. Yield gains attributable to maize research

The economic benefits from maize research result mostly from the productivity gains that farmers experience after adopting MVs. To isolate the contribution of MVs to yield increases, on-farm experimental yield data were assembled from on-farm trials conducted by the network of maize research program partners in the region. Experimental yields have the advantage of holding many of the variables influencing yields constant and hence provide a good approximation of the contribution to yield gains of variety improvement research (Pardey et al., 2002, 2006). The yield gains, estimated this way, are net of the effects of other inputs and hence represent net yield gains. Although absolute yields achieved in experimental trials would be higher than those in farmers' fields, it is not obvious whether the yield gains in trials would also be greater (Pardey et al., 2002, 2006).

[3] Morris et al. (1994) and Byerlee and Traxler (1995) distinguish between Type I and Type II benefits from wheat research associated with two types of varietal technical change—Type I relating to the replacement of traditional varieties with MVs and Type II relating to the replacement of old MVs with newer MVs. The focus of this article is on Type I technical change because the benefits from replacing traditional varieties are believed to be the most important in rain-fed agriculture (Aw-Hassan and Shideed, 2003). In Asia, Type II benefits were found to be significant only in the irrigated environments and during the post-Green Revolution period (Byerlee and Traxler, 1995). In Africa, where Green Revolution has yet to occur and crops are produced almost exclusively under rain-fed conditions, research benefits are derived largely from Type I (or Green Revolution type) technical change.

[4] As seed of improved OPVs can be recycled for several seasons, the initial seed cost can actually be spread across seasons. This can be illustrated using partial budgets prepared to assess the relative profitability of modern varieties under farmer management. Morris et al. (1999, p. 31) present such partial budgets for Ghana. Assuming that a farmer replaces seed every four years, the additional seed cost of ¢10,000, spread over four years, would only be 1% of the total variable cost of ¢222,000 per hectare (i.e., $\Delta C/C = 0.01$). With a yield gain of 24%, this implies that $(\Delta C/C)/(1+\Delta Y/Y) = 0.009$.

It was thus assumed that the relative gains achieved in on-farm experimental trials would be representative of the relative gains realized by farmers. In estimating the yield gains attributable to maize research, the absolute yield gain from adoption of MVs over traditional varieties (ΔY) and the proportional yield gains ($\Delta Y/Y$) were first assumed to be constant through time.

For each country, average yield gains were estimated using yield data from on-farm variety evaluation trials for the popular or most widely cultivated varieties. Given the average on-farm experimental yield of the popular MVs in a country (Y^{MV}) and the average yield of the reference traditional variety (Y^{TV}), the yield gain as a proportion of the yield of the MV was computed as

$$\left(\frac{\Delta Y}{Y}\right) = \left(\frac{Y^{MV} - Y^{TV}}{Y^{MV}}\right). \quad (4)$$

Note that the yield increase is expressed as a proportion of the yield with the MV because the basic data on maize production are observed *ex post* with the contribution of research (Akino and Hayami, 1975; Aw-Hassan and Shideed, 2003; Griliches, 1958; Morris, 2002). Economic benefits from maize research were estimated for each country using yield gains as a proportion of MV yields: Cameroon (19%), Benin (18%), Ghana (17%), Burkina Faso (20%), Mali (25%), Senegal (15%), Côte d'Ivoire (20%), Togo (15%), and Nigeria (27%). An average net yield gain of 23% was estimated as the weighted average (weighted by the maize area under MVs) of the individual country yield gains. The aggregate adoption rate of 60% over the period 1981–2005 and the experimental yield gain of 23% together suggest that maize research efforts have boosted average maize yields realized in West and Central Africa by 0.58% per year. Given the aggregate industry-level maize yield growth rate of 2% per year, this in turn suggests that improved maize germplasm accounted for about 30% of the overall yield growth, with the rest being attributed to crop management.

4.1.3. Price elasticity of supply

Price elasticity of supply is a key determinant of research benefits and is largely determined by the supply of inputs used in production. Credible country-specific estimates of price elasticity of supply were not available except for Benin (Honfoga, 1993). Honfoga (1993) estimated a price elasticity of maize acreage of 0.45 for Mono province in Benin, which is a major maize production and trade zone. Given the importance of maize as a food and cash crop in Benin, the elasticity estimate of 0.45 was applied to all countries. Previous studies using the economic surplus model also applied a single estimate to several countries in a region. For example, Byerlee and Traxler (1995) used a price elasticity of supply of 0.3 for wheat in SSA.

