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# Measuring the Effectiveness of Crop Improvement Research in Sub-Saharan Africa from the Perspectives of Varietal Output, Adoption, and Change: 20 Crops, 30 Countries, and 1150 Cultivars in Farmers' Fields

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Synthesis Report for Objectives 1 and 2 of Bill & Melinda Gates Foundation's Diffusion and Impact of Improved Varieties in Africa (DIIVA) Project

# Measuring the Effectiveness of Crop Improvement Research in Sub-Saharan Africa from the Perspectives of Varietal Output, Adoption, and Change: 20 Crops, 30 Countries, and 1150 Cultivars in Farmers' Fields

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## Tables and figures

# Acronyms and abbreviations

| | |
|---|---|
| ASTI | Agricultural Sciences and Technology Indicators |
| BMGF | Bill & Melinda Gates Foundation |
| BSc | Bachelor of Science |
| CATIE | Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica) |
| CAR | Central African Republic |
| CIAT | Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture) |
| CIMMYT | Centro Internacional de Mejoramiento de Maiz y Trigo (International Center for the Improvement of Maize and Wheat) |
| CIP | Centro Internacional de La Papa (International Potato Center) |
| CIRAD | Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Agricultural Research for Development) |
| CRSP | Collaborative Research Support Program of USAID |
| CSIR | Council for Scientific and Industrial Research (Ghana) |
| DIIVA | Diffusion and Impact of Improved Varieties in Africa |
| EAP | Escuela Agricola Panamericana Zamorano (Zamorano Pan-American Agricultural School) |
| ECABRN | East and Central Africa Bean Research Network |
| EIAR | Ethiopian Institute of Agricultural Research |
| ESA | East and Southern Africa |
| FAO | Food and Agriculture Organization of the United Nations |
| FHIA | Fundación Hondureña de Investigación Agrícola (Honduras Foundation for Agricultural Research) |
| FTE | Full-time equivalent |
| GDP | Gross Domestic Product |
| GxE | Genotype by environment |
| HYV | High-Yielding Varieties |
| IARC | International Agricultural Research Center |
| ICARDA | International Center for Agricultural Research in Dry Areas |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IFPRI | International Food Policy Research Institute |
| IITA | International Institute of Tropical Agriculture |
| INTSTORMIL | International Sorghum and Millet Collaborative Research Project of USAID |
| IRAT | Institut de Recherches Agronomiques Tropicales |
| IRRI | International Rice Research Institute |
| ISNAR | International Service for National Agricultural Research |
| IVT | Institute of Horticultural Plant Breeding |
| JICA | Japan International Cooperation Agency |
| MAPE | Mean Absolute Percent Error |
| MAS | Marker-assisted selection |
| MDV | Millennium Development Goals |
| MSc | Master of Science |
| MV | Modern variety |
| NARO | National Agricultural Research Organization (Uganda) |
| NARS | National agricultural research system |
| NERICA | New Rice for Africa (AfricaRice) |
| NGO | Non-governmental organization |
| NVRS | National Vegetatable Research Station |
| OPV | Open pollinated varieties |
| PABRA | Pan-African Bean Research Alliance |
| PhD | Doctor of Philosophy |
| PPP | Purchasing power parity |
| PSC | Project Steering Committee |
| PVS | Participatory varietal selection |
| QPM | Quality protein maize |
| SABRN | Southern Africa Bean Research Network |
| SPIA | Standing Panel on Impact Assessment |
| SSA | Sub-Saharan Africa |
| SYs | Scientist years |
| USAID | United States Agency for International Development |
| WCA | West and Central Africa |
| WECABRN | West Africa Bean Research Network |

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# Foreword

## Introduction

For fifty years or so, development economists have been concerned with tracking the diffusion of improved agricultural technologies in the developing world. This focus is not based on mere curiosity. One reason for documenting diffusion is that it provides a simple measure of the success of agricultural research: when new crop varieties are taken up, or when new agronomic practices are adopted by farmers, it provides information about the effectiveness of the research. A second reason for documenting diffusion is that the resulting data can be used to shed light on the multidimensional impacts of the research – on productivity, on farm income, even on poverty and inequality. A third reason for documenting diffusion is that the differential patterns observed across space and time can reveal underlying constraints or problems with technology diffusion: perhaps certain technologies fail to gain a foothold in particular agro-ecologies, or perhaps practices beloved by researchers have failed to spread widely. This information can feed back into the research process to inform scientists and shape further research. Indeed, information on diffusion can also inform the broader development community and can shape thinking about a wide set of potential constraints to adoption – resulting, perhaps, from failures in financial markets, extension and information, or simply reflecting high transport and transaction costs.

Efforts to document the diffusion of improved crop varieties date back to the groundbreaking work of Dana Dalrymple (1969, 1978, 1986a, 1986b). Dalrymple's work drew on the cooperation of national research programs and international scientists, and it provided the data on which were based many early analyses of the Green Revolution and its impacts. But for a variety of reasons, the important task of documenting diffusion was left to languish after Dalrymple's last effort in 1986; the next major effort to document diffusion came more than a decade later. Under the leadership of Bob Evenson and drawing on the work of numerous collaborators, this study compiled data on the diffusion of improved varieties of eleven food crops, and it attempted to achieve global coverage. The project included three country case studies and several cross-cutting analyses and modelling exercises. A book (Evenson and Gollin, 2003) summarized the main findings of the project and established a 1998 baseline for crop varietal adoption and diffusion data.

This report represents the first major follow-up of the Evenson and Gollin baseline. The following pages summarize the key findings of the DIIVA project (Diffusion and Impact of Improved Varieties in Africa), which was funded by the Bill and Melinda Gates Foundation with the goal of assessing incremental progress in Sub-Saharan Africa in the years after 1998. The DIIVA project (and a companion project focused on South Asia) have greatly advanced our knowledge of varietal adoption and diffusion, both by expanding knowledge about areas where diffusion was previously not well documented and by improving the methodologies used for measuring diffusion.

The DIIVA project was organized around three distinct activities: documenting key performance indicators of crop genetic improvement, collecting nationally representative survey data on varietal adoption, and assessing the impact of varietal change. This synthesis paper reports on progress in the first two areas. A companion report interprets and summarizes the results of three related case studies on the impact of modern varieties in Sub-Saharan Africa.

The DIIVA report covers 20 crops and 30 countries in Sub-Saharan Africa. Because some crops are locally absent or unimportant, the report does not account for every crop in every country; but coverage extends to 152 crop–country combinations that together account for over 70% of the gross value of agricultural production in Sub-Saharan Africa.

The report's findings represent a major achievement in terms of both the scope and quality of data for Sub-Saharan Africa. In the Evenson-led study of 2003, the available data on varietal adoption and diffusion in Africa were very limited. Many of these data were based on a combination of small-scale studies of adoption and rather vague regional estimates; the specific crop-country estimates of varietal adoption were mostly the product of interpolation and triangulation. The current study has improved enormously the quality of the evidence. In comparisons of adoption estimates between 1998 and 2010, it is important to note that the new data is of substantially higher quality than the old data. Thus, changes in the adoption estimates may simply reflect improvements in data quality, as opposed to changes in the underlying patterns of varietal use.

We note that the entire database for the DIIVA study is publicly available, with full documentation, on the Agricultural Sciences and Technology Indicators (ASTI) website (http://www.asti.cgiar.org/diiva). We encourage readers and researchers to visit the website and to make use of the data. In addition to the data on the adoption of modern varieties (MVs), the database includes observations on varietal releases for each crop-country combination and data related to the number of full-time equivalent scientists engaged in crop improvement research. This will provide a benchmark at the level of individual countries and crops so that specific crop-country combinations can be tracked and analyzed over time. This, of course, assumes a comparable effort will be sustained over time at regular intervals so that progress can be assessed.

## Key findings and implications

Arguably the most significant finding of this report is the impressive growth achieved in terms of the share of cropped area now under MVs in Sub-Saharan Africa. In 1998, about 20–25% of cropped area was under MVs (based on a weighted average across 11 crops). By 2010, this figure had grown to 35% (based on a similarly weighted average across 20 crops).[1] Calculated another way, the annual growth rate in the adoption of MVs was 1.45% per annum over this period.[2] This in itself is a remarkable achievement for agricultural research. Although one can still ask questions about the quality of the data, the DIIVA study provides important evidence that agricultural research is continuing to provide technologies of value to farmers. Technology adoption is, in some sense, a logically sufficient measure of impact; farmers would not use these technologies if they did not provide some advantage.

In the report that follows, Walker et al. argue that the extent of diffusion of MVs is one of the most important measures of the productivity, food security and poverty benefits generated by investments in crop genetic research and development. We agree, in part, but we might add some important qualifiers. The extent of area under MVs is only one of several changes that interact in complex ways. The pathway from adoption to impact depends on a wide range of other factors such as fertilizer use, policy changes and road access. Documenting impacts on poverty and food security is extremely challenging.

Nevertheless, the continued growth in area under MVs indicates that research is continuing to provide farmers with useful technologies – and that farmers are continuing to find ways to take up these new technologies, in spite of the constraints that they face. Of course, there are crop-country combinations where adoption of MVs is still quite low – 14 of the crops are characterized by a mean adoption rate below 35%. It will be important to analyze the factors

1 If we look only at the paired comparison of 61 crop-by-country observations for the 10 continuing crops, area-weighted adoption was 27% in 1998 and 44% in 2010.

2 There are a number of qualifiers that must be kept in mind when making comparisons here, given that the number and types of crops and crop-country combinations varied between the two periods and that the methods used to elicit expert opinion were not always consistent over the periods. Nevertheless, while the confidence interval may be large – perhaps more so for the earlier survey result when less scrutiny was applied to the method for eliciting expert opinion, there is no reason to believe that there is a particular upward or downward bias in these different period estimates. All one can say is that the study is using the best available data, and the methods used to collect those data are documented in the reports.

that have limited adoption rates for these crops. Conversely, there are crop-country combinations that have already achieved a relatively high (for Africa) level of MV adoption (soybean, wheat, maize, cassava, rice) or where adoption has been quite rapid – cassava, barley and maize doubled their share over this period. Here, too, there may be lessons to be learned. But an important point to note is that, whether the 1998 base levels were relatively low or high, over 90% of the crop-country observations experienced a rise in MV adoption between the two studies. The notion that African crop farming is stagnant is not supported by the data from this study.

Over time, as the level of MVs approaches full adoption, other measures of the success of crop improvement programs – in particular, the velocity of varietal change – will become more relevant. Even now, for many crops, this is an important measure of success. The DIIVA study team looked at this and found the area-weighted mean age of varieties in the field was 14 years across all crops – not much change from the earlier period. More analysis is clearly needed here to understand the causes of this. Some older 'modern' varieties are proving to be remarkably robust in the face of many new varieties being released – or, alternatively, recent research has not always succeeded in producing genuinely useful technologies.

How reliable are the estimates of adoption emerging from this study? Is there any way to measure their accuracy? These questions occupied the DIIVA project at every stage. By necessity, the DIIVA data largely draw on judgments made by expert panels. This remains the dominant method for estimating crop area under MVs at a large scale, due to the cost and complexity of collecting data on varietal diffusion through other means. Thus, the DIIVA study relied primarily on expert panel judgments (for 115 crop-country combinations). In a number of cases, however, these expert data were supplemented by estimates based on household surveys (for 36 crop-country combinations). It was possible to compare these two methods for 18 observations. Of these, ten lined up reasonably well, but household survey estimates were lower for eight observations. Unfortunately, there is no easy way of knowing which of the methods is closer to the truth. On the one hand, nationally representative household surveys might be presumed to be more reliable than expert opinion, since they are based on data collected from individual farm households. On the other hand, there may be gaps in coverage (e.g. because of the low probability of sampling from large commercial farms). Moreover, the quality of the data obtained from household respondents may not be higher – in many settings, it is not clear that farmers can accurately identify the varieties, and the vernacular names that they assign to particular varieties may make identification difficult.[3]

Taken together, we conclude only that further research is needed to reconcile the discrepancies between expert opinion data and survey data on varietal adoption. It would be valuable to know whether there are consistent patterns that would allow us to predict which approach is more accurate for a particular crop-country combination. This is certainly an area worthy of further analysis and research. SPIA is currently conducting research to establish cost-effective and reliable methods for measuring adoption, using DNA fingerprinting as a benchmark to assess the accuracy of alternative methods.

Given that expert panel surveys are likely to remain a major source of data in the future when conducting large-scale adoption surveys, there are valuable lessons to be learned from the report's observations concerning how best to conduct expert surveys (p. 37).[4] These lessons should not be lost in the vast array of data generated by this

3 For instance, farmers may use the same name for distinct varieties, and they may use different names for the same variety.

4 In general, more effective elicitation was characterized by:

- close and intensive supervision of CG project-related staff
- organization of, and attendance at, time-bound workshops with direct interaction with expert panel members
- greater spatial resolution in the elicitation of estimates that were subsequently aggregated to regional and national levels
- including more members from the informal sector and from non-governmental organizations with geographic-specific expertise in technology transfer on the panels, and feedback from CG Center breeders in the final stages of the process.

study. Indeed, a major effort to expand this database to Asia has already drawn on the lessons of the DIIVA study.

## Issues emerging and future directions for research

The synthesis report that follows is only a descriptive summary of the data. We hope that many researchers will take advantage of the DIIVA data to construct estimates of productivity and impact, and we also hope for a lively conversation over the key messages to be taken from the data.

The main results raise a number of issues that deserve further exploration. Some are easily answered. Others will require new methods – or perhaps may be so challenging that they simply invite speculation. For instance:

- Is Africa finally experiencing a Green Revolution? If so, does Africa's experience look like the Green Revolutions of Asia and Latin America and the Caribbean? Arguably, we are seeing diffusion of MVs without seeing much intensification of accompanying inputs. In Asia, the spread of MVs was linked to far greater use of fertilizer and mechanization; but in Africa, the growth of these inputs has been much slower.
- Does yield growth in Sub-Saharan Africa seem to match the diffusion of MVs? Do we see substantial yield increases in the crops and countries where we see correspondingly large increases in adoption? This seems like an important question to ask, but perhaps a difficult one. A key challenge is that, by many accounts, crop yield data are very poor in quality. It is not clear whether many countries in Africa conduct regular yield surveys based on crop cuts. Even theoretically, it is possible that the diffusion of improved varieties need not be accompanied by an increase in yields; for instance, a new trait (e.g. cold tolerance) might allow for crop area to expand along an extensive margin where yields are lower. This could, in principle, result in a decline in average yield.
- A related question: In the crops and commodities where adoption levels are high, have crop yields reached levels that might be viewed as satisfactory? If adoption in some crop-commodity combinations is nearly complete, and if yields are still low, what should we conclude? Is this evidence that crop genetic improvement is a weak tool in the Sub-Saharan context? Or should we expect that successive generations of improved varieties will increase yields where previous generations have failed? Or should we simply accept that high rates of adoption provide sufficient evidence that improved varieties are useful, even if this is not manifested in crop yields?
- What can we learn from the patterns of diffusion that might inform the research process? What characteristics seem to be associated with high levels of take-up? How can we learn from the DIIVA study to target future research more effectively?

## The need for continued data collection and analysis

The DIIVA study represents a major contribution towards measuring and understanding the diffusion of modern crop varieties. The value of the study serves as a reminder of the importance of collecting similar data on a regular basis – and of expanding the coverage across geographic areas. In the long run, varietal adoption and diffusion data should ideally become a regular component of national agricultural statistics – collected, for example, as part of national agricultural censuses. In the short run, however, this task remains in the purview of research institutions such as the CGIAR and its partners. SPIA continues to support the collection of diffusion data and to promote the institutionalization of data collection.

Among the activities that SPIA is currently engaged in, as of mid-2014:

- With numerous partners, SPIA is currently working to pioneer and validate new ways of measuring varieties in use, with the hope that these approaches can be incorporated routinely into micro-studies and household surveys.
- SPIA is working to collect and report varietal adoption data from Asia.

- We are looking to expand the set of technologies for which adoption and diffusion data are collected; specifically, we seek to extend the data to include observations on improved agronomic practices (e.g. conservation agriculture); irrigation technologies; livestock technologies and practices; and a range of other changes that can potentially be linked to CGIAR research.

In this sense, we think it is important that the DIIVA project be viewed as part of an ongoing set of research activities designed to reveal the continuing diffusion of agricultural technologies, broadly defined. Much remains to be done, and SPIA welcomes partners and researchers who bring new approaches and ideas.

## SPIA Chair's acknowledgments

As will be apparent from this foreword and the document that follows, the DIIVA project involved a major undertaking. Any project of this size necessarily involves a team effort. In this case, the team was large, including researchers at seven CGIAR Centers and numerous national partner institutions. The acknowledgments section of this report lists the full cast of participants, but I would like to take this opportunity to thank, on behalf of SPIA, all of those who contributed time and effort.

The project depended in the final analysis on the efforts and expertise of many researchers based at CGIAR Centers and in a range of national research institutions across Africa. We are grateful to the hundreds of scientists who contributed their time to this effort – whether through participating in panels or filling out surveys or providing their field notes, based, in some cases, on years of data collection. The detailed field knowledge of scientists was ultimately one of the main sources of data for the DIIVA project. We are grateful to all these scientists for their generosity in sharing time and for their desire to provide thoughtful and objective information about patterns of adoption and diffusion.

Beyond this collective effort, however, I want to single out the outstanding contributions of several individuals who brought the DIIVA project to fruition through their extraordinary efforts.

First and foremost, we were exceptionally fortunate to have Tom Walker leading this effort on behalf of SPIA. Tom was perhaps uniquely qualified to lead this effort, on the basis of his long and distinguished record of research on agricultural technology adoption and its impacts. Not only did Tom effectively manage this large and complex multi-partner undertaking, but he also provided expertise at every stage of the study. He provided crucial insights into methods of collecting varietal data – from experts, from farmers, and from farm communities. Tom's careful probing and his efforts to check and validate the data drew on his deep and detailed knowledge of African agriculture. We are enormously grateful to Tom Walker for his leadership and expertise; without him, the project could not possibly have achieved such a high-quality outcome.

Perhaps no one was more important to the conceptualization and completion of the DIIVA study than Greg Traxler, Program Officer of the Gates Foundation. Along with Prabhu Pingali (who was based at the time at the Gates Foundation), Greg urged the CGIAR to push ahead with a new effort to collect data on varietal diffusion – and he then helped to mobilize the funding for the project. Greg's contributions went far beyond his role as a conduit for funding. Over the course of several years, Greg asked persistently about the scope and quality of data and pushed to set a high standard for the study.