4.1.4. Economic benefits and rates of return

Research-induced yield gains, MV adoption rates, annual maize production, and world prices of maize were used to estimate a stream of benefits from maize research. The streams of benefits (1981–2005) and research costs (1971–2005) were converted into net present values by compounding forward to 2005 at a real discount rate of 5% per annum. A research lag of 10 years was assumed for international maize research and five years lag for NARS due to shorter breeding cycles to release varieties once they have received advanced germplasm from international programs. Therefore, the research costs were calculated for the period 1971–2005 for international maize research at IITA and for the period 1976–2005 for maize research in individual countries. Net present value (NPV) of benefits and rates of return (ROR) were calculated for international and national maize research as well as for each country, with the international research spill-ins for each country treated as a free public good, so that the full surplus generated in each country accrues entirely to the NARS research system (Byerlee and Traxler, 1995). For each country, the benefits or economic surplus and research costs over the 30-year period were compounded forward at a real discount rate of 5% per annum to derive the NPVs in 2005. Benefit–cost ratios were calculated as the ratio of the present value of benefits to the present value of research costs, whereas the ROR were calculated as the discount rate equating the NPV of benefits to zero.

4.2. Analysis of impacts on poverty reduction

As a key driver of broad-based technological change in agriculture, agricultural research can reduce poverty in a number of different ways (David and Otsuka, 1994; Kerr and Kolavalli, 1999; Lipton and Longhurst, 1989). First, it can help reduce poverty directly by raising the incomes (or home consumption) of poor farmers who adopt the resulting technological innovation. Second, technological change can help reduce poverty indirectly through the effects that adoption, by both poor and nonpoor farmers, can have on the real incomes of others through lower food prices for consumers as well as increased employment and wage effects in agriculture and other sectors of economic activity through production, consumption, and savings linkages (de Janvry and Sadoulet, 2002; Haggblade et al., 1991). As much of agricultural output in SSA is consumed on farm, the direct effects of agricultural research—in terms of increased home consumption—are believed to be the most important (de Janvry and Sadoulet, 2002).

In West and Central Africa, maize and maize technologies have a number of important features that enhance the poverty reduction potential of maize research. First, maize grows in a wide range of production environments and is thus very important to the poor in production for home consumption. In Nigeria, for example, maize accounts for the largest share (20%) of total food consumption among the rural poor (Alene et al., 2009). Second, as a cash crop, maize provides producers with greater market opportunities for generating cash incomes. In Ghana, for example, at least half of all maize produced enters the market (Morris et al., 1999). The market potential for maize has considerable welfare implications not only for producers but also for poor consumers who would benefit from research-induced lower prices. Indeed, in many countries in the region, consumer prices of maize are lower than the prices of sorghum and millet, which have benefited little from technical change. Third, available maize technologies—such as improved OPVs—can be adopted by resource-poor farmers who would not otherwise afford to buy fresh seed of hybrid maize every cropping season.

The impact pathway from maize research to poverty reduction discussed above provided the basis for the assessment of the impact of maize research on poverty reduction in West and Central Africa, with poverty defined in terms of the \$1-a-day poverty line. Following Fan et al. (2005), the marginal impact on poverty reduction of an annual increase in the value of agricultural production was first calculated using poverty reduction elasticities of agricultural productivity growth. The reduction in the total number of poor per year due to maize research was then calculated by treating the estimated annual research benefits as additional agricultural production per year that translates into increased incomes or consumption for the poor. Thirtle et al. (2003) estimated that a 1% increase in agricultural productivity reduces the total number of poor in Africa by 0.72%. Although this is an average elasticity measure, the importance of maize and the nature of maize technologies discussed above make it applicable to maize research. Under the assumption of constant returns to scale, a 1% increase in total factor productivity in turn leads to a 1% growth in agricultural production (Fan et al., 2005). For each country and year (thus dropping time subscripts), the number of poor people lifted out of poverty due to maize research was thus estimated as

$$\Delta N = \underbrace{\underbrace{\underbrace{\left(\frac{ES}{\text{AgGDP}} \times 100\%\right)}_{\text{Annual gains from research as \% of agricultural GDP}} \times \underbrace{\frac{\partial \ln(N)}{\partial \ln(\text{AgGDP})}}_{\text{Poverty elasticity} = 0.72}}_{\text{Poverty reduction per year as \% of the poor}} \times N}_{\text{Number of poor escaping poverty annually}}, \quad (5)$$

where ΔN is the number of poor lifted out of poverty, ES is the change in economic surplus due to maize research and represents the value of additional production, AgGDP is agricultural GDP and represents the value of total agricultural production, and N is the total number of poor. It is important to note that maize production and hence agricultural GDP in a given year already reflect the additional maize production due to research because both are observed *ex post* with the contribution of research. Maize production growth and poverty reduction measures thus represent changes relative to the counterfactual scenario without maize research where there would be less maize output and a greater number of poor people. In West Africa during this period the number of poor people may have been rising, with maize research acting to reduce the rate of increase.

4.3. Attribution of research benefits

Successful research involves interaction among different actors. When we can attribute benefits to one or another institution, we make an implicit assumption about what the other actors would otherwise have been able to accomplish. In this study, we follow the recent examples of Pardey et al. (2002, 2006), Morris (2002), and Fan et al. (2005), and use a range of attribution rules based on the ancestry of each variety release. Pardey et al. (2002, 2006), for example, used this approach to attribute benefits to Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) from variety improvement research in Brazil. At one extreme, we could attribute all measured benefits entirely to the institution responsible for the last cross. At the opposite extreme, we can attribute credit to any institution responsible for any cross in the variety's ancestry. Both the "last-cross" and the "any-ancestor" rule implicitly assume that all institutions other than the one being evaluated would be doing their work anyway. These two rules represent polar cases in how benefits can be attributed (Fan et al., 2005): the last-cross rule is the most rigid, allowing a variety's benefits to be claimed only by the institution responsible for the final step, whereas the any-ancestor rule is the most flexible, allowing a variety's benefits to be counted as many times as there were institutions involved in its ancestry.

In this study, we want to consider the work of multiple institutions over many countries and a long time period, focusing particularly on the contributions of CIMMYT, IITA, and the various national programs. In attributing total benefits, we use the shares of germplasm sourced from each of the international centers—IITA and CIMMYT—in total variety releases (Fig. 3), and the content of germplasm sourced from each center measured as the share of direct and adaptive transfers in total variety releases (Fig. 4). With the last-cross rule, the benefits attributable to each international center were estimated based on the respective cumulated shares of only their own direct and adaptive transfers.[5] With the any-ancestor rule, the benefits attributable to each center were estimated based on their share of all germplasm.[6] Both approaches consider the same total flow of benefits from all maize varieties released in the region since the 1970s.

5. Empirical results

5.1. Net benefits and rates of return

Table 3 presents the NPV of benefits from maize research and the corresponding estimates of the benefit–cost ratios and ROR. The total net benefit from international and national maize research in West and Central Africa over the period 1981–2005 is estimated at US\$6.8 billion—equivalent to 12% of the present value of total maize production over the same period. Annual net

[5] For each center, the cumulated shares for the last-cross rule, for example, were calculated as the cumulated number of direct and adaptive releases since the 1970s divided by the cumulated number of all varieties released over the same period.

[6] Actual adoption of individual varieties would be preferred to variety release information for attribution purposes (Pardey et al., 2006), but variety-specific adoption data are hardly available for maize varieties.

Table 3
Summary measures of maize research benefits and costs in West and Central Africa, 1971–2005

	Net present value (US$ million)		B–C ratio	ROR (%)
	Total	Annual		
Nigeria	4,850	194	84	74
Mali	152	6	11	37
Burkina Faso	247	10	14	39
Cameroon	366	15	18	69
Ghana	593	24	12	40
Senegal	118	5	12	28
Benin	209	8	28	64
Togo	117	5	10	31
Côte d'Ivoire	316	13	20	63
Aggregate	6,847	274	21(10)[a]	43(30)[a]

[a]Estimates accounting for all maize research costs (i.e., breeding and nonbreeding costs).

Table 4
Present value of benefits from international maize research in West and Central Africa