Another key figure in the history of the DIIVA project was my predecessor as SPIA Chair, Derek Byerlee, who has remained a key participant throughout the duration of the project. Like Tom Walker, Derek brings an encyclopaedic knowledge of African agriculture, based on years of fieldwork and personal experience in most of the countries covered by the DIIVA study. As a dedicated social scientist of the highest caliber, Derek played a central role in the design and implementation of the study. My own term as SPIA Chair started as the DIIVA project came to a close, so Derek was at the helm of SPIA for almost the entire duration of the project.

Finally, two members of the SPIA Secretariat staff – Tim Kelley and James Stevenson – deserve special recognition for their contributions to the project. Tim Kelley's role cannot be easily described. As the Head of the SPIA Secretariat, Tim played a key administrative role in managing the study. But Tim's first-hand knowledge of the CGIAR, based on some thirty years as a researcher and research manager, was ultimately of enormous importance in the quality of the DIIVA project and its findings. I think it is no exaggeration to say that Tim read every sentence produced by the DIIVA project; his critical eye and high standards were matched by his constantly positive outlook. Tim played a similar role in shepherding and reviewing the earlier Evenson-led study, and this provided him with a valuable long-term perspective on the DIIVA study. In both cases, Tim's contributions proved enormously valuable.

Also at the SPIA Secretariat, James Stevenson has played a key role both administratively and substantively in the DIIVA study. As a member of the Project Steering Committee for DIIVA, James participated in every stage of the project; SPIA is fortunate to be able to draw on his skills as a researcher and his thoughtful analysis.

In closing, I would like to honor the memory of Bob Evenson, who died in February 2013. Bob's career-long efforts to document the diffusion and impact of agricultural technologies grew out of his passionate belief that science had the potential to improve the lives of the poor and of rural people. His illness prevented Bob from taking part in the planning of the DIIVA project, but I have no doubt that he would have been delighted and impressed by the work that has been done – and eager to see it continued through the future.

*Douglas Gollin*
Chairperson, SPIA
University of Oxford, UK

# Executive summary

By the 1970s, farmers began to benefit from recently bred varieties in several primary and secondary food crops in Sub-Saharan Africa (SSA). In the late 1990s, a global impact assessment estimated that modern varieties (MVs) accounted for only 22% of the growing area for most primary food crops across SSA (Evenson and Gollin, 2003a; Maredia and Raitzer, 2006).

The estimates reported by Evenson and Gollin (2003a) were based on partial results and limited data for a number of crops and countries. As a result, the picture of MV adoption in SSA was unclear and fragmented, and over the last decade no comprehensive study has updated or clarified these estimates.

Here, the baseline established by Evenson and Gollin (2003a) has been updated, widened and deepened. We report on the results of a CGIAR project: Diffusion and Impact of Improved Varieties in Africa (DIIVA) Project – the first major study to focus on the diffusion of improved crop varieties in SSA. Supported by the Bill & Melinda Gates Foundation (BMGF), seven CGIAR Centers and their partners carried out adoption research and impact assessments as part of DIIVA, which was directed and coordinated by CGIAR Independent Science & Partnership Council's (ISPC) Standing Panel on Impact Assessment (SPIA) and administrated through Bioversity International.

This work has been driven by three complementary activities that respond to three project objectives: (1) documenting the key performance indicators of crop genetic improvement; (2) collecting nationally representative survey data on varietal adoption; and (3) assessing the impact of varietal change. This synthesis paper reports on progress in the first two areas: documenting the performance of crop improvement in SSA and validating estimates from expert panels with results from nationally representative surveys on the diffusion of MVs.

The raw material for the descriptive analysis has been drawn from three databases: (1) recent cross-sectional data on the strength of human resources in national agricultural research systems (NARS) by discipline; (2) historical data on varietal release; and (3) recent cross-sectional data on cultivar-specific levels of adoption estimates elicited mainly from expert panels and, to a lesser extent, from nationally representative surveys. The unit of observation for the three datasets is a crop-by-country combination.

In Section 7, inferences are examined from the perspective of the Millennium Development Goals (MDGs). In particular, the feasibility of measuring the adoption of MVs in the DIIVA Project provides an opportunity to redress one of the deficiencies of the MDGs, which have been criticized for neglecting agriculture (Eicher, 2003).

The Project's databases contain about 150 crop-by-country observations, selected to cover the most important food crops in the main producing countries. Twenty crops and two large maize-producing regions result in 21 crop categories. The area harvested within the 20 study crops in SSA totals around 140 million hectares. These 20 primary and secondary food staples make up about three-quarters of the total crop area in SSA including annuals and perennials. Overall, 83% of the area of the included crops in SSA is covered in the 21 crop categories. For 62 observations, data are available for comparative analysis between 1998 and 2010 on the scientific strength, varietal output, and adoption of MVs.

The national scientific capacity of the 150 crop improvement programs examined in the DIIVA Project totals 1,289 full-time equivalent (FTE) scientists. But the actual number of scientists who work in these programs is likely to be more than double this sum. In rice, for example, 125 FTE scientists equates to 289 researchers, because only about 25–30% of these scientists commit 75–100% of their time to rice research. More scientific resources are allocated to maize than to any other crop in SSA. Cassava is a distant second to maize.

Of the 20 crops, cassava, yams, and pearl millet consistently rank at the bottom of the charts on research intensity. Relative to their area, production, and value of production, all three of these semi-subsistence food crops appear to be extremely short on research resources. In terms of harvested area, groundnut and sorghum are also characterized by very low research intensities.

Results on the differences in scientific strength over time are mixed. Between 1998 and 2010, more programs have gained scientists than have lost researchers. However, because of rising levels of crop production, mainly attributed to area expansion, estimates of research intensity have not increased and have even declined for most of the 65 programs that have information available to carry out paired comparisons.

Comparing these findings to the 2010 results highlights several transparent differences. Nigeria, for example, has invested significantly in maize research, while its scientific capacity in rice and cassava has also improved. But by far the largest increase in scientific capacity has occurred in maize across East and Southern Africa (ESA), thanks largely to the dynamism of the private sector in this region. Notably, the comparisons also strongly suggest that larger public sector crop improvement programs may be highly susceptible to downsizing in times of financial crisis or when donor support ends.

Concerns in scientific capacity in national programs in West Africa reflect not only a problem of relative numbers but also of scientist age. About 65% of the scientists working on sorghum, pearl millet, and groundnut in the five project countries in West Africa were older than 50 in 2010.

Scientists engaged in crop improvement across West and Central Africa (WCA) appear to be more highly educated than their ESA counterparts, with around 2.6 Doctor of Philosophy (PhD) holders per program. But in future an estimated lower number of Bachelor of Science (BSc) holders in WCA is a cause for concern because fewer younger scientists are available for mentoring by older, experienced scientists.

Nevertheless, the overall number of scientists with PhDs and Master of Science (MSc) qualifications is encouraging. Only 24 of the 135 crop improvement programs do not have a PhD presence. Only four programs have neither a PhD nor an MSc scientist involved directly in their research. More than half of the programs have at least 1.0 FTE PhD scientist working in research.

With regard to crop type and the pattern of disciplinary research resource allocation, the main distinction centers on roots and tubers on one hand and cereals and grain legumes on the other. Root and tuber programs invest considerably less in plant breeding per se but more in closely allied disciplines such as tissue culture. Molecular biology only accounts for 3.4% of the mean resources across the 150 programs in the database. This 3.4% is equivalent to only 40 FTE scientists, 17 of whom are involved in studies of banana in Uganda.

Varietal release, interpreted broadly to include improved materials that are or are supposed to be available to farmers, is equated to output in this research. The historical data on varietal release across the 20 crops approaches 3,600 entries. About 90% of these have information on the year of release. Maize leads all crops with over 1,000 entries. Rice is a distant second. Both rice and maize in ESA have benefited from multiple institutional sources of modern genetic materials. By contrast, low research intensities in pearl millet, sorghum, and cowpea in West Africa have translated into low output intensities.

About 45% of 3,194 dated entries had been released since 2000. The mid-point date for varietal release was 1998. Decade by decade, the incidence of release has increased steadily over time. Varietal output rose exponentially in maize in ESA between the 1990s and the 2000s because of surging private-sector releases. However, not all crops in all countries fit the pattern of a steady rise in varietal output over time. Between one-fifth to one-quarter of the

146 crop-by-country observations were characterized by more releases in the 1980s than in the 2000s. Some plausible explanations for declining varietal output centered on civil war, such as in Sierra Leone; the strength of several crop improvement programs in Nigeria in the 1980s; and the weak scientific capacity of the recent past in grain legume and coarse cereal improvement programs in West Africa.

About 43% of the varieties released since 1980 are related to the work of the CGIAR – a proportion that has remained relatively stable (40–45%) over the past three decades. In total, the CGIAR contribution was greater than 40% for 14 crops. Viable alternative international suppliers, a dynamic private sector, strong NARS, and failed breeding strategies figure prominently as reasons why the CGIAR share is below 40% for banana, beans, barley, field peas, maize, and sorghum.

The evidence was mixed for the development of crop improvement programs. A few programs followed a transition over time that reflected increasing sophistication in plant breeding research. These programs initially relied on landrace materials for varietal release. Subsequently they engaged in multi-locational adaptation trials of introduced elite materials. Finally, they selected varieties from their own crosses or introduced progenies. But, for most, the evidence was fuzzy or not transparent that programs had advanced in plant breeding capabilities. More specifically, few released varieties traced their origins to crosses made by national crop improvement programs. This negative finding stands in contrast to the evidence that plant breeding capabilities increased steadily over time in Asia and Latin America (Evenson and Gollin, 2003a).

The area-weighted grand mean adoption level of improved varieties across the 20 crops is 35%. The distribution of adoption of improved varieties is skewed as 14 of the crops are characterized by a mean adoption level that falls below 35%. Crops with an estimated adoption performance superior to the overall average included soybean, wheat, maize, pigeonpea, cassava, and rice. About 23% of the 35% – i.e. a share of 65% – of MV adopted area is related to International Agricultural Research Centers (IARC)-contributed genetic materials. The IARC-related share in adoption is about 20% higher than its 45% contribution to released varieties.

The problem of lagging countries was also evident in the cross-sectional adoption estimates based on 152 crop-by-country observations. Adoption of MVs was uniformly low in Angola, Mozambique, and Niger across all crops.

Spill-over varieties were prevalent, but, unlike in South Asia, so-called mega-varieties that claimed millions of hectares of arable land were not found. Of the over 1000 improved varieties listed in the DIIVA adoption database, SOSAT C88, a short-duration pearl millet variety, was the most extensively cultivated on just over one million hectares in Nigeria, Mali, Niger, and Burkina Faso. In maize, Obatanpa, derived from quality protein maize (QPM) materials, and TZEE-Y, an International Institute of Tropical Agriculture (IITA)-bred variety, fit the description of spillover varieties that have crossed over the borders of several countries in WCA. The incidence of spillover varieties appears to be higher in WCA than in ESA and in groundnut than in other crops.

The paired comparison of 61 crop-by-country observations for the 10 continuing crops showed that area-weighted adoption was 27% in 1998 and 44% in 2010. The 95% confidence interval for the 17.6% gain in adoption was 12.3% to 22.9%. Over 90% of the observations experienced a rise in MV adoption, which increased at a rate equivalent to a linear annual gain of 1.45 percentage points over the 13-year period. With the exception of rice and potatoes, all crops experienced an expansion in the use of MVs. Uptake was especially robust in barley, cassava, and maize with adoption levels more than doubling during the period. Civil war and changing methods in measuring adoption loom large as plausible explanations for why improved varieties lost ground in a few countries and a few crops. Crop-by-country observations with a low level of MV adoption in 1998 were more likely to experience positive outcomes in adoption than those with moderate levels of adoption in 1998.

The velocity of varietal change is as important as the adoption level of MVs in assessing plant-breeding performance especially for countries approaching moderate to full adoption. Varietal turnover is measured by the age of improved varieties weighted by their area in production.

The area-weighted mean age was 14 years, indicating that the average MV in farmers' fields was released in 1996. The average age-related results by crop were tightly clustered in the range of 10–20 years. This means that there may be few, if any, crops where older adopted improved materials have substantially eroded the profitability of plant breeding. But, by the same token, there was also little evidence that rapid varietal change is taking place. Some crops and important producing countries are characterized by older than expected improved varieties. For a new expanding crop, the youngest soybean varieties in farmers' fields in Nigeria are 'old' as they were released in the early 1990s.

Sixteen crop-by-country programs scored well on both varietal adoption and turnover. These better performing crop-by-country entries combined larger area programs in maize, cassava, and cowpea with several smaller programs in soybean and rice.

The largest area and value shares came from varieties that were released in the late 1990s, suggesting that CGIAR Centers were able to supply materials for release by their NARS partners during a time of financial crisis. The 15% value share for varieties released in 2006–2011 is encouraging and indicates that materials continue to find a home in farmers' fields. Materials released prior to 1980 in the early years of the CGIAR were comparatively limited and their impact has eroded over time. In contrast, those produced in the 1980s account for more than 20% of the area and value resulting from MV adoption.

Comparing the 1998 estimates to those in 2010 suggests that improved varieties are not getting any younger in farmers' fields. For maize and wheat, age is roughly the same as 12 years ago. For three of the four countries producing potatoes, varieties are becoming older. For rice, the average age of MVs was the highest of the four crops in both 1998 and 2010.

About one-third of the resources of the DIIVA project were invested in nine nationally representative adoption surveys that were designed to validate the estimates from expert panels and provide raw material for impact assessment. In carrying out the process of estimate elicitation from a standardized protocol, participants also generated considerable anecdotal evidence on what worked. The protocol was adapted to regional and crop-specific circumstances that featured a considerable amount of 'learning by doing' by CG Center staff conducting the expert panels. In general, more effective elicitation was characterized by:

- close and intensive supervision of CG project-related staff;
- organization of and attendance at time-bound workshops with direct interaction with expert panel members;
- greater spatial resolution in the elicitation of estimates that were subsequently aggregated to regional and national levels;
- including more members from the informal sector and from non-governmental organizations (NGOs) with geographic-specific expertise in technology transfer on the panels; and
- feedback from CG Center breeders in the final stages of the process.

Lessons on what did not work were transparent. The CG Center that relied solely on NARS scientists as consultants to carry out expert elicitation was only able to provide quality cultivar-specific adoption estimates for two of their 14 assigned crop-by-country observations. Much more intensive supervision was needed.

Survey estimates and those from expert opinion panels were within ten percentage points for ten of the 18 observations suitable for validation. Survey estimates were lower for the other eight observations, and for two of these they were markedly lower. Ignoring these two outliers, survey estimates were about seven-eighths the size of expert elicitations. Therefore, the mean estimate of 35% for MVs for SSA as a whole is likely to be overestimated because the majority of estimates came from expert opinion. Applying the seven-eighths finding from the validation exercise gives a more conservative estimate of about 31% for MV adoption if surveys had replaced expert opinion panels.

Higher mean absolute percentage errors between the two sources did not seem to be associated with variations in the elicitation approach or specific to a crop or country. They had more to do with the extenuating circumstances of rapid change or disruption associated with rampant over-optimism about the prospects for large technology transfer efforts and with civil war that also can be devastating for the applicability of prior knowledge in circumstances where confirmation is difficult.

Slightly over 70% of the mean adoption estimates in the national surveys were composed of MVs for which the panel held positive adoption beliefs; the other 30% came from unnamed or other named materials believed to be MVs. The size of the second component varies from survey to survey, but it is usually sizable as there is always a leftover quantity of MV area that cannot be assigned to a specific cultivar. For this reason, the summed area of specific MVs will typically be less than an aggregate adoption level. Surveys are likely to understate the importance of specific improved cultivars; detailed estimates from expert opinion that feature few, if any, varieties in a residual 'other' category are likely to overemphasize the uptake of specific MVs. Accuracy in survey estimates depends heavily on whether or not numerous regional- and location-specific names can reliably be assigned to specific varieties.

This synthesis of the first two objectives of the DIIVA Project is laden with numbers. Some are more important than others. We estimate that MVs of food crops in SSA in 2010 covered slightly more than 35% of the total harvested area. In the period 1998–2010 the uptake of MVs increased at around 1.45% per year.

Incorporating the adoption of improved varieties into the MDGs would be desirable for economic development in general and agricultural development in particular. Based on past performance, a target of about 50% can be projected for MV adoption by 2020.

Realizing outcomes consistent with this solid trend in performance will require several changes. Lagging crops and/or lagging countries or both were identified as an area of concern, particularly for sorghum, pearl millet, and groundnut in West Africa where scientists' advancing age and low levels of research intensity are important issues that threaten enhanced varietal output and adoption. Efforts will have to be redoubled in West Africa if a goal of 50% coverage in improved varieties for SSA is to be attained. Some thinking out of the box may be required to address the problem of stagnating and eroding scientific capacity in several West African crop improvement programs on coarse cereals and grain legumes. Performance also has to improve in Angola and Mozambique, the only two countries in southern Africa where adoption of MVs is low for all primary and secondary food crops.

The descriptive research in this paper clearly does not begin to exhaust the relevant themes that can be tackled using the DIIVA 1998 and 2010 databases. The relationships among scientific capacity, varietal output and varietal adoption need to be explored in a more rigorous analytical manner. The data can be integrated with other datasets to shed light on recent tendencies in, and determinants of, productivity growth in African agriculture. Indeed, documenting productivity growth from adoption is a possibly more challenging proposition than documenting adoption.

Most of the above research priorities are easy to visualize. Years from now they should pale in comparison to output stimulated by making the database accessible to the public. Analytically, this study does not break new ground. Its novelty and value stems from its wide scope in terms of crops and countries with intensive data collection, using the same protocols with an emphasis on validation.

## Introduction

In 1978, Dana Dalrymple completed the sixth edition of his life's work: chronicling the development and spread of the High-Yielding Varieties (HYVs) of wheat and rice in developing countries. These semi-dwarf, short-duration varieties had entered Africa as early as the late 1960s. Dalrymple estimated that the diffusion of modern rice varieties had reached 4% by 1978. He included 15 rice-growing countries in his assessment that was based mainly on direct communication with in-country scientists working on rice genetic improvement in Africa.

Dalrymple could not have foreseen the Millennium Development Goals (MDGs) that facilitate the assessment of progress and guide development efforts in the early 21st Century. But he realized the potential for improving poor people's welfare from the adoption of modern varieties (MVs). The extent of the area planted with improved varieties is often the most important determinant of productivity, food security, and poverty benefits generated by investments in crop genetic research and development (Walker and Crissman, 1996; Evenson and Gollin, 2003b; Fuglie and Rada, 2011).

He also knew how hard it was to measure varietal uptake and change. He typically began his edition-ending summary chapter with a note of caution.