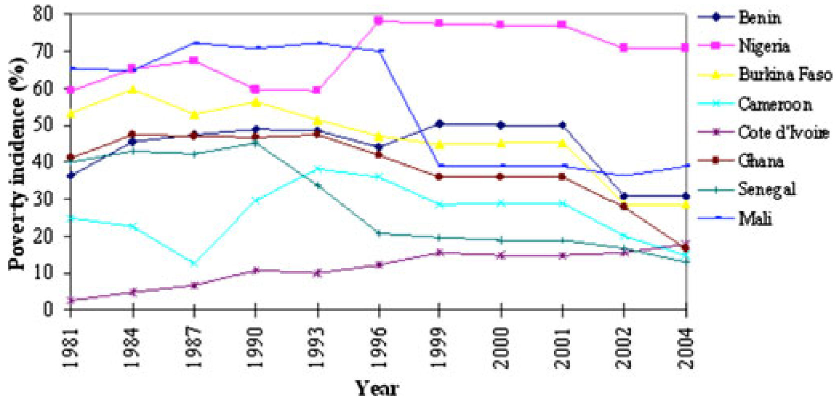
Year	Last-cross rule			Any-ancestor rule		
	IITA	CIMMYT	Total	IITA	CIMMYT	Total
	(US$ million)					
1981	18	6	24	26	15	41
1982	16	5	21	23	13	36
1983	23	8	31	33	19	52
1984	29	9	38	41	23	64
1985	34	11	45	48	27	75
1986	46	15	61	65	37	102
1987	52	17	69	74	42	116
1988	85	28	113	121	69	190
1989	93	30	123	132	75	207
1990	104	34	138	147	84	231
1991	112	36	148	159	90	249
1992	99	32	131	141	80	221
1993	106	34	140	151	86	237
1994	127	41	168	180	102	282
1995	151	49	200	214	122	336
1996	166	53	219	235	134	369
1997	117	38	155	167	95	262
1998	100	32	132	142	81	223
1999	97	31	128	138	79	217
2000	78	25	103	111	63	174
2001	84	27	111	119	68	187
2002	101	32	133	143	81	224
2003	117	38	155	166	95	261
2004	142	46	188	201	114	315
2005	129	42	171	183	104	287
Total	2,227	718	2,945	3,161	1,796	4,957
Mean	89	29	118	126	72	198

benefits increased from US$43 million in 1981 to over US$400 million in 2005, with an average of US$274 million per year. The NPV of annual benefits to Nigeria is estimated at US$194 million, representing 70% of the annual benefits to the region. This is consistent with the fact that Nigeria accounts for about half of the maize area as well as the area planted to MVs in the region.

International and national maize improvement research in West and Central Africa had an impressive benefit–cost ratio of 21, indicating that each dollar invested in maize improvement research generated 21 dollars worth of additional food. Even when both breeding and nonbreeding costs are included, the aggregate ROR reduces only to 30% per year and the benefit–cost ratio reduces to 10, suggesting that benefits from maize genetic improvement alone are in excess of all maize research costs in the region. Country-level benefit–cost ratio estimates have been even much higher, due in part to the research spill-ins from international maize research, and range from 11 in Mali to 84 in Nigeria. Consistent with the payoffs implied by the estimated benefit–cost ratio, maize improvement research in West and Central Africa generated an ROR of 43%. The estimated ROR is much higher than the prevailing market interest rates and confirms that maize research has generated a stream of benefits in excess of the expenditures and has thus been a worthwhile investment in the region.

The ROR for individual countries—calculated with international maize research spill-ins treated as a free public good—range from 28% in Senegal to 74% in Nigeria. The aggregate as well as individual country estimates of ROR to maize research are generally comparable to those of previous studies. Consistent with our aggregate ROR estimate of 43%, Evenson (1987) estimated an aggregate ROR of 30–40% for maize and staple crops research in Africa for the period 1962–1980. In cases where germplasm and crop management research benefits are assessed jointly or where technologies are borrowed from elsewhere thus involving little research costs, earlier studies of ROR to maize research provide evidence of greater returns to maize research. For Ghana, for example, Sanders (1994) estimated an ROR of 74% for the period 1968–1991, which is higher than our estimate of 43% due in part to the fact that the study assessed the effects of both varieties and inorganic fertilizer. For southern Mali, where much of the technical package was borrowed from research conducted elsewhere in West Africa, Boughton and de Frahan (1992) estimated an ROR of 135% for the period 1969–1991.

Table 4 presents the results of attribution of benefits from maize research in West and Central Africa to IITA and CIMMYT. The present value of benefits attributed to international maize research ranges from an estimated US$2.5 billion (37%) with the last-cross rule to US$4.3 billion (63%) with the any-ancestor rule. With an estimated 37% minimum contribution to total benefits, international maize research generates at least US$99 million per year to the region. The present value of benefits attributable to international maize research at IITA ranges from an estimated US$89 million per year with the last-cross rule to US$126 million per year with the any-ancestor rule. On the other hand, the present value of benefits attributable to international maize research at CIMMYT ranges from an estimated US$29 million per year with the last-cross rule to US$72 million per year with the any-ancestor rule.



Source: World Bank PovcalNet database (Chen and Ravallion, 2007).

Fig. 6. Trends in poverty incidence in West and Central Africa, 1981–2005.

5.2. Impact on poverty reduction

While the number of poor people in SSA rose sharply in the 1980s, the rate of increase has since slowed down and the proportion of all people in poverty has declined (Chen and Ravallion, 2007). Fig. 6 shows the trends in poverty incidence—the percentage of the population living on less than $1 a day—for our sample of countries in West and Central Africa over the period 1981–2004. Poverty incidence increased throughout the 1980s and early 1990s, but generally declined thereafter, most notably in Senegal, Mali, Ghana, Burkina Faso, Benin, and Cameroon. In Ghana and Senegal, both the poverty incidence and the number of poor have declined, due partly in Ghana to recent improvements in cocoa production and prices (World Bank, 2007).

The estimated poverty reduction impacts of maize research over the period 1981–2004 are presented in Table 5. Poverty reduction expressed as a percentage of the poor ranges from less than 0.1% in 1981 to over 1.26% in 2004, with an average of 0.75% per year. In terms of the number of poor lifted out of poverty, the impact ranges from over 58,000 in 1981 to 1.4 million in 2004, with an average of 740,000 per year. Estimated impacts by country range from less than 0.2% of the poor per year in Cameroon to 0.6% in Benin, 0.75% in Ghana, and 0.9% in Nigeria. The relatively greater poverty impacts in Benin, Ghana, and Nigeria are consistent with the fact that, in these countries, maize accounted for about 10% of the value of agricultural production over the period 1981–2004. In 2005, maize accounted for 15% of the value of agricultural production in Nigeria and 13% of the value of agricultural production in Ghana. In Ghana, the dramatic growth in maize production over the period 1979–1998 is cited as a major success brought about through sustained research and extension investments (Morris et al., 1999; World Bank, 2007).

We now turn to the poverty reduction that can be attributed specifically to international maize research (Table 6). On average over the entire period, the number of people moved out of poverty due to the international centers ranges from over 300,000 per year with last-cross rule to over 500,000 poor with the any-ancestor rule. Most of this is attributable to activities at IITA. Given total IITA spending, we estimate that every US$1 million invested in international maize research at IITA on average lifted between 35,000 and 50,000 people out of poverty. There is no sign of any decline in the poverty impacts of MVs, suggesting that maize research will continue to be a factor in promoting poverty reduction in the future.

5.3. Sensitivity analysis

In an effort to gain confidence in the results, we evaluated the sensitivity of the base model estimates to variations in the values of some key parameters. Recognizing that the supply shift parameter—a function of yield gains and price elasticity of supply—is the major determinant of research benefits, the model was estimated under two conservative scenarios. First, the proportional yield gains attributable to maize research were assumed to be half of the base yield gains. Second, the elasticity of maize supply was assumed to be one, up from the estimated base value of 0.45. Several countries mounted costly extension campaigns focusing on the maize package—such as the seed–fertilizer package programs supported by the Sasakawa-Global 2000 initiative. However, data on extension costs relating to maize technologies were not available. Given the key role of extension in realizing the gains from research, the sensitivity of the estimated ROR was evaluated by estimating the model with extension costs assumed to be double the research costs based on Evenson's (1986) upper-bound estimate of extension–research cost ratio for Africa. Finally, given the very long, or even infinite, lag between research investments and reaping the full benefits (Alston and Pardey, 2001), our analysis that links the stream of past investments (1971–2005) to a finite stream of benefits (1981–2005) is bound to understate the true benefits. To gain a sense of the magnitude of the biases, we estimated the model with the benefit stream extended by five years to 2010.

Table 5
The poverty reduction impact of maize research in West and Central Africa (percentage and number of poor people)