> *The individual country data which are summarized here, and the regional totals themselves, are labeled estimates for good reason. They cannot be considered very precise because of problems in both definition and in reporting (Dalrymple, 1978, p. 125).*

He went on to describe in detail well-documented cases where the spread of HYVs had been overestimated.

By the 1970s, farmers began to benefit from recently bred varieties in several primary and secondary food crops in Sub-Saharan Africa (SSA). In the late 1990s, a global initiative on the impact assessment of varietal change estimated that MVs accounted for only 22% of the growing area of most primary food crops across SSA (Evenson and Gollin, 2003; Maredia and Raitzer, 2006).

The estimates reported in Evenson and Gollin (2003a) were based on partial results with limited data available for a number of crops and countries. As a result, the picture of MV adoption in SSA was somewhat fuzzy and fragmented even at that time and, in the past decade, no comprehensive study has updated or clarified those estimates.

Here, the baseline established by Evenson and Gollin (2003a) has been updated, widened and deepened. We report on the results of a CGIAR project – Diffusion and Impact of Improved Varieties in Africa (DIIVA) Project – the first major study to focus on the diffusion of improved crop varieties in SSA. Supported by the Bill & Melinda Gates Foundation (BMGF), seven CGIAR Centers and their partners carried out adoption research and impact assessments as part of DIIVA, which was directed and coordinated by CGIAR Independent Science & Partnership Council's (ISPC) Standing Panel on Impact Assessment (SPIA) and administrated through Bioversity International. The DIIVA Project began on 1 December 2009 and ended on 30 June 2013.

A budget of slightly under US$3 million was allocated to three objectives designed to:

- attain a wider understanding of key aspects of the performance of food-crop genetic improvement in priority crop-by-country combinations in SSA;
- verify and gain a deeper understanding of the adoption and diffusion of new varieties in selected priority countries and food crops in SSA; and
- acquire more comprehensive insight about the impact of crop improvement on poverty, nutrition, and food security.

The DIIVA project is viewed as a major building block in the construction of a routine system for monitoring varietal adoption and impact in SSA for the CGIAR Research Programs. This work has been driven by three complementary activities that respond to three project objectives: (1) documenting the key performance indicators of crop genetic improvement; (2) collecting nationally representative survey data on varietal adoption; and (3) assessing the impact of varietal change.

This Synthesis Report looks at progress in the first two areas, documenting the performance of crop improvement in SSA while validating estimates from expert panels with results from nationally representative surveys on the diffusion of MVs. A companion report interprets and summarizes the results of three related case studies on the impact of MVs in SSA (Larochelle et al., 2013; Ndjeunga et al., 2011; Zheng et al., 2013).

Results are presented in Sections 2–5 on key performance indicators of crop genetic improvement. The raw material for the descriptive analysis in these sections consists of three databases: (1) recent cross-sectional data on the strength of human resources in National Agricultural Research Systems (NARS) by discipline; (2) historical data on varietal release; and (3) recent cross-sectional data on cultivar-specific levels of adoption estimates taken mainly from expert panels and, to a lesser extent, nationally representative surveys. The unit of observation for the three datasets is a crop-by-country combination.

These datasets are comparable to, but more uniform than, those collected in Evenson and Gollin (2003a) in the late 1990s. For the purposes of this report, the work underlying the 13 crop chapters in Evenson and Gollin (2003a) is referred to as the '1998 Initiative'.

The results of the validation of experts' adoption estimates are presented in Section 6. Inferences from Sections 2–6 are examined from the perspective of the MDGs in Section 7. In particular, the feasibility of measuring the adoption of MVs in the DIIVA project provides an opportunity to redress one of the deficiencies of the MDGs that have been criticized for neglecting agriculture (Eicher, 2003).

Before describing and discussing the results in the main body of the report, we briefly review crop, country, and data coverage in the next section.

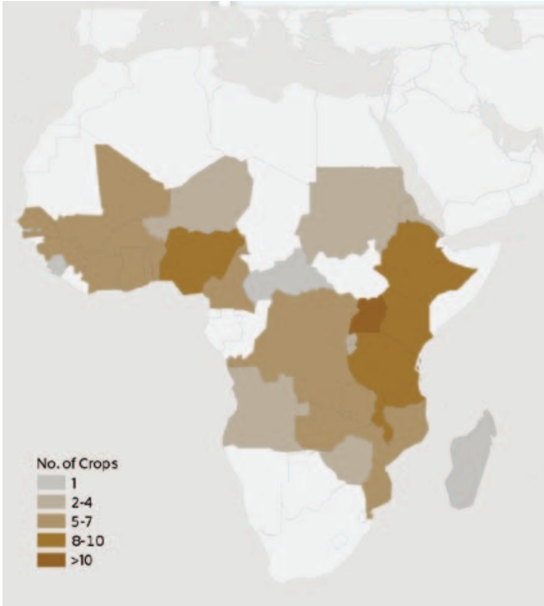
# 1. Crop and country coverage

The Project's databases contain about 150 crop-by-country observations selected to cover the most important food crops in the main producing countries (Map 1).[5] The planned design of coverage was balanced in the proposal; but, for multiple reasons,[6] the number of observations varies somewhat by type of data.

In Table 1.1 coverage is described for the national-level adoption data. Twenty crops and two large maize-producing regions result in 21 crop categories. About half of these were included in the '1998 Initiative' and are described in Table 1.1 as 'continuing'. The other half is 'new' indicating where a baseline on varietal diffusion has been constructed for the first time.

The area harvested within the 20 study crops in SSA totals about 140 million hectares. These 20 primary and secondary food staples make up about three-quarters of the total crop area in SSA including annuals and perennials.

The number of observations varies from one for lentil, wheat, banana, and field pea to 17 for cassava and 20 for maize in East and Southern Africa (ESA) and West and Central Africa (WCA) combined. Maize is split regionally, not only because of its relevance as a food crop, but because the ESA and WCA are so distinct in their uptake of hybrids in relation to improved open-pollinated varieties (OPVs). The private sector is dynamic and now dominant as the source of MVs in several important maize-producing countries in ESA, but is only recently emerging in the production of hybrids in a few West African countries.




Map 1: Frequency of crops in the 30 countries covered in the DIIVA Project in SSA

Overall, 83% of the crop study area in SSA was covered in the 21 cropping categories.[7] Only three crops were sparsely represented at a level below 60% area coverage. Beans in Kenya, sorghum in Ethiopia, and sweetpotatoes in Nigeria are arguably the most important omissions in the DIIVA Project at this time.

Breadth of coverage by database is addressed in Table 1.2. The proposal envisaged coverage of 104 crop-by-country observations. Field pea, banana, and yam were brought in during the course of the Project. Moreover, AfricaRice, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Institute of Tropical Agriculture (IITA) covered many more countries than was initially planned. The International Sorghum and Millet collaborative research project (INSTORMIL) of the

5 The data are available online at: http://www.asti.cgiar.org/diiva.

6 Incomplete data collected on improved wheat varieties adopted on large irrigated farms in Kenya, Zambia, and Zimbabwe and the lack of Food and Agriculture Organization (FAO) and/or national production data in very small producing countries for cowpea and soybean are two prominent considerations that led to an unbalanced coverage across the three databases. However, this effort is substantially more balanced than the '1998 Initiative'.

7 For banana, area coverage in 2010 refers to East Africa. For the purposes of the project and this paper, production in South Africa is not included in SSA. South Africa was included in the '1998 Initiative' for maize and wheat.

**Table 1.1. Area coverage in SSA in 2010 by crop[a]**

| Crop | Description | Number of countries | Share (%) of total SSA for the DIIVA countries |
|---|---|---|---|
| Faba bean | New[b] | 2 | 100 |
| Cowpea | New | 18 | 98 |
| Maize–ESA | Continuing | 9 | 97 |
| Yam | New | 8 | 95 |
| Lentil | New | 1 | 95 |
| Barley | Continuing | 2 | 91 |
| Cassava | Continuing | 17 | 90 |
| Soybean | New | 14 | 86 |
| Maize–WCA | Continuing | 11 | 85 |
| Wheat | Continuing | 1 | 84 |
| Chickpea | New | 3 | 80 |
| Pearl millet | Continuing | 5 | 80 |
| Pigeonpea | New | 3 | 79 |
| Rice | Continuing | 19 | 79 |
| Sorghum | Continuing | 8 | 78 |
| Banana | New | 1 | 71 |
| Potato | Continuing | 5 | 65 |
| Groundnut | Continuing | 10 | 63 |
| Bean | Continuing | 9 | 59 |
| Sweetpotato | New | 5 | 54 |
| Field pea | New | 1 | 46 |
| **Total/ Weighted mean** | | **152** | **83** |

a Refers to the national aggregate adoption data
b Refers to crops that were not covered in the 1998 Initiative

United States Agency for International Development (USAID) has partnered with the DIIVA Project to improve coverage in sorghum, which now includes the Sudan (Zereyesus and Dalton, 2012). Hence, the database contains about 50% more observations than was proposed. This bonus coverage drew on the efforts of CGIAR Centers and other partners to establish a comprehensive baseline of varietal diffusion in food crop production in SSA.

Expanded coverage by AfricaRice brought a few very small producers, such as the Central African Republic (CAR) and Guinea Bissau, into the Project that now covers 30 countries. The median country in the national adoption database contributes five crop observations. Four countries – CAR, Eritrea, Madagascar and Sierra Leone – have only one crop observation. At the other end of the range, Uganda supplies 11 of a possible 20 crop observations.

For 62 observations, data are available for comparative analysis between 1998 and 2010 on scientific strength, varietal output, and MV adoption. This before and after analysis, along with a recent assessment of the 103 crop-by-country observations in the 1998 data, figure prominently in the next four sections in which the performance indicators on crop genetic improvement in SSA are highlighted.

**Table 1.2. The number of crop-by-country observations in the DIIVA Project by type of data**

| Category | Number |
|---|---|
| Proposed (intended) | 104 |
| Scientist Years (SYs) | 151 |
| Varietal release | 149 |
| National adoption | 152 |

# 2. Scientific strength in crop improvement

Information was compiled on different aspects of the scientific strength in crop improvement programs in SSA. 'Crop improvement' is a broad definition that includes plant breeding's closely allied disciplines, such as genetic resources, molecular biology, and tissue culture. It also covers pathology, entomology, agronomy, and any other discipline – such as social science and post-harvest technology – that helps to identify priorities in the development of genetically improved materials. Natural resource management is excluded as is soil science, unless the research focuses on genotype by environment (GxE) interactions. Therefore, the definition of crop improvement used in this project and report focuses on genetic research – broadly defined and potentially fully supported.

All participating CG Centers collected cross-sectional data on the number of Full-Time Equivalent (FTE) scientists which are referred to as Scientist Years (SYs). Data on the level of education and disciplinary orientation in the program were also collected. Like the other databases in the DIIVA Project, participants were given a set of guidelines on data collection and assembly in this narrowly focused but important input that potentially affects crop improvement output (Walker, 2010). Briefly, 'scientists' are defined as public sector, private sector, and university staff who work in crop improvement research and who have an educational level equivalent to a Bachelor of Science (BSc) degree or above. Research technicians and staff working in seed production and related transfer and extension activities are excluded, but scientists active in producing breeders' seed are included.

Several CG Centers also collected individual information on gender, age, and experience of scientists as well as on program infrastructure. Here, we focus mainly on the number of FTE scientists, but also cite other aspects of scientific strength from the CG Center draft reports where appropriate. We conclude this section with a brief analysis on how these data fit into the broader and long-standing Agricultural Sciences and Technology Indicators (ASTI) initiative that was started by International Service for National Agricultural Research (ISNAR) and is currently led by the International Food Policy Research Institute (IFPRI). For matching crop-by-country observations, the estimates of total FTE scientists are compared between the two data sources.

Using genomic techniques in marker-assisted selection to incorporate striga resistance in sorghum cultivars that farmers are already growing in the Sudan

## Scientific staff strength by research program in 2010

Table 2.1 on page 11 provides the estimated numbers of FTE scientists involved in the 151 crop improvement programs. Although the total number of FTE scientists approaches 1,300, the actual number of scientists who work in these programs is likely to be considerably greater. For example, the 126 FTE scientists in rice refers to the time allocated to 289 researchers (Diagne et al., 2012). Only about 25–30% of these scientists commit 75–100% of their time to rice research.

As expected, more scientific resources are allocated to maize than to any other crop in SSA (Table 2.1). Cassava is a distant second to the total for maize across its two major regions of production.

Maize in ESA, with a longstanding tradition of national programs promoting hybrids, has benefitted from a sharp and sustained increase in private sector maize breeding, especially in Kenya, Malawi, Zambia, and

Zimbabwe (De Groote et al., 2011). The private sector has yet to make its presence felt in maize production in much of WCA where national programs have emphasized OPVs (Alene and Mwalughali, 2012a). Relative to other crops, the public sector has allocated substantial scientific resources to maize research in several of the 11 producing countries covered in WCA.

Maize in Nigeria has the largest scientific cadre of 77 scientists. Some of these are university research staff who allocate part of their time to maize research.

The median program size is 8–9 FTE scientists, which should be sufficient to get the job done for all small and most medium-sized producing countries unless the crop is produced in highly diverse agro-ecologies or unless changes in basic knowledge lead to a radical shift in the distribution of yield potential, as there are diminishing marginal returns to sampling from the same distribution when knowledge is stagnant or only increasing incrementally (Kislev, 1977). Banana is the largest average-sized program by crop because only Uganda, a large producing country is included. Its size of 40 scientists seems appropriate for the importance of a crop in a country with 9.5 million tonnes of production (Kagezi et al., 2012).

In contrast to other crops, the quantity of scientists engaged in maize improvement programs in ESA is not a cause for concern. The nine programs are all staffed by more than 10 FTE scientists with Angola and Mozambique (12 scientists each) tied for the smallest program. In other words, even the smallest maize programs in ESA have more scientists than the median sized program for 16 of the 19 other crops (Table 2.1).

A median program size of 15 for wheat underscores the continuing commitment of governments to invest heavily in this import substitute that is grown on large farms, often with access to irrigation, in Kenya, Zambia, and Zimbabwe. Ethiopia, where wheat is grown by smallholders, is by far the largest wheat producer in SSA. A value of 11 for barley reflects the emphasis that Ethiopia places on agricultural research.

Pearl millet is at the other end of the human resource spectrum. Indeed, its

**Table 2.1. FTE scientists by crop improvement program in SSA in 2010**

| Crop | Countries | Total FTE scientists | Min | Median | Max |
|---|---|---|---|---|---|
| Maize–ESA | 9 | 243.2 | 12.0 | 17.0 | 62.0 |
| Maize–WCA | 11 | 139.5 | 3.0 | 5.8 | 77.5 |
| Cassava | 17 | 138.8 | 1.0 | 7.2 | 22.5 |
| Rice | 14 | 125.0 | 0.9 | 8.3 | 15.3 |
| Bean | 10 | 86.5 | 2.6 | 5.9 | 21.4 |
| Potato | 5 | 57.3 | 3.0 | 4.6 | 30.0 |
| Cowpea | 18 | 76.5 | 0.4 | 2.9 | 16.0 |
| Wheat | 4 | 70.1 | 12.0 | 15.0 | 28.0 |
| Soybean | 14 | 52.2 | 0.8 | 2.4 | 14.6 |
| Sweetpotato | 5 | 32.7 | 2.0 | 4.0 | 15.9 |
| Yams | 8 | 49.5 | 3.0 | 4.6 | 12.1 |
| Sorghum | 7 | 42.3 | 2.4 | 3.0 | 18.2 |
| Groundnut | 10 | 23.9 | 1.15 | 2.1 | 5.0 |
| Banana | 1 | 40.0 | 40.0 | 40.0 | 40.0 |
| Chickpea | 2 | 27.0 | 8.4 | 13.5 | 18.6 |
| Pigeonpea | 3 | 6.9 | 3.9 | 1.2 | 5.0 |
| Barley | 2 | 22.1 | 1.0 | 11.1 | 21.1 |
| Pearl millet | 5 | 20.4 | 1.5 | 4.5 | 6.8 |
| Faba bean | 2 | 15.5 | 6.9 | 7.8 | 8.7 |
| Lentil | 3 | 11.0 | 2.0 | 3.7 | 5.3 |
| Field pea | 1 | 6.9 | 6.9 | 6.9 | 6.9 |
| **Total/mean** | **151** | **1,289.0** | **na** | **8.2** | **na** |

largest country program only has about seven FTE scientists. With the exception of the largest producing countries in West Africa, pearl millet is almost always a shared program with other coarse cereals. Groundnut suffers a similar outcome (Table 2.1) and is often a member of a composite program made up of pulses and/or oilseeds.

Saying something more conclusive about the data in Table 2.1 requires adjusting for the differences in the size of production across different countries. Attaining a critical mass of scientists is needed to make progress in large-producing countries and crossing a threshold size of production is required before resources should be committed to investing in crop improvement in very small-producing countries (Maredia and Eicher, 1995).

In Table 2.2 (below), the size of production has been normalized across crops and countries by calculating research intensities that express FTE scientists as ratios from the perspectives of area, production, and value of production. As anticipated, crops characterized by small area and value of production are associated with higher estimated research intensities than those with very large area, production, and value of production.

The ranking of the crops in terms of research intensity varies somewhat across the three criteria in Table 2.2. Potato ranks high in research intensity on area but occupies a low position on production and value. Banana ranks high on area, low on production and high on value. However, there are more aspects in common than are different across the three criteria.