Year	Benin		Nigeria		Burkina Faso		Cameroon		Côte d'Ivoire		Senegal		Ghana		Mali		Aggregate	
	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)	%	# ('000)
1981	0.24	3	0.10	43	0.10	3	0.16	3	0.09	0.2	0.01	0.1	0.04	2	0.06	3	0.09	58
1982	0.19	3	0.09	39	0.08	3	0.15	3	0.09	0.2	0.00	0.1	0.04	2	0.04	2	0.08	52
1983	0.27	4	0.17	70	0.07	3	0.20	4	0.13	0.3	0.01	0.2	0.03	2	0.16	8	0.15	90
1984	0.35	7	0.23	117	0.09	4	0.15	3	0.18	1	0.03	1	0.15	9	0.13	6	0.20	148
1985	0.36	7	0.29	146	0.15	7	0.11	2	0.20	1	0.05	2	0.14	8	0.17	9	0.25	181
1986	0.26	5	0.45	225	0.14	6	0.10	2	0.13	1	0.05	1	0.12	8	0.18	9	0.35	256
1987	0.20	5	0.58	328	0.13	5	0.10	1	0.14	1	0.07	2	0.15	10	0.14	8	0.45	360
1988	0.41	9	0.89	501	0.29	12	0.15	2	0.21	1	0.15	5	0.30	20	0.24	14	0.71	564
1989	0.45	10	0.95	531	0.41	17	0.17	2	0.25	1	0.28	9	0.36	24	0.24	14	0.76	608
1990	0.46	12	1.10	597	0.48	23	0.16	6	0.26	4	0.36	13	0.34	25	0.22	14	0.83	693
1991	0.49	12	1.14	620	0.54	26	0.24	8	0.28	4	0.37	13	0.65	47	0.32	20	0.90	751
1992	0.48	12	1.04	566	0.55	26	0.21	7	0.27	4	0.41	15	0.53	38	0.19	12	0.81	681
1993	0.51	15	1.14	665	0.42	20	0.20	10	0.29	4	0.55	16	0.77	61	0.31	22	0.90	812
1994	0.57	16	1.41	822	0.66	31	0.23	11	0.33	4	0.45	13	0.93	74	0.39	27	1.11	999
1995	0.83	23	1.68	982	0.51	25	0.30	14	0.40	6	0.52	15	1.30	104	0.39	27	1.33	1,195
1996	0.97	28	1.72	1,437	0.88	42	0.43	21	0.53	10	0.50	10	1.67	126	0.54	40	1.50	1,713
1997	0.91	26	1.17	977	0.88	42	0.31	15	0.41	8	0.25	5	1.26	96	0.47	34	1.05	1,203
1998	0.75	21	0.99	825	0.79	38	0.27	13	0.37	7	0.15	3	1.16	88	0.47	34	0.90	1,030
1999	0.82	29	0.95	843	0.91	45	0.23	11	0.33	8	0.18	4	1.06	74	0.65	28	0.88	1,043
2000	0.79	28	0.72	641	0.85	42	0.22	10	0.33	8	0.20	4	1.09	77	0.26	12	0.70	821
2001	0.74	26	0.80	711	1.32	65	0.21	10	0.34	9	0.26	5	1.01	71	0.35	15	0.77	912
2002	0.73	17	0.92	807	1.51	52	0.27	8	0.40	11	0.27	5	1.63	94	0.50	23	0.91	1,017
2003	1.04	25	1.04	911	1.77	61	0.31	10	0.45	12	1.21	22	1.61	92	0.61	27	1.04	1,160
2004	1.35	34	1.31	1,198	1.37	50	0.40	10	0.54	17	1.41	21	1.67	60	0.82	42	1.26	1,433
Annual	0.60	16	0.90	608	0.60	27	0.22	8	0.30	5	0.30	8	0.75	50	0.30	18	0.75	740

Table 6
Poverty reduction in West and Central Africa due to international maize research

Year	Last-cross rule			Any-ancestor rule		
	IITA	CIMMYT	Total	IITA	CIMMYT	Total
	('000)					
1981	18	6	24	26	15	41
1982	16	5	21	23	13	36
1983	28	9	37	40	22	62
1984	46	15	61	65	37	102
1985	56	18	74	80	45	125
1986	79	26	105	113	64	177
1987	111	36	147	158	90	248
1988	175	56	231	248	141	389
1989	188	61	249	268	152	420
1990	215	69	284	305	173	478
1991	233	75	308	330	188	518
1992	211	68	279	300	170	470
1993	252	81	333	357	203	560
1994	310	100	410	439	250	689
1995	371	120	491	526	299	825
1996	531	171	702	754	428	1,182
1997	373	120	493	529	301	830
1998	319	103	422	453	257	710
1999	323	104	427	459	261	720
2000	255	82	337	361	205	566
2001	283	91	374	401	228	629
2002	315	102	417	448	254	702
2003	360	116	476	510	290	800
2004	444	143	587	630	358	988
Annual	230	74	304	326	185	511
Per $1 million	35			50		

The results of the sensitivity analysis show that, as a consequence of changes in supply shift, the present value of benefits is sensitive to changes in yield gains and price elasticity of supply (Table 7). Halving yield gains to less than 12% has a proportional effect of halving NPV benefits to about US$3.3 billion, but the ROR drops only to 33% and poverty reduction to 380,000 per year. Increasing the price elasticity of supply from 0.45 to one (i.e., more than double), as recommended by Alston et al. (1995) when there are no reliable estimates, reduces the benefits by more than half but the aggregate ROR only reduces by a quarter to 32% per year. Accounting for extension costs, approximated as double the research costs, reduces net benefits by only 6%, with the ROR (to research and extension) dropping only to 33%. Whether extension costs are accounted for has no effect on estimated poverty reduction because research and extension are funded by the public sector whereas benefits accrue to individual households. Finally, extending the time path of benefits by five years to 2010 has the effect of increasing net benefits by over 25%.