In general, several pulses rank high in research intensity in all three criteria. The first five crops listed in the production column of Table 2.2 are all pulse crops with relatively small areas of production. The exceptions are soybean in Nigeria and pulses that are produced in Ethiopia, which

**Table 2.2. Estimated research intensities by crop in SSA in 2010 from the perspectives of area, production, and value of production[a]**

| Area | | Production | | Value of production | |
|---|---|---|---|---|---|
| Crop | FTE scientists per million tonnes of production | Crop | FTE scientists per million hectares | Crop | FTE scientists per US$100 million of the crop |
| Chickpea | 112.4 | Lentil | 89.1 | Banana | 25.2 |
| Pigeonpea | 64.2 | Chickpea | 83.6 | Soybean | 21.4 |
| Potato | 61.3 | Soybean | 45.6 | Chickpea | 18.4 |
| Lentil | 55.6 | Bean | 43.3 | Pigeonpea | 17.5 |
| Banana | 45.9 | Field pea | 31.4 | Lentil | 16.2 |
| Soybean | 44.0 | Wheat | 20.5 | Field pea | 14.0 |
| Wheat | 42.9 | Faba bean | 20.5 | Wheat | 13.7 |
| Beans | 32.5 | Pigeonpea | 20.3 | Barley | 12.8 |
| Field pea | 29.7 | Barley | 15.1 | Maize–ESA | 8.5 |
| Faba bean | 25.3 | Maize–ESA | 12.3 | Sweet potato | 7.0 |
| Rice | 24.0 | Cowpea | 11.3 | Faba bean | 6.2 |
| Barley | 22.8 | Rice | 10.1 | Beans | 6.1 |
| Sweetpotato | 22.1 | Maize–WCA | 8.1 | Maize–WCA | 5.7 |
| Maize–ESA | 16.5 | Potato | 6.5 | Cowpea | 5.3 |
| Maize–WCA | 14.0 | Groundnut | 4.2 | Rice | 3.9 |
| Cassava | 12.6 | Banana | 4.2 | Potato | 3.4 |
| Yam | 10.6 | Sweetpotato | 3.6 | Sorghum | 2.2 |
| Cowpea | 6.6 | Sorghum | 2.9 | Groundnut | 1.4 |
| Groundnut | 5.3 | Pearl millet | 1.6 | Cassava | 1.2 |
| Sorghum | 2.5 | Yam | 1.0 | Pearl millet | 1.0 |
| Pearl millet | 1.4 | Cassava | 0.9 | Yam | 0.4 |

a All estimates are weighted averages.

has invested substantial scientific resources in its NARS – at least in terms of the number of scientists. Bean's high ranking speaks to the stability of the Pan-African Bean Research Alliance (PABRA) – one of the regional crop improvement associations that survived a shrinking budget for international crop improvement research in the 1990s and early 2000s. Cowpea, which is the lowest ranking pulse in Table 2.2, is produced almost entirely in West Africa.

Turning to the cereals in Table 2.2, barley does well because of its location in Ethiopia, which has a large and regionally decentralized national program at the Ethiopian Institute of Agricultural Research (EIAR). Rice also displays a research intensity estimate above 10.0 from the perspective of production. Potato has a leading position in roots and tubers because of its high market orientation and demand in East Africa.

Cassava, yams, and pearl millet appear at the bottom of Table 2.2. Relative to their area, production, and value of production, all three of these semi-subsistence food crops appear to be starved for research resources. In terms of area, groundnut and sorghum are also characterized by very low research intensities.

Specific cases of resource deprivation can be identified by counting the incidence of falling below an arbitrary, but seemingly reasonable, threshold of critical mass. This lower bound threshold for large programs exceeding two million tonnes of production is established at nine scientists (the median-size program as shown in Table 2.1). Ten large-producing crop-by-country combinations fall below this minimum threshold: cassava in Benin, Côte d'Ivoire, Malawi, and Mozambique; cowpea in Côte d'Ivoire and Guinea; groundnut in Nigeria; pearl millet in Niger and Nigeria; and sorghum in Nigeria. From the perspective of production, the estimated research intensity of these 10 crops is in the range of 0.2–2.0 and averages 1.0.

Conducting a simple regression analysis is another way to shed light on the data on scientific strength in Tables 2.1 (page 11) and 2.2 (page 12). Regressing polynomial production terms on SYs to hold the effects of production constant with binary variables for region and crop type reinforces the evidence from the tabular results. Shifting to East Africa from West Africa is accompanied by an increase of five FTE scientists. In the same 'holding everything else equal' format, shifting from roots and tubers to the so-called 'superior' cereals of maize and rice results in an even larger increase, an addition of about nine FTE scientists (Walker et al., 2011a).

## The congruence rule: How many FTE scientists are desirable?

Building on the estimated research intensities in Table 2.2, it is useful to compare the actual allocations of FTE scientists with normative allocations calculated from a congruence rule. This states that research resources should be allocated in proportion to the value of production across commodities, if all other things are considered equal (Alston et al., 1995). In priority setting, 2% of value of production is a common assumption because studies have shown that research investment proportional to agricultural gross domestic product (GDP) often exceeds 2% in developed countries (Walker et al., 2006). In developing countries in SSA, the 2% criterion is rarely obtained (Beintema and Stads, 2011). In large countries, such as China and India, where economies of scale and size prevail, research investments of the order of 1% of agricultural GDP are commonplace.

When comparing normative to actual allocations, we have assumed that 1% of the value of production is desirable for the size of research investment and that each scientist costs on average US$115,000 in purchasing-power parity (PPP) in 2010. The latter assumption is well within the range of comparable estimates in the ASTI country studies. We also cap the maximum size of a crop-by-country program at 80 FTE scientists, recognizing economies of size and scale in agricultural research. This admittedly arbitrarily imposed limit is slightly above the size of the largest program – maize in Nigeria.

In order to achieve congruence or parity in research intensities across crops with a fixed budget, resources would have to be reassigned from the crops with positive estimates in Table 2.3 (below) to the commodities with negative estimates. The sign and size of the estimates by crop are sensitive to our assumptions on a desirable target for research intensity, the cost of each FTE scientist, and the limit on the size of the program. The relative position of the crops in Table 2.3 will change somewhat as these assumptions vary, but not as much as their numerical values. Assuming payoffs are the same, these more formal results reinforce the findings on research intensities in Table 2.2 (on page 12). Using the congruence rule to set priorities shows that research into cowpea, groundnut, pearl millet, sorghum, and yams is underinvested relative to other crops, from the perspective of the value of production. The deficit of FTE scientists encountered for these largely West African crops has more to do with the reliability of FAOSTAT data (from the statistics division of the Food and Agriculture Organization) on the value of production than with economic assumptions on priority setting.

## Differences in scientific strength over time

Results on differences in scientific strength over time are mixed. Between 1998 and 2010 more programs have gained scientists than have lost researchers but, because of rising production, estimates of research intensity have not improved and have even declined for the majority of the 65 programs with information available to carry out paired comparisons. Before addressing changes over time, we briefly examine the results of previous estimates of scientific staff strength in 1998 for SSA (Walker et al., 2011a).

1. Nigeria stood out as a country with consistently low researcher intensity. Indeed, Nigerian farmers appeared to be afflicted by some of the lowest readings on researcher intensity ever estimated anywhere in the world. Mean readings of the ratio of FTE scientists to million tonnes of production were 0.1 for cassava, 0.5 for sorghum, 1.7 for rice, 1.8 for pearl millet and 2.6 for

**Table 2.3. Comparing the actual allocation of FTE scientists to a normative allocation by crop**

| Crop | Simple average in FTE scientists | | |
|---|---|---|---|
| | Actual allocation | Normative allocation[a] | Difference |
| Banana | 42.0 | 11.1 | 30.9 |
| Wheat | 17.5 | 8.5 | 9.0 |
| Chickpea | 13.5 | 4.9 | 8.6 |
| Maize–ESA | 27.0 | 21.3 | 5.8 |
| Barley | 11.1 | 5.8 | 5.3 |
| Pigeonpea | 7.8 | 3.0 | 4.8 |
| Soybean | 3.9 | 1.2 | 2.7 |
| Lentil | 3.6 | 1.5 | 2.1 |
| Field pea | 6.9 | 5.2 | 1.7 |
| Sweetpotato | 6.5 | 6.3 | 0.3 |
| Faba bean | 7.8 | 8.4 | -0.6 |
| Beans | 8.7 | 9.5 | -0.9 |
| Cowpea | 4.5 | 5.6 | -1.2 |
| Maize–WCA | 12.7 | 14.7 | -2.0 |
| Rice | 9.6 | 16.6 | -7.0 |
| Potato | 7.6 | 14.7 | -7.1 |
| Groundnut | 3.4 | 16.4 | -13.0 |
| Sorghum | 6.6 | 20.3 | -13.7 |
| Pearl millet | 4.1 | 27.8 | -23.8 |
| Cassava | 8.2 | 32.1 | -24.0 |
| Yams | 7.0 | 47.3 | -40.4 |

a Assumes a research intensity of 1% of value of crop production, a cost per FTE scientist of US$115,000 and a maximum program size of 80 FTE scientists.

maize, which benefited from some private sector participation in research. Nigeria ranked among the lowest in researcher intensity in each of the five commodity groups to which it was a major contributor. The country also figured prominently when the performance indicators for these same crops were aggregated.

2. Ethiopia, Kenya, South Africa, and Sudan were characterized by a higher investment in scientific staff than other countries in the 1998 dataset. This behavior was reflected in positive and statistically significant estimated country coefficients in an additive effects model regressing total SYs on production, crops and countries.
3. Researcher intensity was lower in cassava than in other crops even when the relatively inferior output value of cassava was factored into the calculation. Rice and sorghum also had lower than expected research intensities, although not as extreme as cassava.
4. Estimates of researcher intensity declined exponentially as the size of production increased from under 50,000 tonnes to more than 5 million tonnes. This is similar to the findings of other enquiries (Maredia and Eicher, 1995).

Data are available for a before-and-after analysis of the changes in scientific capacity for 65 matching crop-by-country observations that feature eight of the continuing crops (Table 2.4, below). Thirty of the 65 programs had fewer FTE scientistis in 2010 than in 1998. Among the 35 programs that gained staff, two observations were unduly influential in the results – maize programs in Nigeria and Zimbabwe both experienced increases that were equivalent to over 40 FTE scientists.

Some of this change is undoubtedly real, but some may be attributable to an underestimation of scientific capacity in 1998, e.g. maize in Nigeria included substantially more university researchers in 2010 than in 1998. Excluding maize in Nigeria and Zimbabwe, the mean scientific strength in 1998 was 8.4 FTE scientists compared to 9.7 in 2010, resulting in a positive but statistically insignificant change at the 0.05 level. The median program also gained 1.3 FTE scientists as the difference between the two time periods was normally distributed. Overall, these results suggest a marginal increase in scientific capacity.

Cassava appears in Table 2.4 as the largest loser of scientific capacity. Maize in ESA, potato, rice, and wheat were the biggest gainers.

These gains in staff were not sufficient to translate into increased research intensity in most crops. The net decline in research intensity was about 1.7 scientists per million tonnes of production, which suggests that growth in production outstripped the smaller positive changes in staffing. Maize and wheat in ESA were the only crop

**Table 2.4. Differences in estimated FTE scientists and research intensities between 2010 and 1998 by crop based on 65 paired comparisons**

| Crop | Mean FTE scientists | Median FTE scientists | Mean research intensity | Paired observations |
|---|---|---|---|---|
| Bean[a] | -0.6 | -0.8 | 1.3 | 8 |
| Cassava | -2.4 | -2.3 | -4.7 | 14 |
| Maize–ESA | 10.8 | 7.0 | 3.9 | 9 |
| Maize–WCA | 4.3 | -3.3 | -32.4 | 9 |
| Pearl millet | -1.1 | -1.0 | -0.9 | 5 |
| Potato | 6.9 | 3.6 | -7.9 | 4 |
| Rice | 4.3 | 3.8 | -4.3 | 6 |
| Sorghum | 1.9 | 1.4 | -10.3 | 6 |
| Wheat | 7.3 | 8.5 | 110.9 | 4 |

a For Bean, the definition of scientists applies only to breeders.

categories that accrued substantial gains in researcher intensity (Table 2.4).[8]

A first-difference comparison of the bulk of the overlapping crop-by-country observations is presented in Figure 2.1 (below). For reasons of scale, three high-end outliers are excluded: maize in Kenya that had very large values in 1998 and 2010, and maize in Nigeria and Zimbabwe that had very high values in 2010.

A small majority of the 62 remaining observations increased their numbers of scientific staff between the two periods. One of these was cassava in Nigeria which added about six scientists. Notably, we also see that several of the largest commodity programs on the right-hand side of Figure 2.1 could not sustain their staff strength. These were mainly concentrated in cassava-growing programs. For example, Benin, Guinea, and Tanzania downsized to only 2–3 scientists per program.

For a few maize programs in WCA, the numbers of scientific staff also declined over time. But these declines were more than compensated for by Nigeria's dramatic increase in scientific staff, discussed earlier in this report (see Table 2.1). Overall, the data presented in Figure 2.1 convey the message that larger crop improvement programs may be highly susceptible to downsizing in times of financial crisis or when donor support ends.

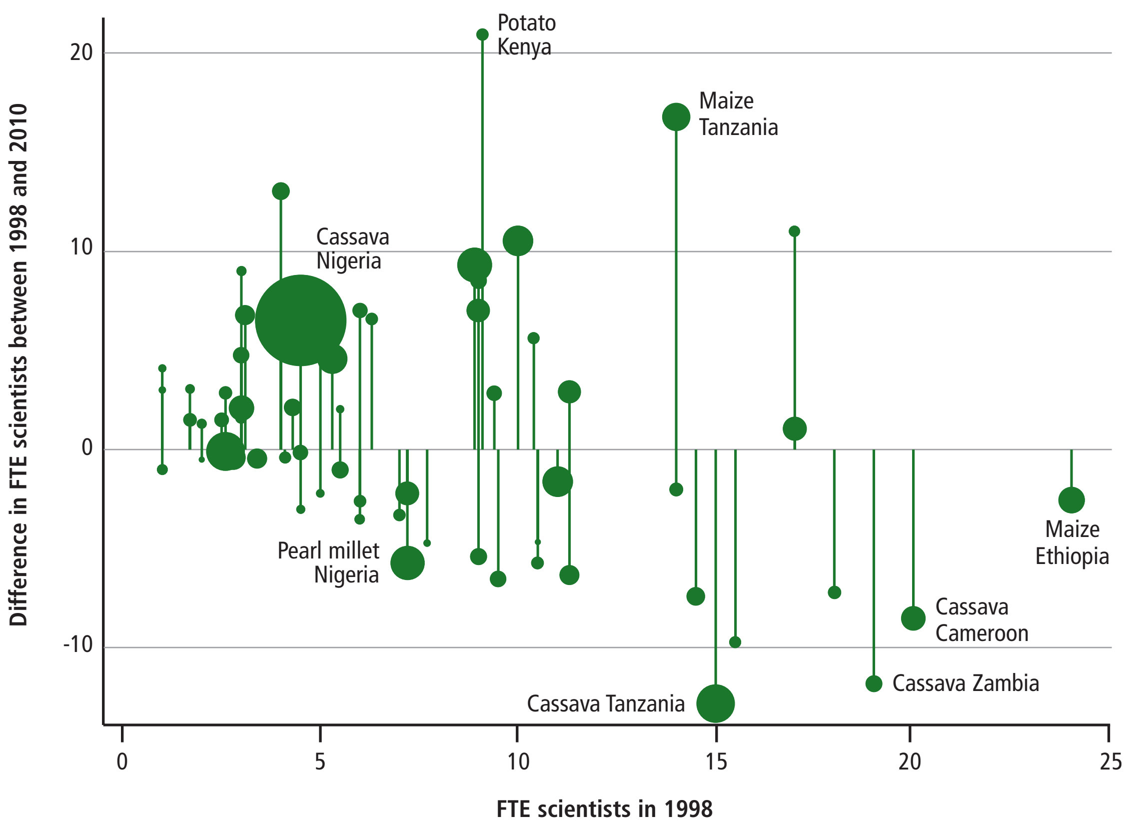



**Figure 2.1. Change in scientific staff strength in food crop improvement programs between 1998 and 2010. (The size of the circles reflects the size of production value in 2010. Note that Nigeria's observation for cassava is the largest circle in the bubble graph.) (Source: DIIVA SY Database)**

8 Declining production in a crop can lead to rising research intensity. But among these observations, only wheat in Zimbabwe seems to demonstrate increasing research intensity attributed to steadily decreasing output.

## Other aspects of scientific capacity: age, education, experience, and area of specialization

The problem of scientific capacity in NARS in West Africa is not only a problem of relative numbers of scientific staff but also of age. About 65% of the scientists working on groundnut, pearl millet, and sorghum in the five project countries in West Africa were over 50 years in 2010 (Ndjeunga et al., 2012). Rice shows a more typical age profile – about half of the 289 rice scientists documented in the Project were older than 50 years (Diagne et al., 2012).

Scientists engaged in crop improvement across WCA appear to be more highly educated than their ESA counterparts, with around 2.6 Doctor of Philosophy (PhD) holders per program. But in future an estimated lower number of BSc holders in WCA is a cause for concern because fewer younger scientists will be available to be mentored by, and capitalize on the experience of, older scientists (Table 2.5 below).

The incidence of scientists with PhDs and Master of Science (MSc) qualifications is encouraging (Table 2.5). Only 24 of the 135 programs did not have a PhD presence. Only four programs had neither a PhD nor an MSc scientist involved directly in their research. More than half of the programs have at least 1.0 FTE PhD scientist working in research. For the most part, all crops and most countries have at least one program supported by several PhDs and MScs. Eritrea was the exception among the 30 countries in the DIIVA Project. Nonetheless, it was still possible to find programs, such as cassava in Tanzania, that were severely understaffed from both a numerical and educational perspective.

Staff stability is a primary ingredient for a recipe of sustained output from investing in crop improvement research (Eicher, 1995). Even with increasing participatory varietal selection (PVS) and marker-assisted selection (MAS) it can take, on average, about 10 years from parental crossing to progeny release in the same country. PVS is increasingly becoming a reality in rice and beans among the food crops in the DIIVA Project. MAS is still rare and newsworthy in SSA. It has been applied to facilitate varietal development in only a few successful cases, such as sorghum in the Sudan (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], 2009). The DIIVA Project sought to collect information on the duration of varietal generation, selection, and testing. However, reliable data over time on this aspect of crop improvement performance were not forthcoming, so we cannot say whether the gestation period of new MVs is shortening or staying the same. We can say, though, that instability in scientific staffing levels within crop improvement programs can severely curtail their potential. Full potential will only be reached if the routine work of varietal selection and testing takes place season after season and year after year.

Estimates on experience levels within the same area of research suggest that many scientific staff have been able to work on the same crop for an extended period of time. For example, the 289 NARS rice scientists had worked on rice improvement for an average of 12.25 years as of 2010 (Diagne et al., 2012). Scientists with ten or more years' experience made up the majority of staff in five of the ten bean programs in ESA (Muthoni and Andrade, 2012). This level of experience is surprising because only about one scientist in six was older than 50 years in 2010 across the ten programs.

Estimates on the allocation of scientists across specialized areas of crop improvement

**Table 2.5. Educational level of scientists in crop improvement programs by region in SSA**

| | Number of observations | Mean number of FTE Scientists by educational level | | | |
|---|---|---|---|---|---|
| | | PhD | MSc | BSc | Total |
| ESA | 65 | 1.51 | 3.20 | 2.33 | 7.03 |
| WCA | 70 | 2.61 | 2.84 | 1.66 | 7.12 |
| **Total** | **135** | **2.08** | **3.01** | **1.98** | **7.07** |

are presented in Tables 2.6 (below) and 2.7 (overleaf) on two aspects: crop type and strength of scientific resources. We expect that relative allocations across areas of specialization will vary substantially across cereals, grain legumes, and roots and tubers. Root and tuber programs that are based on vegetatively propagated material and on clonal selection are hypothesized to be characterized by a more diverse area allocation than cereals and grain legumes, which typically are more heavily concentrated in classical plant breeding. It was expected that increasing human resources would be accompanied by a lower concentration in plant breeding and agronomy, which are conventionally viewed as the core disciplinary areas of crop improvement research.

These expectations are largely confirmed in Tables 2.6 and 2.7, although the differences among programs based on generalized crop orientation as well as small versus large programs are not as obvious as anticipated. With regard to crop type, the main distinction focuses on roots and tubers on one hand and cereals and grain legumes on the other. Root and tuber crop programs invest considerably less in plant breeding and more in the biotechnological areas of molecular biology and tissue culture than cereal and grain legume programs. With the exception of post-harvest research, the other research areas are surprisingly similar across the generalized crop types. The emphases on entomology, pathology, agronomy, and social science are not markedly different across the three groups of crops.

Three other findings in Table 2.6 warrant comment. First, molecular biology only accounts for 3.4% of the mean resources across the 150 programs in the database. This level of investment is not significantly different from tissue culture, which has been a staple area in root and tuber crop improvement since the 1970s. The 3.4% is equivalent to only 40 FTE scientists; 17 of whom work on banana in Uganda. Secondly, the level of social science involvement in crop improvement work is much higher than expected. Thirdly, post-harvest work is concentrated on maize and cassava in Nigeria.

The differences between more sparsely and densely staffed crop improvement programs were also less than anticipated. The largest programs in Quartile 4 in Table 2.7 display a more even disciplinary allocation pattern across disciplines than the smallest programs in Quartile 1, but the differences are milder than expected. On average, even the smallest programs from the perspective of total scientists invest about half of their resources in disciplines other than plant breeding. Nevertheless, the smallest programs invest relatively few resources in molecular biology, entomology, social science, and post-harvest research, compared to programs in the quartiles with higher relative allocations. By contrast, the relative research allocations to tissue culture, pathology, agronomy, and seed production do not vary systematically by size of the program. This lack of response to program size suggests that these areas are viewed as essential investment areas for crop improvement.

**Table 2.6. Relative allocation of scientists by disciplinary specialization across roots and tubers, grain legumes, and cereals in SSA in 20l0 in % shares[a]**

| Broad areas of crop improvement work | Root and tuber crops (5) | Grain legumes (8) | Cereals (7) | All 20 crops |
|---|---|---|---|---|
| Plant breeding including germplasm conservation | 21.8 | 45.8 | 44.39 | 39.6 |
| Plant pathology | 8.3 | 10.9 | 7.80 | 9.2 |
| Molecular biology and genetic engineering | 11.4 | 0.5 | 1.22 | 3.4 |
| Tissue culture | 11.9 | 0.1 | 0.40 | 3.0 |
| Entomology and nematology | 5.4 | 6.1 | 7.38 | 6.3 |
| Agronomy, weed science, and seed production | 25.2 | 24.6 | 23.68 | 24.4 |
| Social science | 8.7 | 10.3 | 9.36 | 9.6 |
| Post-harvest and food science | 5.0 | 0.6 | 4.55 | 3.6 |
| Other areas including soil science | 1.2 | 0.2 | 0.20 | 0.6 |

a Numbers in parentheses refer to the number of observations in each crop category

**Table 2.7. Relative allocation of scientists by disciplinary specialization across program-size quartiles in SSA in 2010 in % shares**

| Broad areas of crop improvement work | Quartile 1 | Quartile 2 | Quartile 3 | Quartile 4 |
|---|---|---|---|---|
| Plant breeding including germplasm conservation | 49.4 | 40.0 | 32.7 | 35.8 |
| Plant pathology and virology | 5.9 | 7.6 | 11.19 | 7.1 |
| Molecular biology and genetic engineering | 1.0 | 2.3 | 2.44 | 3.7 |
| Tissue culture | 3.2 | 3.9 | 2.74 | 3.3 |
| Entomology and nematology | 3.9 | 7.4 | 11.01 | 5.4 |
| Agronomy, weed science, and seed production | 24.3 | 20.4 | 15.51 | 20.5 |
| Seed production | 7.9 | 8.4 | 6.38 | 10.3 |
| Social science | 2.8 | 6.6 | 12.90 | 8.6 |
| Post-harvest and food science | 1.6 | 3.4 | 5.1 | 5.3 |
| **Total FTE scientists** | **63.1** | **137.9** | **292.0** | **796.1** |

The term 'essential' should not convey the notion that all programs are active in these areas. Fifty of the 150 programs do not have any representation in pathology, which historically has been one of the most productive areas in plant breeding in screening for varietal resistance and tolerance to economically important plant diseases. Investment in entomology in grain legumes was also lower than expected.

## FTE scientists in the CGIAR

Evidence on the levels of, and changes in, investment in crop improvement in SSA from the perspective of scientific capacity in the CGIAR is not transparent. This is because only two of the CG Centers, IITA and AfricaRice, operate exclusively in SSA. ICRISAT – which has several long-standing regional programs and country research agreements – has allocated a large share of its budget to crop improvement research in SSA. The International Center for Tropical Agriculture (CIAT), International Center for the Improvement of Maize and Wheat (CIMMYT), International Potato Center (CIP) and ICARDA have also made sizeable commitments. Only including staff posted in SSA does not do justice to the size of that investment, but partially assigning headquarters and even staff from other regions to more fundamental research in SSA is a difficult exercise to assess. Fortunately, there is sufficient evidence to piece together a coherent story under the assumption that financial trends in regional and global crop improvement research have not varied much from Center to Center.

Data from IITA address the issue of the relative importance of scientific capacity in the national programs as compared with the CG Centers. Over its five mandated crops, the ratio of the Centers' FTE scientists to the total number allocated to NARS ranges from about 0.06 for cowpea and maize to 0.14 for yams, which have commanded little attention from national programs. About 40 FTE Center scientists and 450 FTE national program scientists worked on the improvement of cassava, cowpea, maize, soybean, and yams in 2009 (Alene and Mwalughali, 2012a). Hence, the share of CG Center scientists in total scientific capacity was about 8%.

In four of the five IITA crop improvement programs, the disciplinary allocation of scientists to CG Center programs differs markedly to their allocation in national programs. The IITA allocations are based heavily on plant breeding – just over half of IITA's scientists are plant breeders. Meanwhile, the allocations within national programs show significantly more diversification across disciplines. The difference suggests that the CG Center programs are highly focused on genetic improvement. In contrast, the yam program at IITA resembles national programs in terms of its level of disciplinary diversification, although the disciplines vary between the two types of programs. Tissue culture and social science are well represented in IITA's yam improvement program, which seems to be at the early stage of development when diagnoses of constraints and market opportunities are important.

The cross-sectional evidence from IITA is indicative of the relative contribution of CG

Centers to the total scientific capacity within SSA in the very recent past. Time-series information on scientific capacity at ICRISAT suggests that the past has been anything but constant. Since its establishment in 1972, the number of PhD scientists working in crop improvement programs on chickpea, groundnut, pearl millet, pigeonpea, and sorghum expanded rapidly in the 1970s at its headquarters in Patancheru, India (Figure 2.2). During the 1980s and into the early 1990s, that level stabilized at about 75 FTE scientists. At the same time, the number of PhD scientists was steadily increasing in SSA until the early 1990s when capacity peaked at about 30 scientists. In the 1970s and 1980s, most of these scientists worked on pearl millet and sorghum improvement in West Africa. In the late 1980s and into the early to mid-1990s, genetic research expanded to include groundnut and two pulse crops (chickpea and pigeon pea) as well as millet and sorghum improvement in southern Africa.

The mid-1990s ushered in a period of budget tightening that threatened institutional collapse. CG Centers were required to make an investment in newer initiatives such as resource management research. PhD scientists in crop improvement plummeted to 30 (Figure 2.2). By the late 1990s and early 2000s, genetic improvement in SSA was staffed by just 12 internationally recruited scientists. More recently, scientific capacity has recovered with increased project funding from donors such as the BMGF.

ICRISAT – with its large cadre of national-level PhD qualified scientific staff – was arguably more affected by the financial crisis of the early to mid-1990s than any other CG Center. However, the same pattern is visible over time when other definitions, such as the number of staff recruited internationally, are used to describe the regional allocation of CG scientists over time. Moreover, the loss of scientific capacity in the 1990s and early 2000s is not unique to ICRISAT. For instance, the investment made by CIAT in bean improvement grew from about US$350,000 and two principal scientists in 1970 to about US$8 million in 1985 with 20 principal scientists. Expenditures peaked around US$13.8 million in 1990 with 26 principal scientists and seven internationally recruited breeders. By 1997/98, investment in bean improvement by CIAT had declined to about US$7.7 million with 18.5 internationally recruited scientists (Johnston et al., 2003).

Rating budget expenditures by internationally recruited scientists over time shows that CIAT's resources allocated to

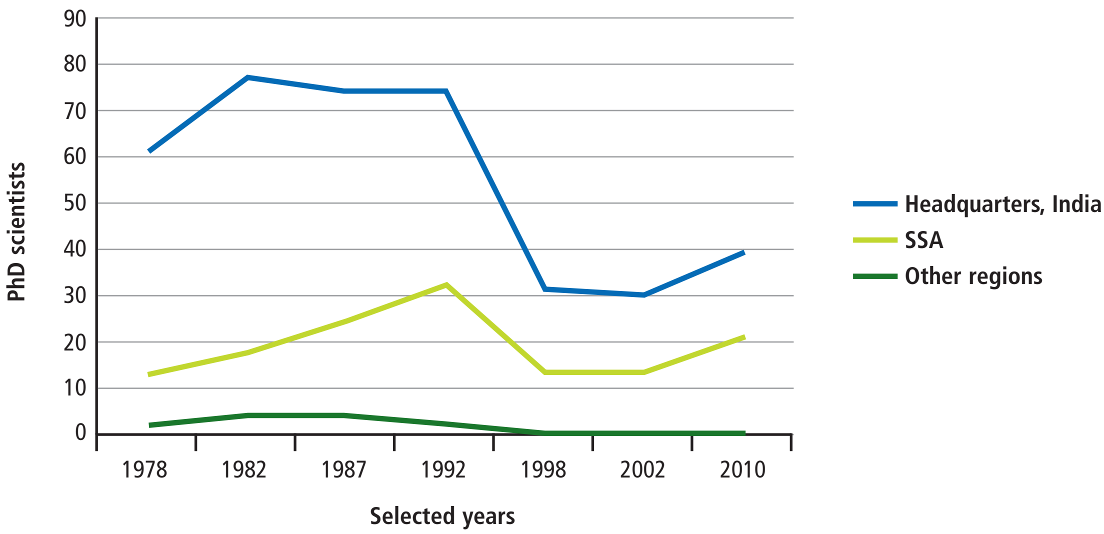



**Figure 2.2. Number of PhD scientists working in the groundnut, pearl millet, sorghum, and pulse improvement programs in ICRISAT by location for selected years in 1978–2010. (Source: ICRISAT Annual Reports for 1978, 1982, 1987, 1992, 1998, 2002, and 2010)**

bean improvement further declined from about US$7 million in 2002 to just under US$3 million in 2007. A substantial decrease in core funding and major restructuring processes in the CGIAR and CIAT led to a reduction in major operations in the bean improvement program. The most affected bean research activities were in CIAT headquarters in Cali, Colombia.

Recently, funding has increased and stabilized at about US$5.5 million annually. The entry of new donors who were interested in targeting genetic improvement as a means of increasing food security led to a recovery in funding. Recent growth has been targeted at small-scale bean production in Africa and is mediated through the PABRA network.

The story of budgetary woe for crop improvement also applies to CIP in the mid-1990s to the mid-2000s. By the late 1980s, more than 70 PhD scientists were working for CIP in a decentralized research organization that featured outreach in eight regional programs. In 1988, the genetic improvement mandate also expanded to sweetpotato. By the early 2000s, the number of scientists fell to 30 whereas the regional research programs reduced to two, one in ESA and the other in Southeast Asia. The distribution of plant materials became a trickle of the flow of genetic resources and elite varieties exchanged in the 1980s and early 1990s (Thiele et al. 2008).

Following the establishment of the commodity Centers and their rapid growth in the 1970s and 1980s, there is perhaps something to be said for a rationalization process to augment the efficacy of genetic improvement. But the cuts in the 1990s and early 2000s were too severe to be classified as necessary adjustments. They jeopardized the stability of crop improvement and exacted a high opportunity cost in terms of varieties that were never released and impact that was never realized.

## Agreement between the DIIVA and the ASTI FTE estimates

The DIIVA Project was not the first to gather information on the health of, and trends in, agricultural research in SSA. Since the late 1980s, economists at ISNAR and now at IFPRI, working under ASTI, have collected comprehensive information on agricultural research in SSA.

Although DIIVA focuses on specific crop improvement programs and ASTI addresses country-level sectoral agricultural research as a whole, the substantive findings in this section resonate well with those from a recent analysis of the latest round of ASTI inquiries (Beintema and Stads, 2011). Results on the lack of investment in agricultural research in West Africa and concerns about scientists' ageing profiles are common to both DIIVA and ASTI. The absence of BSc entry-level scientists in agricultural research in the Francophone countries as an important component of the demographic problem has also been identified in both studies. In addition, this has called attention to the empirical fact that variation in investment in agricultural research is high in SSA, with sizable gainers and losers in a generalized picture of stagnation. The ASTI reports also found plausible explanations for the results on the changing effectiveness of NARS (Alene and Mwalughali, 2012a).

In general, ASTI researchers collect data on all institutional agencies engaged in agricultural research and aggregate the information to the national level, while relevant budgetary information is documented annually. Data collection for the DIIVA Project was at a lower, more disaggregate level – its sources of information were the scientists in, and leaders of, commodity improvement programs. Many of these contacts were long-standing partners of the participating CG Centers.

The DIIVA approach to information gathering was not cost effective for all data. With hindsight, data gathered on the age, educational level and gender of scientists could have been more reliably and easily obtained at the institutional level. What is more, DIIVA Project data – sourced, collected, and analysed for different thematic areas – was limited compared with ASTI's information for the same country. But there is no reason to hypothesize that one or more crop improvement programs would seriously depart from the general tendencies of the research institute or country in these cases.

On the other hand, ASTI has not gathered information systematically on the scientific capacity in crop improvement programs at the level of discipline, such as plant breeding, entomology, pathology, etc. However, ASTI researchers have collected data on the total number of FTE scientists per crop, commodity, or thematic research area in more than 20 countries in SSA. Those data are presented as percentage shares at the national level and are available on the ASTI website.

Nonetheless, complementarity between the two sets of estimates could be high. Documenting and understanding the differences between the two sets of data could also be used to highlight future research priorities in assessing the scientific capacity of crop improvement programs.

Forty-eight paired observations are readily available from the two sources in 21 countries. The difference in FTE scientists is charted in Figure 2.3 (below) from a baseline of scientific capacity estimated in the DIIVA Project. Although about 25% of the ASTI estimates – such as maize in Nigeria and banana in Uganda – are lower than the DIIVA figures, the majority of ASTI estimates exceed the DIIVA estimates.

The matched observations are for the larger research programs as only a few of these are listed numerically for each country on the ASTI website. The smaller research areas are relegated to a residual 'other' category. This means that the base DIIVA estimate for these programs is also high with a mean of 13.5 FTE scientists per program. At the midpoint of the 48 observations, the ASTI estimate exceeds the DIIVA estimate by 4.15 FTE scientists, implying a 30% increase.

Three other explanations are also plausible. Firstly, researchers in higher education are well-represented in each country in the ASTI estimate. Few universities release varieties directly in SSA, but most have staff who engage in research in addition to their

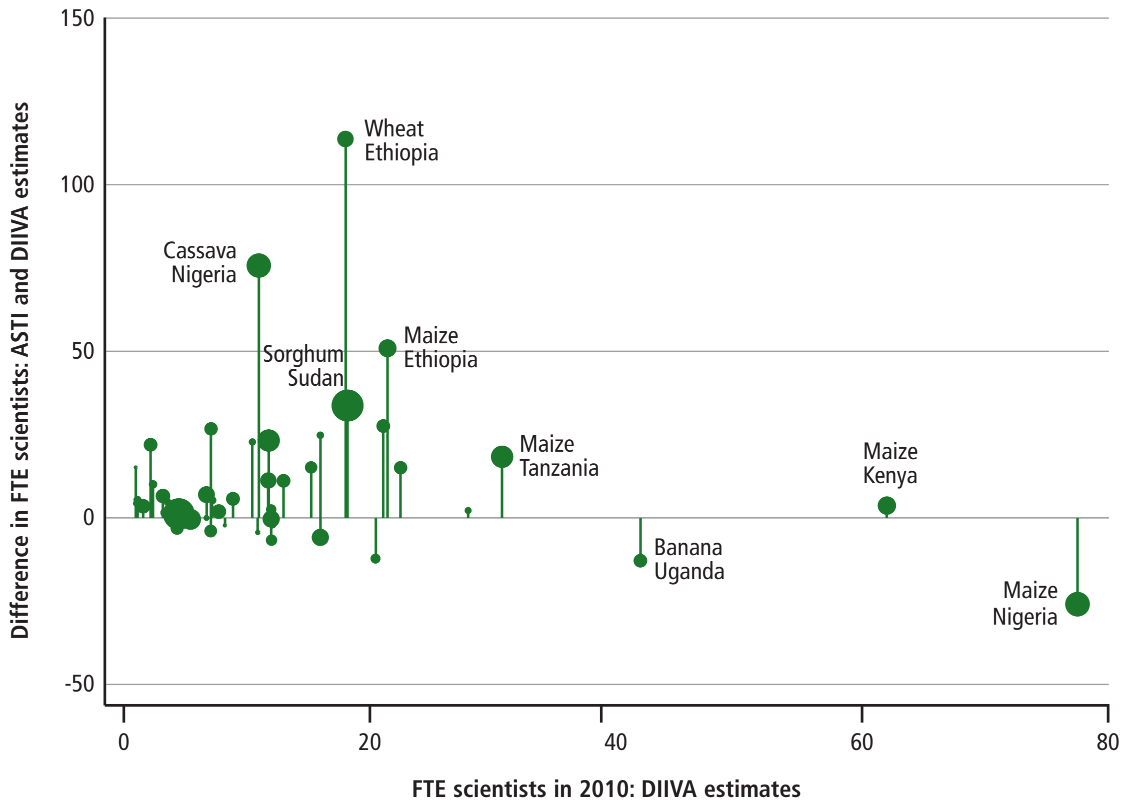



**Figure 2.3. Comparing ASTI and DIIVA estimates of scientific strength. (Source: ASTI estimates from the ASTI website; DIIVA estimates from DIIVA SY database)**

teaching responsibilities. On average, higher education contributes about 25% of the total FTE estimate across the 21 countries in the ASTI database. About 1% of FTE scientists are located in the non-profit sector – in this specific ASTI database, the contribution of the private sector was negligible. In contrast, DIIVA Project participants focused their attention on public sector institutions that had a well-known history and reputation in carrying out crop improvement research.