Overall, the summary measures suggest that the scenario with unitary price elasticity of supply is the most conservative, with the aggregate benefit–cost ratio reduced by more than half and the ROR reduced by a quarter. Nonetheless, the implied minimum net benefits would still be an impressive US$116 million per year, with an ROR of 32% and poverty reduction of over 300,000 per year. On the other hand, the scenario with an extended time path yields the upper-bound estimates—annual net benefit of US$288 million and poverty reduction of about 880,000 per year. Clearly, the base model estimates based on the observed values of various parameters are within the range of possible benefits implied by alternative assumptions. The analysis thus lends credence to the main results.

6. Conclusions and implications

Using data on variety performance and adoption patterns implied by the S-shaped logistic curve, this article estimates the benefits from maize research in West and Central Africa over the last three and half decades. The article also estimates the benefits due to international maize research at IITA and CIMMYT using alternative attribution rules. A large number of modern varieties have been developed and farmers in the region have gained an increased access to these varieties. Consistent with the need for a gradual transformation of the scientific capacity of national programs, the content of earlier varietal releases points to the predominance of CIMMYT and IITA germplasm supplied for direct release to farmers, whereas the content of recent releases shows that national programs are developing at least as many varieties as they source from IITA for direct release. However, there is much to be desired beyond capacity strengthening of NARS, and international research will continue to be complementary to NARS research even after full scientific capabilities have been transferred. For example, national research efficiency gains from international spillovers of technology in an era of declining budgets would justify increased support for international maize research to generate widely adapted materials and to coordinate international variety trials for testing and distributing germplasm.

Over the last three and half decades, maize research in West and Central Africa had an estimated ROR of 43% per year. Individual country rates of return are much higher due to international research spillovers, suggesting that failure to account for research spillovers would grossly overestimate research returns. With over half of the economic and poverty impacts attributed to IITA and CIMMYT, international maize research played an important role in these successes. Future research accounting for the nonyield benefits of modern varieties—such as early maturing varieties that escape drought and avert possible hunger and QPM varieties that improve nutrition and health—might reveal even greater benefits from maize research. The results suggest that poverty in the region would have been substantially worse had there been no research to increase, or at least maintain, maize yields in the face of pest and disease pressure, soil fertility decline, and area expansion onto marginal lands.

There is no sign of any decline in the benefits from modern varieties of maize in the region, suggesting that maize research will continue to be a factor in reducing poverty. If there is any decline in variety adoption and benefits, this would likely be due to constraints outside the research system. For example, maize

Table 7
Sensitivity analysis of the economic and poverty impacts of maize research in West and Central Africa