Supporting this explanation is the finding that the deviations in the two estimates were greatest in the largest and strongest NARS in terms of numbers of FTE scientists. Marked disparities between estimates were found in Ethiopia, Kenya, Sudan, and Tanzania where the ASTI estimates were considerably higher than the DIIVA estimates. In these larger countries, technology transfer and other programs not strictly related to research may find their way into the ASTI estimates. For example, in Kenya, a large potato seed program related primarily to technology transfer was initially included but subsequently excluded from the DIIVA FTE estimate for potato scientific capacity in Kenya. That program absorbs most of the discrepancy between the two estimates; therefore, in practice, it is likely that DIIVA's definition of crop improvement is narrower than ASTI's.

Analysis of the smaller programs in the ASTI 'other' category could partially reverse the finding of lower DIIVA estimates of scientific strength. In terms of size distribution, the DIIVA estimates could even be higher than ASTI's as smaller programs tend to be shared across the same crop types, whose components are sensitive to assumptions on the allocation of scientists' time across crops in the same program.

The findings on cassava and maize in Nigeria are one of the puzzling features of this exercise. The same researchers estimated substantially more FTE scientists in maize and substantially fewer in cassava compared to the ASTI estimate for each crop in the same country. Indeed, this comparison suggests that rationalizing the differences between the estimates for cassava in several of the larger growing countries, such as Nigeria and Tanzania, is a priority. The easiest way to do this would be to compare rosters of scientists working on the crop in large countries characterized by large differences in the estimates. Highly focused, comparative checking should lead to converging estimates during the next round of inquiry.

## Summary

The national scientific capacity of the 150 crop improvement programs examined in the DIIVA Project approaches 1,300 FTE scientists. But the actual number of scientists who work in these programs is likely to be more than double this sum. In rice, for example, 125 FTE scientists equates to 289 researchers, because only about 25–30% of these scientists commit 75–100% of their time to rice research. More scientific resources are allocated to maize than to any other crop in SSA. Cassava is a distant second to maize.

Of the 20 crops, cassava, yams, and pearl millet consistently rank at the bottom of the charts on research intensity. Relative to their area, production, and value of production, all three of these semi-subsistence food crops appear to be research resources. In terms of harvested area, groundnut and sorghum are also characterized by very low research intensities.

Results on the differences in scientific strength over time are mixed. Between 1998 and 2010, more programs have gained scientists than have lost researchers. However, because of rising levels of crop production, mainly attributed to area expansion, estimates of research intensity have not increased and have even declined for most of the 65 programs that have information available to carry out paired comparisons.

Comparing these findings to the 2010 results highlights several transparent differences. Nigeria, for example, has invested significantly in maize research, while its scientific capacity in rice and cassava has also improved. But by far the largest increase in scientific capacity has occurred in maize across ESA, thanks largely to the dynamism of the private sector in this region. Notably, the comparisons also strongly suggest that larger public sector crop improvement programs may be highly susceptible to downsizing in times of financial crisis or when donor support ends.

Concerns over scientific capacity in national programs in West Africa reflect not only a problem of relative numbers but also of scientist age. About 65% of the scientists working on sorghum, pearl millet, and groundnut in the five project countries in West Africa were older than 50 years in 2010.

Scientists engaged in crop improvement across WCA appear to be more highly educated than their ESA counterparts, with around 2.6 PhD holders per program. But in future an estimated lower number of BSc holders in WCA is a cause for concern because fewer younger scientists are available for mentoring by older, experienced scientists.

Nevertheless, the overall number of scientists with PhDs and MSc qualifications is encouraging. Only 24 of the 135 crop improvement programs do not have a PhD presence. Only four programs have neither a PhD nor an MSc scientist involved directly in their research. More than half of the programs have at least 1.0 FTE PhD scientist working in research.

With regard to crop type and the pattern of disciplinary research resource allocation, the main distinction centers on roots and tubers on one hand and cereals and grain legumes on the other. Root and tuber programs invest considerably less in plant breeding per se but more in closely allied disciplines such as tissue culture. Molecular biology only accounts for 3.4% of the mean resources across the 150 programs in the database. This 3.4% is equivalent to only 40 FTE scientists, 17 of whom are involved in studies of banana in Uganda.

# 3. Varietal output

'Output' refers to the expansion that can be attributed to genetic improvement in the potential availability of valuable genotypes for cultivation. Ideally, attribution is measured from a with and without perspective, i.e. the difference between what is potentially available with genetic improvement and what is available without an investment in plant breeding.

By its nature, crossing and selection is a winnowing process that is characterized by a search for a smallish number of genotypes that are perceived to be valuable. Elements of perceived value are encoded in government registry and release practices that place an imprimatur on breeders' elite selections. Official release is tantamount to saying that 'liberated' varieties are potentially valuable for cultivation in the sense that they have satisfied rigorous criteria, such as threshold yield advantages, compared to check varieties in multi-locational testing on research stations over time. In well-functioning systems of varietal release and registry, information on the quantity and location of breeders' seed is published. In this report, output is synonymous with varietal release – the most immediate and observable indicator of progress in crop improvement.

Varietal release is not a perfect indicator and, in specific cases, may not even be a good measure of varietal output in agriculture within developing countries. Both private sector and public sector improved varieties may be available for adoption but may not appear in release registries. Escapes from breeding programs may be widely adopted and not well identified.

Cowpea seeds show wide varietal diversity. Varietal release, for all of its imperfections, is still an important benchmark for assessing progress in varietal output

Almost all countries have well described procedures for varietal release, but few – like Ethiopia and Kenya – have compiled comprehensive release registries for downloading on the Internet. An exhaustive review of varietal registration in 24 rice-growing countries shows that nine do not have an established release and registry system in place (Sanni et al., 2011). In some countries with established systems, release committees do not meet periodically and are financially constrained because of pressures on government operating budgets.

Moreover, changes in the release practices over time may give the illusion of increased varietal output when, in fact, its true trajectory has not changed. Comparing release lists over two points in time also suggests that older improved varieties can reappear at a later date in the registry, giving the impression of recent output when in fact the cultivar was generated much earlier.

One can also cite cases such as Guinea (with a rare institutional setup of multiple institutions releasing varieties of the same crop) where more than 100 rice varietal releases in the 1980s and 1990s has resulted in limited discernible adoption. However, rice in Guinea is an outlier in the joint varietal release and adoption database. The estimated simple correlation between total historical releases and the percentage of adoption for improved varieties in 2010 is a statistically significant but modest 0.17. However, the 'weighted by area' association is markedly higher at 0.47.

The relationship between varietal release, adoption and subsequent impact is asymmetric. Large numbers of releases can result in substantial or no adoption, but zero or negligible releases rarely result in appreciable adoption of improved varieties. Absence of release activity is synonymous with negligible output from plant breeding. Performance in crop improvement needs to be measured and varietal release, for all its imperfections, is still an important benchmark for assessing progress in varietal output.

## Findings on varietal output in 1998

In the '1998 Initiative', most CGIAR participants were successful in assembling valid release data for almost all countries, supplemented by information on so-called informal releases of suspected improved varieties. For maize in ESA, release was equated to varietal availability in the market in the late 1990s because of heavy private sector participation in seed production and distribution. In spite of the inherent difficulties in inferring varietal output from varietal release, such data present an historical benchmark that, once consolidated carefully, can provide a firm foundation for updates over time.

In the pooled analysis of varietal release covering the period 1965–1998 (Walker et al., 2011a), relevant findings included:

1. Across all crops, annual releases increased at an accelerating rate from the 1960s to the late 1990s. This positive trend in the rate of release over time is one of the shared findings across the commodity chapters in Evenson and Gollin (2003b). However, beans, cassava and maize in ESA were the only commodity groupings that truly fit the positive-trend stereotype. Varietal output for the other crops peaked in the 1980s and was maintained at roughly the same level in the 1990s.
2. Political instability adversely affected varietal output in some crops in key countries in the 1990s.
3. Some crops were characterized by high numbers of releases prior to 1975. A few countries could identify stable lines of research that generated early varietal output, which existed prior to and continued immediately after the country declared independence. These early positive performers also released substantially more varieties from the mid-1970s to the late 1980s; however, the advantage of an early start vanished in the 1990s. The crop improvement programs of the CGIAR were most likely a force that contributed to offsetting differences in initial advantage in research endowments because most CG Centers reached their full potential to generate varietal output in the 1990s.
4. Across the eight food crops in the study, the higher and more stable release rate in wheat was anticipated. In contrast, the very low release intensity for cassava was unanticipated. Cassava ranked last in the average varietal output by a wide margin on any criterion of release intensity. For cassava, the size of country production was not positively correlated with the number of releases. Cassava did have a colonial legacy of genetic research in the 1960s to draw from, but governments were slower to invest in this important staple than in grain crops, where technological change was perceived to be more of a reality (Nweke, 2009). Other crops, especially rice, have had a substantially richer institutional milieu in the form of national, regional, and international organizations that have been actively involved in promoting crop improvement over the past 50 years in SSA.
5. Release profiles were often punctuated by bursts of activity sandwiched between long periods of inactivity. For example, Sierra Leone released one variety of rice in 1964, five in 1978, and 18 in 1988. Most, but not all, extreme cases in release behavior could be explained.

## Updating varietal output in 2010

Updating the database for the continuing crops and assembling fresh historical data on varietal output for the new crops in Table 3.1 (overleaf) broadly confirms the five findings cited above from the 1998 analysis. The historical data on varietal output across the 20 crops contains 3594 entries.

About 90% of these have information on the year of release. The undated entries in the database are associated with modern materials that were judged to be available to farmers or are located in countries that do not maintain a formal release registry. Many of these come from the IITA report (Alene and Mwalughali, 2012a) and are listed as 'informal' releases. Participants were encouraged to add escapes and other adopted materials perceived as modern to the release database so that information on their identity and characteristics was available (Walker, 2010). Most, but not all, the dated entries in Table 3.1 imply official release.

Maize leads all crops with over 1000 entries in the cultivar-release database. Rice is a distant second. Both rice and maize in ESA have had access to multiple institutional sources of modern genetic materials.

A simple index of output intensity can also be constructed for comparative analysis across crops. In Table 3.1 below, output intensity is expressed in terms of total releases per million hectares (ha) in 2009. Similar to research intensity, we expected the results to show that less extensively grown crops are characterized by higher levels of output intensity. Indeed, this expectation was confirmed for lentil, soybean, potato, and wheat, all of which were associated with strong market demand. Additionally, during the mid-20$^{th}$ Century, both wheat and potato benefited from a strong program of genetic improvement thanks to the Rockefeller Program in Mexico. The genetic base for many released varieties in SSA came from that early work.

At the other end of the spectrum, five crops fell under the low threshold of less than 20 cultivars released per million ha of harvested area in 2009. Low research intensities in pearl millet and sorghum have translated into low output intensities. The same finding applies to countries producing cowpea. Relatively few varieties have been released recently (Alene and Mwalughali, 2012a). A low estimated research intensity

**Table 3.1. Counting the number of cultivars in the varietal release database by crop in SSA from before 1970 to 2011[a]**

| Crop | Number of countries | Number of cultivars in the varietal release data | Number of released cultivars with year of release information | Output intensity (total releases/ million ha) |
|---|---|---|---|---|
| Banana | 1 | 13 | 6 | 14 |
| Barley | 2 | 41 | 41 | 42 |
| Bean | 9 | 250 | 232 | 100 |
| Cassava | 17 | 355 | 207 | 32 |
| Chickpea | 2 | 27 | 26 | 108 |
| Cowpea | 17 | 200 | 157 | 17 |
| Faba bean | 2 | 28 | 28 | 46 |
| Field pea | 1 | 26 | 26 | 113 |
| Groundnut | 10 | 140 | 137 | 22 |
| Lentil | 3 | 15 | 14 | 158 |
| Maize–ESA | 8 | 692 | 664 | 47 |
| Maize–WCA | 11 | 330 | 271 | 33 |
| Pearl millet | 5 | 121 | 120 | 9 |
| Pigeonpea | 3 | 17 | 17 | 46 |
| Potato | 5 | 117 | 117 | 190 |
| Rice | 11 | 436 | 428 | 64 |
| Sorghum | 8 | 174 | 180 | 11 |
| Soybean | 15 | 201 | 156 | 170 |
| Sweetpotato | 5 | 89 | 89 | 60 |
| Wheat | 5 | 244 | 243 | 146 |
| Yam | 8 | 78 | 35 | 17 |
| **Total/average** | **148** | **3594** | **3194** | **68** |

a This count also includes the same cultivar released in different countries under a different name.

for banana is derived from the observation that hybridization is still difficult. More than all other crops in Table 3.1 (page 27), low output intensity in yams is attributed to historically negligible levels of research investment.

The parity between the output intensity of cassava and that of maize in WCA is perhaps the most interesting finding in Table 3.1. The total number of releases and their total harvested area are almost identical for the two crops. The example of cassava suggests that low research intensity does not preordain mediocre performance in output.

## Varietal output over time

Tracking cultivar release over five time periods that mostly correspond to decades supports the anticipated finding that varietal output has been increasing over time. About 45% of the 3194 dated entries in Table 3.1 were released since 2000 (Table 3.2, below). The mid-point for data release was 1998. Decade by decade, the incidence of release has steadily increased over time.

However, not all crops fit the pattern of a steady rise in varietal output over time. In ESA, varietal output rose exponentially in maize between the 1990s and the 2000s because of surging private-sector releases. On the other hand, groundnut displays a flat trajectory in output for more than four decades and then output rises abruptly from 2000. Unfortunately, this increase in releases is confined mainly to smaller producing countries in ESA. Meanwhile, WCA is still associated with stagnation in the incidence of released varieties, e.g., varietal output in cowpea has declined sharply from its peak in the 1990s.

Three cereals have also not been able to maintain an increase in varietal production. Varietal output in pearl millet peaked in the 1980s. Meanwhile, varietal performance in sorghum tapered off in

**Table 3.2. The frequency of cultivar release by decade by crop in SSA**

| | Released varieties and hybrids by decade | | | | |
|---|---|---|---|---|---|
| **Crop** | **Pre-1970** | **1970s** | **1980s** | **1990s** | **2000s[a]** |
| Banana | 0 | 0 | 0 | 0 | 6 |
| Barley | 0 | 3 | 3 | 4 | 31 |
| Bean | 1 | 6 | 22 | 73 | 130 |
| Cassava | 0 | 2 | 31 | 61 | 113 |
| Chickpea | 0 | 3 | 2 | 9 | 12 |
| Cowpea | 3 | 8 | 49 | 65 | 32 |
| Faba bean | 0 | 3 | 2 | 8 | 15 |
| Field pea | 0 | 2 | 2 | 10 | 12 |
| Groundnut | 20 | 23 | 25 | 21 | 48 |
| Lentil | 0 | 0 | 4 | 5 | 5 |
| Maize–ESA | 7 | 10 | 34 | 159 | 455 |
| Maize–WCA | 12 | 25 | 75 | 76 | 82 |
| Pearl millet | 1 | 7 | 46 | 28 | 38 |
| Pigeonpea | 0 | 0 | 3 | 2 | 12 |
| Potato | 3 | 18 | 29 | 24 | 43 |
| Rice | 27 | 53 | 133 | 138 | 77 |
| Sorghum | 2 | 25 | 36 | 63 | 54 |
| Soybean | 2 | 13 | 32 | 52 | 57 |
| Sweetpotato | 0 | 0 | 9 | 20 | 60 |
| Wheat | 20 | 43 | 43 | 40 | 97 |
| Yam | 0 | 0 | 0 | 5 | 30 |
| **Total** | **98** | **244** | **580** | **863** | **1409** |

a The end year for the period is either 2009, 2010, or 2011 depending on the crop.

the 2000s. In spite of the widespread introduction of the New Rice for Africa (NERICA) varieties starting in the mid-1990s in most rice-growing countries in SSA, varietal release also slowed in rice in the 2000s. Political instability and civil war in Côte d'Ivoire and Sierra Leone severely curtailed releases caused by the closure of several rice research stations. With the exception of Senegal, West Africa shows a downturn in releases in the 2000s compared to the 1980s and 1990s. Even in Guinea, where varietal output exceeded 100 varieties in the 1980s and 1990s, rice releases are becoming increasingly rare.

Releases in the post-1998 period are described in Table 3.3 (below). Five crops have been able to maintain a simple average annual release rate of at least one variety released per program. Fueled by Kenya's and Zambia's high production – with over 100 varieties released since 1998, mostly by the private sector – maize in ESA easily tops the list at five varieties released per annum per program. Seven of the eight maize-growing countries released more than 29 varieties during this recent period.

But, in general, releases were unevenly distributed across all countries within each crop. Thirty country programs reported no releases, and 45% of the 148 crop-country programs released fewer than five varieties during the 12-year period. The country with the most releases often accounted for more than one-third of the total releases and, in the case of yams in Côte d'Ivoire, the vast majority of total releases. In contrast with cowpea, none of the 17 countries in the dataset released more than ten varieties in the ten-year period.

Returning to the top of Table 3.3, wheat's position in weighted annual release rate was anticipated. Ethiopia is by far the largest producer and recently has been prolific in varietal release, which explains why the weighted annual rate is substantially higher than the simple annual rate. The release performance of the smaller wheat-growing countries of Kenya,

**Table 3.3. Performance in varietal release from 1999 to 2011 by country program**

| | | Annual release rate | | Total releases | |
|---|---|---|---|---|---|
| Crop | Total releases | Simple | Weighted by area | Maximum | Minimum |
| Maize–ESA | 485 | 5.1 | 5.1 | 143 | 0 |
| Wheat | 106 | 1.8 | 4.0 | 53 | 5 |
| Barley | 31 | 1.3 | 2.2 | 28 | 3 |
| Bean | 148 | 1.4 | 1.4 | 27 | 8 |
| Maize–WCA | 91 | 0.6 | 1.4 | 37 | 0 |
| Yam | 30 | 0.3 | 1.3 | 23 | 0 |
| Cassava | 128 | 0.6 | 1.2 | 20 | 0 |
| Sweetpotato | 66 | 1.1 | 1.1 | 28 | 1 |
| Faba bean | 15 | 0.6 | 1.0 | 14 | 1 |
| Field pea | 12 | 1.0 | 1.0 | 12 | 12 |
| Chickpea | 12 | 0.5 | 1.0 | 12 | 0 |
| Potato | 47 | 0.8 | 0.8 | 24 | 1 |
| Sorghum | 58 | 0.6 | 0.6 | 30 | 0 |
| Banana | 6 | 0.5 | 0.5 | 6 | 6 |
| Rice | 77 | 0.6 | 0.5 | 23 | 0 |
| Cowpea | 34 | 0.2 | 0.5 | 8 | 0 |
| Soybean | 61 | 0.3 | 0.4 | 16 | 0 |
| Pearl Millet | 39 | 0.7 | 0.4 | 17 | 1 |
| Pigeonpea | 12 | 0.3 | 0.4 | 6 | 2 |
| Groundnut | 46 | 0.4 | 0.4 | 9 | 0 |
| Lentil | 5 | 0.1 | 0.3 | 4 | 0 |

Tanzania, Zambia, and Zimbabwe has slowed somewhat recently.

Ethiopia's sustained efforts in varietal release also explain barley's ranking near the top of Table 3.3. Moreover, a decentralized regional research emphasis has reinforced release activities in Ethiopia. The buoyancy and productivity of the aforementioned PABRA network – the umbrella organization that oversees three regional genetic networks in SSA – contributed heavily to the release performance of beans in the recent period. Sweetpotato programs also released varieties at a rate of more than 1% per annum. The fruition of a longstanding CIP-supported breeding program in Mozambique made a substantial contribution to this output.

The lower end of Table 3.3 shows the same crops that displayed lagging levels of human resources investment in genetic improvement programs. The estimated release rate for cowpea, groundnut, pearl millet, and sorghum indicate one release per program every three to five years.

The low position of soybean for the recent period in Table 3.3 is a surprise for an expanding commercial crop from a very small production base in most countries except Nigeria. Such countries are most likely following a cost-effective strategy of capitalizing on finished materials from other tropical and semi-tropical countries, especially Brazil and Argentina. Nevertheless, those varieties should still appear in the varietal registries maintained by countries in SSA.

Between one-fifth to one-quarter of the 146 crop-by-countries observations were characterized by more releases in the 1980s than in the 2000s. These observations are identified in Figure 3.1 (overleaf) by the number of releases in the 1980s and the change in releases between the two periods. The observations included in this dropline graph imply declining productivity in crop improvement over time. Some of these observations were casualties of civil war during the 1990s and early 2000s.

Civil war, as a major explanation for falling varietal output, applies to rice in Sierra Leone, potato in Rwanda, and rice in Côte d'Ivoire. For other observations, the explanation appears to be country- or region-specific. Most of the observations come from West Africa. As the balloons in Figure 3.1 show, Nigeria accounts for a large share of total area of all the observations. Cowpea, groundnut, pearl millet, rice, and sorghum are well represented in Figure 3.1. With the exception of rice, these crops finished at the bottom of Table 2.2 (page 12) describing estimated research intensities in 2010.

## The historical record on CGIAR contributions to varietal output

The commodity centers of the CGIAR can leverage varietal output through the direct distribution of elite material and their finished varieties, progenies for selection, and parents for direct crossing by NARS. About 43% of the varieties released since 1980 in Table 3.1 (above) are related to the work of the CGIAR.

The CGIAR contribution is greater than 40% for the majority of crops in Table 3.4 (page 32). In several cases, two or more CG Centers contribute to varietal releases of the same crop. Notable examples of joint contributions include ICRISAT and ICARDA for chickpea; IITA and CIMMYT for maize in WCA; and AfricaRice, the International Rice Research Institute (IRRI) and IITA for rice (before IITA closed its rice program).

The six crops below the 40% contribution level in Table 3.4 are suitable candidates for discussion about why their estimates are lower than those of other crops. Barley and field pea are primarily grown in Ethiopia and are researched in a strong NARS setting where the crops have considerable genetic diversity as a locus of domestication.

Other institutional suppliers play a large part in the reported estimates for banana and maize in ESA. The Honduras Foundation for Agricultural Research (FHIA) has contributed significantly to the improvement of banana in SSA, especially in finding cultivars resistant to Fusarium Wilt – a soil-borne fungal disease – in the brewing, cooking, and dessert types of banana.

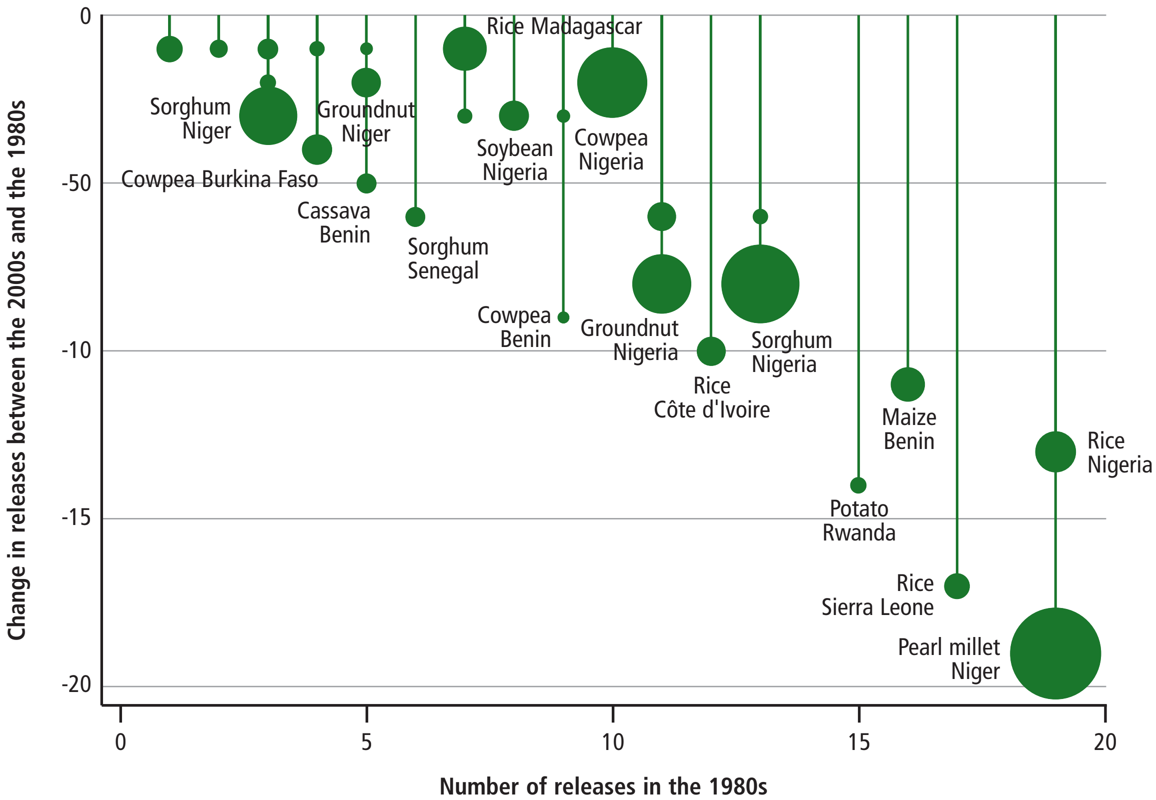



**Figure 3.1. Crop-by-country observations with more releases in the 1980s than in the 2000s.**

Between 1958 and 2010, the private sector – without direct participation from other institutions – was responsible for 56% of maize releases in ESA (De Groote et al., 2011). In Figure 3.2 (page 33), the CGIAR is credited with a 23% share of improved maize variety releases, together with NARS and the private sector. This estimate is substantially higher than currently shown in the DIIVA database, but even a 23% contribution to varietal output is low compared with estimates for other crops in Table 3.4.[9] Historically, the public sector's contribution to varietal research declines when the private sector becomes established in cross-pollinated crops that can be readily hybridized (Fuglie and Walker, 2001). The private sector is well established in Kenya, Zambia, and Zimbabwe where hybrids dominate the market.

9 Recently, CIMMYT has released more than 100 varieties in SSA as part of its Drought Tolerance for Maize in Africa Initiative.

The 39% estimate for beans approaches the average level of CGIAR contribution in Table 3.4. Multiple smaller institutional providers have added a global perspective to CIAT's primary role as a source of genetic materials for the generation of bean varietal output in ESA. These include the Bean and Cowpea Collaborative Research Support Program in the USA, Institute of Horticultural Plant Breeding (IVT) in the Netherlands, Zamorano Pan-American Agricultural School (EAP) in Honduras, Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica, National Vegetable Research Station (NVRS) – Wellsbourne Project in the UK, and the Tokachi Agricultural Experiment Station in Japan. Genetic materials from the gene bank in Beltsville, Maryland, USA have also figured prominently in several varietal releases.

The Institut de Recherches Agronomiques Tropicales (IRAT) now Agricultural Research for Development (CIRAD) has played a large role in generating materials that have resulted in varietal change in several food crops in West

**Table 3.4. The contribution of IARCs of the CGIAR to varietal output in SSA, 1980–2011**

| Crop | Number of dated released varieties related to CGIAR activity | Share of CGIAR-related varieties to total dated releases in % |
|---|---|---|
| Chickpea | 23 | 95.8 |
| Lentil | 13 | 86.7 |
| Pigeonpea | 14 | 82.4 |
| Potato | 72 | 75.0 |
| Yam | 26 | 74.3 |
| Maize–WCA | 173 | 74.2 |
| Cassava | 143 | 68.1 |
| Sweetpotato | 59 | 66.3 |
| Cowpea | 88 | 57.5 |
| Rice | 179 | 51.4 |
| Soybean | 69 | 48.9 |
| Wheat[a] | 81 | 45.0 |
| Groundnut | 41 | 43.6 |
| Pearl millet | 45 | 40.2 |
| Faba bean | 10 | 40.0 |
| Bean | 88 | 39.1 |
| Sorghum | 38 | 24.8 |
| Maize–ESA | 171 | 22.8 |
| Barley | 8 | 21.1 |
| Banana | 1 | 16.7 |
| Field pea | 4 | 16.7 |

a The share estimate for wheat is understated because data collected in the smaller producing countries did not contain information on the institutional source of genetic material since 2000.

Africa. CIRAD also works on non-staple crops and has historically placed less emphasis on genetic enhancement than the CGIAR. But the relatively low level of CGIAR contribution to sorghum releases in West Africa is not related to strong NARs in centers of diversity or to alternative suppliers of material. The overly aggressive pursuit of a breeding strategy focusing on shorter statured, photoperiod-insensitive material is a plausible explanation for why ICRISAT's contribution is not greater, especially in West Africa (Ndjeunga et al., 2012). Farmers strongly prefer tall, photoperiod-sensitive Guinean types of sorghum.

The commodity centers in the CGIAR mostly date from the late 1960s and the early 1970s. We would expect to see a rising contribution from CG-related materials over time from 1980. That expectation is confirmed here. Between the 1980s and 1990s the CGIAR share in varietal output rose from 42 to 46% (Table 3.5, page 33). But, contrary to our expectation, the role of the CGIAR declined in the 2000s compared with the 1990s.[10] This decline could be attributed to the funding crisis in the mid- to late-1990s and early 2000s when the exchange of germplasm and genetic materials became more constricted. The increasing rate of private sector releases in maize in ESA – especially in Kenya and Zambia with more than 100 releases since 2000 – has directly had a dampening effect on the CGIAR share. When maize in ESA is omitted, the revised estimate in the second row of Table 3.5 shows a plateauing of the CGIAR contribution at about 56% in the 1990s and 2000s.

## The maturity of crop improvement programs over time

One of the relevant findings in the 1998 global Initiative (Evenson and Gollin, 2003b) concerned the sequential nature of the breeding process at NARS and International Agricultural Research Centers (IARCs) over time. The commodity centers in the CGIAR began by sending out elite material and finished products for testing. This stage was quickly followed by distribution of progenies for selection by NARS who later matured to the stage of crossing parental materials often provided by the commodity centers. NARS also started the process with the introduction of local landraces that they 'purified' for subsequent distribution.
The transition from the introduction of finished materials to progeny selection from introduced crosses to selection from national crosses was not linear, but it was well documented for several crops at the global level in Evenson and Gollin (2003a). This was especially true for stronger NARS with larger volumes of production, where it made economic sense to enter the mature phase. Direct crossing in the target country was hypothesized to enhance prospects for making progress when confronted with strong GxE interactions.

10 In one sense, this could be viewed as progress: NARS and the private sector are taking on additional responsibilities, freeing the CGIAR to focus on basic research.

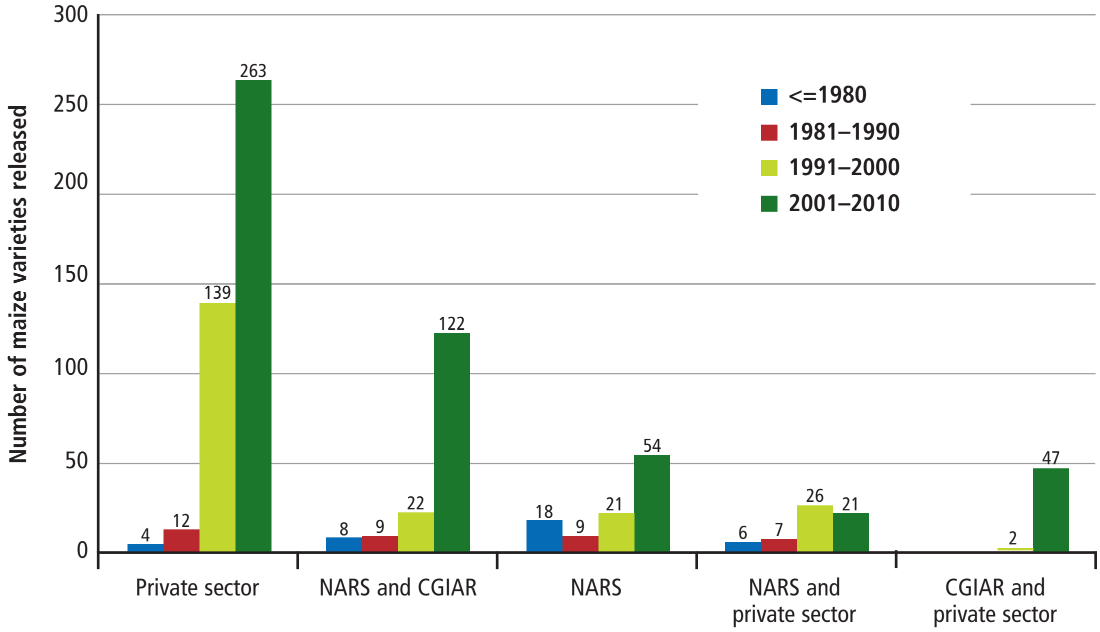



**Figure 3.2. Number of improved maize varieties released by decade and by origin (Source: DeGroote et al., 2011)**

**Table 3.5. IARC-related percent share estimates over time with and without maize in ESA**

| Basis for the estimation | The 1980s | The 1990s | The 2000s | Average share |
|---|---|---|---|---|
| All crops and regions in the database | 41.5 | 45.8 | 41.0 | 42.8 |
| Without maize in ESA in the estimation | 43.6 | 55.9 | 56.2 | 51.9 |

There is weak evidence for this transition in the DIIVA database, but it is not usually transparent as each crop seemingly has a different story to tell. For beans, the transition from the selection of local landraces to the selection from introduced progenies is marked in Figure 3.3 (overleaf). Since 2000, the majority of released varieties have been derived by NARS from introduced progenies. Direct crossing by NARs and subsequent selection is still rare.

The cassava story fits the transition stereotype quite well (Figure 3.4, overleaf). The incidence of IITA-bred materials plateaued in the 1990s and the importance of NARS-bred material from IARC parents rose from a small base in the 2000s.

A weaker story applies to groundnut, sorghum and pearl millet in West Africa. The data in Table 3.6 (page 35) are consistent with a gradual shift in the relative importance of basing varieties on finished products from ICRISAT in the 1970s and 1980s,to progeny selection in the 1990s and finally to direct crossing of ICRISAT parental material in the 2000s.

Cowpea seems to be a counterfactual to the transition hypothesis as the relative shares between bred and parental material have stayed relatively constant over time (Figure 3.5, page 35). Cowpea is also a counterfactual to the confirmed secular rise in the incidence of released varieties.

In general, the incidence of direct crossing was less than expected in most crops in the DIIVA Project release database. Even large NARS programs, such as rice in Nigeria, still rely heavily on introduced finished varieties, although they generated and released varieties from direct crosses in-country as early as the mid-1980s. Releases from landraces continue to figure prominently in a sizeable minority of programs in the 2000s.