Parameter	Country	Parameter values			NPV (US$ m)		B–C ratio		ROR (%)		Poverty reduction (%)	
		Base	New	Δ(%)	New	Δ(%)	New	Δ(%)	New	Δ(%)	New	Δ(%)
Yield gain (%)	Nigeria	27	13.5	−50	2,458	−49	43	−49	58	−22	0.45	−48
	Mali	25	12.5	−50	70	−54	6	−47	26	−30	0.17	−48
	Burkina Faso	20	10.0	−50	117	−53	7	−50	28	−28	0.32	−48
	Cameroon	19	9.5	−50	174	−52	9	−51	47	−32	0.11	−50
	Ghana	17	8.5	−50	278	−53	6	−49	30	−25	0.38	−49
	Senegal	15	7.5	−50	56	−53	6	−50	21	−25	0.17	−47
	Benin	18	9.0	−50	102	−51	14	−50	47	−27	0.3	−49
	Togo	15	7.5	−50	53	−55	5	−48	22	−29	0.29	−50
	Côte d'Ivoire	20	10.0	−50	152	−52	10	−50	44	−30	0.15	−48
	Aggregate	23	11.5	−50	3,339	−51	11	−48	33	−23	0.38	−49
Price elasticity of supply (ε)	Nigeria	0.45	1.00	+122	2,150	−56	38	−55	55	−26	0.39	−55
	Mali	0.45	1.00	+122	60	−60	5	−53	25	−32	0.15	−55
	Burkina Faso	0.45	1.00	+122	100	−59	6	−56	26	−33	0.28	−55
	Cameroon	0.45	1.00	+122	152	−58	8	−56	44	−36	0.1	−55
	Ghana	0.45	1.00	+122	237	−60	5	−55	28	−30	0.34	−55
	Senegal	0.45	1.00	+122	47	−60	5	−56	5	−82	0.15	−53
	Benin	0.45	1.00	+122	90	−57	12	−56	20	−69	0.27	−54
	Togo	0.45	1.00	+122	46	−61	5	−54	20	−35	0.26	−55
	Côte d'Ivoire	0.45	1.00	+122	133	−58	9	−56	42	−33	0.13	−55
	Aggregate	0.45	1.00	+122	2,895	−58	10	−54	32	−26	0.34	−55
R&E costs (US$ m/year)	Nigeria	0.86	2.58	+200	4,769	−2	28	−67	70	−5	0.87	0
	Mali	0.32	0.96	+200	131	−14	4	−65	30	−19	0.33	0
	Burkina Faso	0.13	0.38	+200	214	−13	5	−68	29	−26	0.62	0
	Cameroon	0.32	0.95	+200	334	−9	6	−68	63	−9	0.22	0
	Ghana	1.02	3.05	+200	497	−16	4	−67	32	−20	0.75	0
	Senegal	0.18	0.55	+200	103	−12	4	−67	23	−18	0.32	0
	Benin	0.15	0.46	+200	196	−6	9	−67	60	−6	0.59	0
	Togo	0.23	0.69	+200	98	−16	3	−66	22	−29	0.58	0
	Côte d'Ivoire	0.26	0.77	+200	290	−8	7	−67	56	−11	0.29	0
	Aggregate	8.70	15.9	+83	6,412	−6	6	−69	33	−23	0.75	0
Time path of benefits from investments made during 1971–2005	Nigeria	1981–2005	1981–2010		5,908	+22	105	+25	74	0	0.96	+10
	Mali	1981–2005	1981–2010		221	+45	17	+53	37	0	0.43	+30
	Burkina Faso	1981–2005	1981–2010		378	+53	21	+52	39	0	0.77	+24
	Cameroon	1981–2005	1981–2010		463	+27	23	+26	69	0	0.26	+18
	Ghana	1981–2005	1981–2010		785	+32	16	+34	40	0	0.93	+24
	Senegal	1981–2005	1981–2010		181	+53	18	+52	28	0	0.54	+69
	Benin	1981–2005	1981–2010		282	+35	38	+37	64	0	0.74	+25
	Togo	1981–2005	1981–2010		160	+37	14	+43	31	0	0.8	+38
	Côte d'Ivoire	1981–2005	1981–2010		390	+23	25	+23	63	0	0.34	+17
	Aggregate	1981–2005	1981–2010		8,647	+26	27	+31	43	0	0.85	+13

Notes: Δ represents percentage change from the base model value.
US$ m = US$ million; R&E = research and extension.

research benefits stagnated during the late 1990s when maize area declined and the area under modern varieties stagnated following the removal of fertilizer subsidies and the collapse of support services. High fertilizer prices and poor access to credit together reduce the profitability of modern varieties and limit further adoption. For Nigeria, which actually accounted for much of the maize area decline during the late 1990s, the fertilizer liberalization policy adopted in 1996 effectively ended the heavy subsidies of up to 85% and resulted in a sharp decline in fertilizer use from over 500,000 tons in 1994 to about 100,000 tons in 1999 (Bumb et al., 2000). The evidence points to the fact that the impacts of research investments are conditioned by farmers' physical and economic access to a number of complementary inputs. High rates of return to agricultural research are difficult to sustain in an environment where inputs are not accessible or affordable to farmers. A critical input for achieving greater adoption is an efficient seed system for supplying improved seed. Modern varieties can disseminate only with the help of an effective national seed industry, but this is still lacking in many countries in West and Central Africa. More efficient extension and input supply systems and improved market infrastructure would thus be needed to achieve greater impacts from maize research in West and Central Africa.

Acknowledgments

The authors are grateful to the leaders of the national maize research programs for their excellent assistance during data collection: C. G. Yallou, J. Sanou, C. Thé, Louise Akanvou, M. Ewool, N'tji Coulibaly, S. A. Olakojo, and A. Didjeira. Lum Fontem coordinated data collection in Cameroon. We thank three anonymous reviewers for useful comments and suggestions on an earlier version of the article.

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