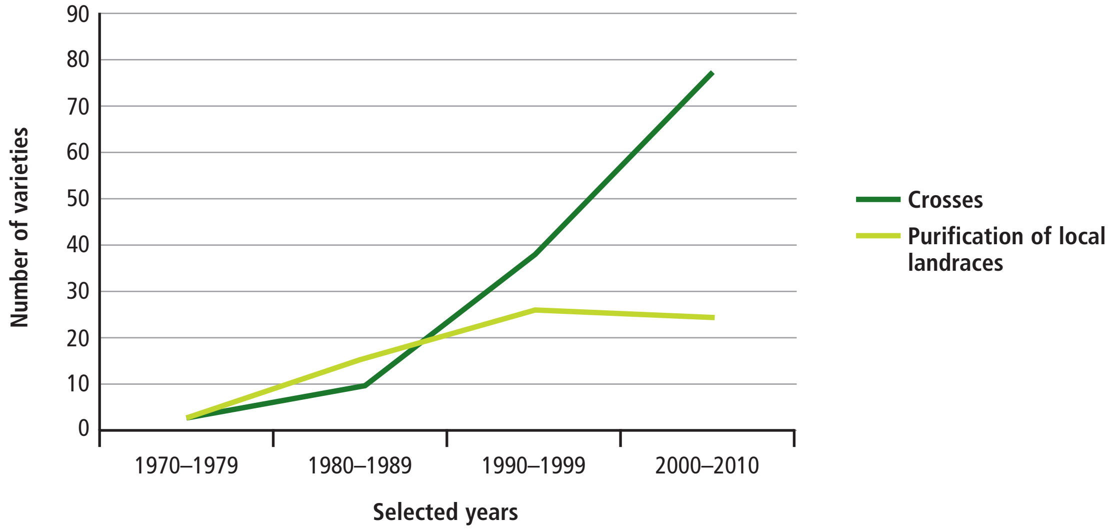



**Figure 3.3. Trend in the release of bean varieties by germplasm source, 1970–2010 (Source: Muthoni and Andrade 2012)**

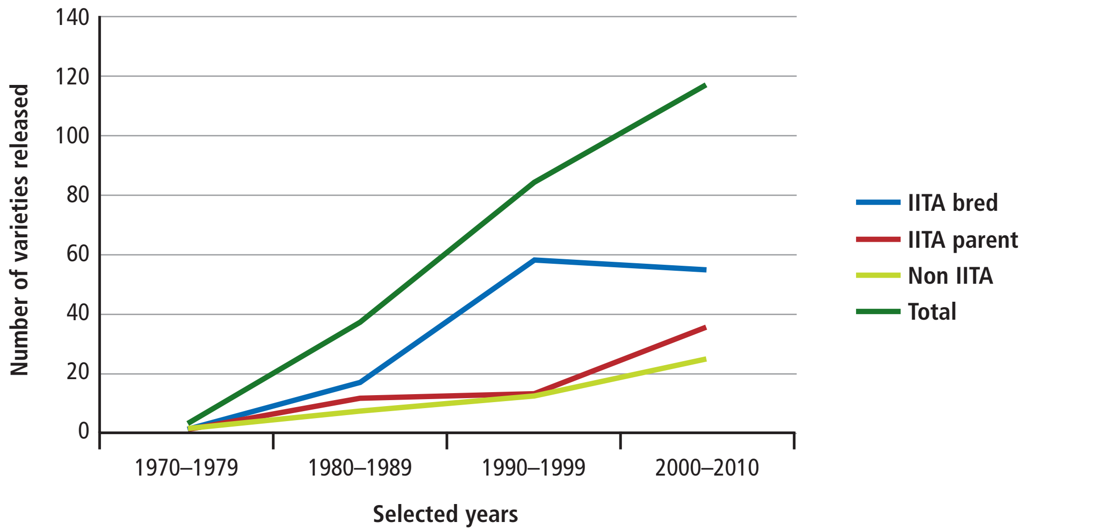



**Figure 3.4. Trend in cassava variety releases by IITA content, 1970–2010 (Source: Alene and Mwalughali 2012a)**

**Table 3.6. Trend in the number of sorghum, pearl millet, and groundnut varieties released by germplasm origin, 1970–2010 (Source: Ndjeunga et al. 2012)**

| | Year range | | | | Total |
|---|---|---|---|---|---|
| | 1970–80 | 1980–90 | 1990–2000 | 2000–2010 | |
| Parent-ICRISAT/cross NARS | 0 | 0 | 0 | 5 | 5 |
| Cross ICRISAT/selection NARS | 0 | 5 | 11 | 2 | 18 |
| Cross ICRISAT/Selection ICRISAT | 4 | 17 | 14 | 5 | 40 |
| **Total** | **38** | **92** | **86** | **50** | **266** |

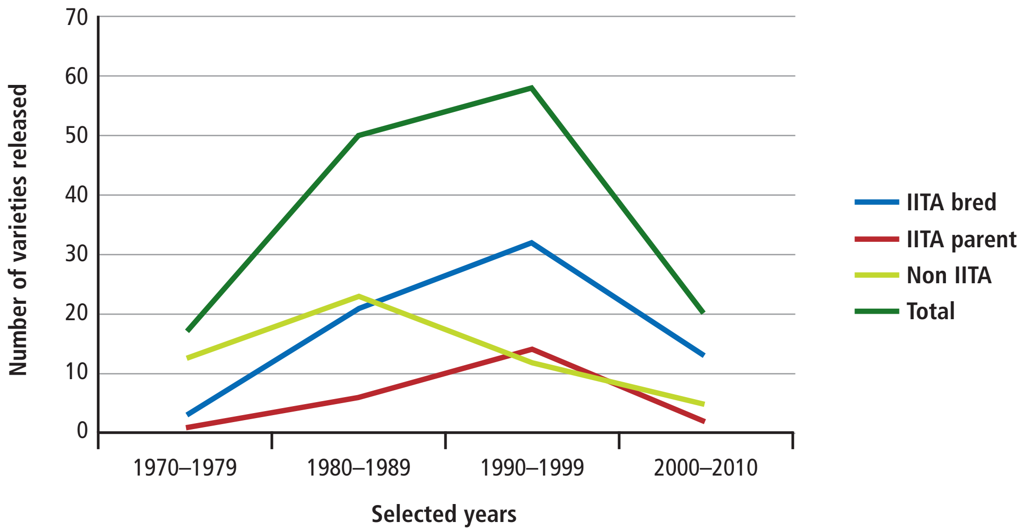



**Figure 3.5. Trend in cowpea varietal releases by germplasm content, 1970–2010 (Source: Alene and Mwalughali 2012a)**


## Summary

Varietal release, interpreted broadly to include improved materials that are or are supposed to be available to farmers, is equated to output in this research. The historical data on varietal release across the 20 crops approaches 3,600 entries. About 90% of these have information on the year of release. Maize leads all crops with over 1,000 entries. Rice is a distant second. Both rice and maize in ESA have benefited from multiple institutional sources of modern genetic materials. By contrast, low research intensities in pearl millet, sorghum, and cowpea in West Africa have translated into low output intensities.

About 45% of 3,194 dated entries had been released after 2000. The mid-point date for varietal release was 1998. Decade by decade, the incidence of release has increased steadily over time. Varietal output rose exponentially in maize in ESA between the 1990s and the 2000s because of surging private-sector releases. However, not all crops in all countries fit the pattern of a steady rise in varietal output over time. Between one-fifth to one-quarter of the 146 crop-by-country observations were characterized by more releases in the 1980s than in the 2000s. Some plausible explanations for declining varietal output centered on civil war, such as Sierra Leone; the strength of several crop improvement programs in Nigeria in the 1980s; and the weak scientific capacity in the recent past in West Africa of grain legume and coarse cereal improvement programs.

About 43% of the varieties released since 1980 are related to the work of the CGIAR – a proportion that has remained relatively stable (40–45%) over the past three decades. In total, the CGIAR contribution was greater than 40% for 14 crops. Viable alternative international suppliers, a dynamic private sector, strong NARS, and failed breeding strategies figure prominently as reasons why the CGIAR share is below 40% for banana, beans, barley, field peas, maize, and sorghum.

The evidence was mixed for the development of crop improvement programs. A few programs followed a transition over time that reflected increasing sophistication in plant breeding research. These programs initially relied on landrace materials for varietal release. Subsequently they engaged in multi-location adaptation trials of introduced elite materials. Finally, they selected varieties from their own crosses or introduced progenies. But, for most, the evidence was fuzzy or not transparent that programs had advanced in plant breeding

capabilities. More specifically, few released varieties traced their origins to crosses made by national crop improvement programs. This negative finding stands in contrast to the evidence that plant breeding capabilities increased steadily over time in Asia and Latin America (Evenson and Gollin, 2003a).

# 4. Varietal adoption

## Defining MVs and estimating adoption

Arriving at reliable estimates of varietal adoption of improved varieties is an important step towards assessing impact and providing a baseline for commodity-oriented collaborative research projects. The use of different definitions of 'adoption' can lead to misleading results across commodities and countries, as well as over time. Because establishing a reliable baseline was a major aim of the DIIVA project, 'adoption' needed to be well defined.

Harvested area is the basis for the adoption estimates that follow, and has been taken from the FAO production database with some notable commodity and country exceptions. These are where national and regional surveys are believed by experienced crop scientists and technology transfer practitioners to be more reliable. Exceptions pertained to a few countries for potatoes and sweetpotatoes and to banana in Uganda. For beans, area data from the CIAT Bean Atlas are used.

Pearl millet OPV SOSAT C88 is the most extensively grown improved variety documented in the DIIVA Project. Arriving at reliable adoption estimates of improved varieties is an important step in assessing impact. Photo: T. Hash/ICRISAT

For the few crop-by-country observations where FAOSTAT was not used, the alternative area estimates may be higher or lower than the FAOSTAT national figures. For beans, the greatest variations in the data sources were observed in Burundi, Tanzania, and Uganda. In Tanzania, for example, 393,716 ha under beans were identified from agriculture production census data for 2008/2009; this compares to 1,245,623 ha in FAOSTAT, when averaged over three years from 2008 to 2010. In Burundi, bean area was estimated at 405,715 ha by expert sources, whereas the FAOSTAT estimate was 203,367 ha. Overall, the expert panel estimated 19% of the total agricultural land in Burundi to be under beans, whereas FAO results imply that only 9% of area cultivated is put to beans. A large discrepancy was also observed in the data from Uganda; the Uganda Bureau of Statistics identified 532,883 ha under beans, whereas FAOSTAT reported 917,000 ha (Muthoni and Andrade, 2012).

Similar discrepancies between FAOSTAT alternative estimates have been noted in potato (Labarta, 2012). Compared to FAOSTAT, alternative estimates are characterized by substantially higher area estimates for potato in Ethiopia and substantially lower estimates in Malawi, where it is suspected that 'sweetpotato' historically has been classified as 'potato' in FAOSTAT.

Harvested area is a desirable measure because it is relatively easy to interpret in terms of production impacts. However, expert panels and focus group respondents in community surveys are much more comfortable giving adoption estimates in terms of the percentage of farmers using improved varieties. This is measured easily in surveys of farm households and does not require estimates of the area planted. It also says something about the access of individual farmers to technology. But using the percentage of farmers leads to an overestimate of the use of specific improved varieties and cannot easily be used to interpret economic impact.

Furthermore, an area measure imposes the added discipline that area shares between traditional and improved varieties must add to 100, and area shares among specific improved varieties must add to their aggregate total.

What constitutes an improved variety is perhaps the most important aspect of estimating adoption levels. Reaching a robust definition begs several questions:

- Would the variety be available to farmers without research in crop improvement?
- Are breeding and selection embodied in readily identified materials that farmers are growing but that have not achieved formal release?
- Is the seed of improved OPVs renewed periodically?
- Is the seed of hybrids renewed annually?
- Should very old released varieties be included?

Responding to these questions often requires more information on the seed sector as well as careful inspection of the varietal release database in the country studied. Ideally, landrace materials should not qualify as improved varieties in their country of origin, even though their seed is purified and they are formally released. Farmers would most likely be producing these materials with or without a crop improvement program; although their identification does require some effort in selection. Moreover, variety-specific comparisons show that productivity gains from released in-country landraces are substantially lighter than those estimated for more modern materials with greater breeding content (Dalton and Guei, 2003).

For most crops, some released landraces have been included within the category of improved varieties in our adoption estimates, but have been excluded for bean and sweetpotato where landraces are more important. Released landraces from other countries are also included on the assumption that such materials would not be available to farmers without the intervention of adaptation trials by the national crop improvement program.

Our definition of an 'improved variety' is inclusive of escapes, products of participatory varietal selection from improved materials, and breeding outputs in countries that do not have a functioning formal release and registry system. Focusing only on released varieties would understate the performance of investments in crop improvement.

The issue of the frequency of seed renewal for improved OPVs and hybrids in open-pollinated crops is one that needs to be addressed in the future. This aspect acquires heightened importance in comparing estimated adoption levels in maize between regions in SSA. Where survey data were available, i.e. maize in Ethiopia, an OPV was considered to be an MV if the age of the seed was three years or less. In the Ethiopian nationally representative survey of varietal adoption, "maize seed was considered an improved variety if the farmer used freshly purchased hybrid seeds, freshly purchased Open-Pollinated Varieties, and recycled OPVs for not more than three production seasons" (Jaleta et al., 2013).

Unfortunately, survey data on seed vintage in OPVs were only available in this one case. Older OPVs released in the 1970s and 1980s in countries where seed renewal from government or private sector sources is limited were also deleted from the list of improved varieties. Matuba, which was released in 1984 in Mozambique, where civil war prevailed until 1992, and where seed programs are still not institutionally well developed, is an example of an OPV that is now considered to be a local variety. In general, the problem of outcrossing in defining an improved variety is most pronounced in maize, pearl millet, and pigeonpea among the 20 crops in this study.

Likewise, we have not confronted the issue of varietal age with great analytical rigor in defining MVs. Arbitrarily, we have used 1970, the year IR-8, the first Green Revolution semi-dwarf HYV, was introduced into SSA (Dalrymple, 1986), as the cutoff point to define MVs. The use of 1970 as a cutoff point means that improved materials bred in SSA during the colonial era are not included. Using an earlier cutoff date, such as 1950 or 1960, would have resulted in markedly greater estimated adoption levels in groundnut and in rice in several countries in West Africa. The adoption results for most crops and countries are not very sensitive to the use of an earlier cutoff date.

In groundnut, the estimates based on a large survey in northern Nigeria and expert opinion in Mali suggests that two varieties bred in the colonial period are still extensively grown. Variety 55-437 is estimated to cover about 40% of groundnut-growing area in Nigeria; 47-10 is believed to be cultivated on about the same percentage of groundnut area in Mali (Ndjeunga, et al., 2012). Groundnut varieties seem to have remarkable staying power in farmers' fields. Groundnut is self-pollinated, has a low multiplication ratio that results in slow diffusion, does not degenerate appreciably from seed-borne viruses, and is not characterized by a high rate of somatic mutations. Variety 55-437 still appears to be expanding in area in Nigeria (Ndjeunga et al., 2012).

In rice, using a cutoff date of 1960 or 1965 would bring several popular introduced purified landraces into play. Inclusion of these materials in the set of modern cultivars would result in a sharp rise in the adoption level of some large rice-growing agroecologies in West Africa (Dalton and Guei, 2003). They were listed, but not included, as improved varieties in the '1998 Initiative'; therefore, we opted for the same course of action for consistency in comparing estimates over time.

The source of the adoption information potentially affects estimates in terms of their variance and bias. With 20 crops in multiple countries, a uniform application of a protocol is needed to elicit information on adoption (Walker, 2010). The same protocol also needs to be used in the future to generate valid time-series estimates. The protocol used in the '1998 Initiative' was adhered to as strictly as possible in this study and featured the elicitation of adoption estimates based on expert opinion. That protocol was administered by seven different institutional partners resulting in some variation. But, in general, usable estimates were obtained. In the small minority of cases where such information was incomplete, survey estimates were relied on if they were nationally representative. The expert opinion protocol and its validation are described in detail in Section 6 of this report.

Similar to the '1998 Initiative', adoption estimates were mainly generated by elicting expert opinion. This may still be the only cost-effective option for arriving at reasonable adoption estimates for SSA, which is characterized by multiple food crops and a diversity of countries. One hundred and eleven crop-by-country combinations in the DIIVA adoption dataset of 152 observations are based on expert opinion (Table 4.1, below). Highly focused, nationally representative surveys account for 36 observations – 16 of these were financed and canvassed by the DIIVA Project; 20 drew on complementary research by other CG Centers and donors, especially AfricaRice's Japan Project; several others were inferred from recent literature; and one observation, maize in Tanzania, relied on variety-specific seed production information.

## Adoption levels of improved varieties by crop in 2010

The area-weighted grand mean adoption level of improved varieties across the 20 crops in the project is 35% (Table 4.2, overleaf).

Two-thirds of the crop entries in Table 4.2 fall below the mean weighted level of adoption of 35%. Starting at the bottom of the table, the low estimate for field pea, which is produced primarily in Ethiopia, is not surprising. Internationally and nationally, field pea is arguably the crop species in Table 4.2 that has had the smallest amount of resources allocated to its improvement. In contrast, both chickpea and lentil have benefited from international agricultural research in the CGIAR since the early- to mid-1970s. Although progress has been

**Table 4.1. Source of the national adoption estimates by number of observations.**

| Source | Number |
|---|---|
| Expert opinion | 111 |
| DIIVA adoption survey | 15 |
| Non-DIIVA adoption survey | 20 |
| Inferred from the literature | 5 |
| Seed production and trade | 1 |
| Total | 152 |

made, adoption of improved cultivars of both crops is concentrated in small pockets of production regions in Ethiopia where extension programs have been active (Yigezu et al., 2012a). This apparent location specificity is typical of pulse crops, but it is surprising in light of improved lentil varieties that have reportedly significantly heavier yields than their local counterparts.

Adoption levels of faba bean and chickpea are buoyed by a reportedly higher penetration of improved varieties in the Sudan. Indeed, chickpea in the Sudan is the only crop-by-country observation to have been at full adoption level in 2010, albeit on a very small area of 21,000 ha (Yigezu et al., 2012a). Meanwhile, Ethiopia harvests more than 0.5 million ha of faba bean, yet the perceived adoption of improved cultivars is very low at 3.5%.

Cooking, dessert, and beer bananas in Uganda are also characterized by a low rate of adoption. This finding is not surprising. Stimulating varietal change in a clonally propagated crop – and one that is not an annual – is a challenging proposition anywhere in the world. A focus on disease resistance is necessary, but entrenched consumption preferences are potentially major constraints to adoption which may be only partial in the best of circumstances (Kagezi et al., 2012).

The National Banana Research Program of Uganda's National Agricultural Research Organization (NARO) also faces the challenge that elite clones for evaluation were only introduced on farms from 1991. NARO has made a considerable commitment to biotechnology in order to exploit to the fullest the opportunity for varietal change and has mobilized several international partners in the supply of elite clonal materials. The potential for harnessing biotechnology in Uganda for regional varietal change is a recurring theme that has been reported in the DIIVA Project for other clonally propagated crops such as cassava (Alene and Mwalughali, 2012a).

Groundnut, sorghum, and pearl millet also fall below the adoption average of 35% in Table 4.2. They are produced extensively in the Sahelian, Sudanian, and Guinean zones

**Table 4.2. Adoption of MVs of food crops in SSA in 2010**

| Crop | Country observations | Total area (ha) | Adopted area (ha) | % MVs |
|---|---|---|---|---|
| Soybean | 14 | 1,185,306 | 1,041,923 | 89.7 |
| Maize–WCA | 11 | 9,972,479 | 6,556,762 | 65.7 |
| Wheat | 1 | 1,453,820 | 850,121 | 62.5 |
| Pigeonpea | 3 | 365,901 | 182,452 | 49.9 |
| Maize–ESA | 9 | 14,695,862 | 6,470,405 | 44.0 |
| Cassava | 17 | 11,035,995 | 4,376,237 | 39.7 |
| Rice | 19 | 6,787,043 | 2,582,317 | 38.0 |
| Potatoes | 5 | 615,737 | 211,772 | 34.4 |
| Barley | 2 | 970,720 | 317,597 | 32.7 |
| Yams | 8 | 4,673,300 | 1,409,309 | 30.2 |
| Groundnut | 10 | 6,356,963 | 1,854,543 | 29.2 |
| Bean | 9 | 2,497,209 | 723,544 | 29.0 |
| Sorghum | 8 | 17,965,926 | 4,927,345 | 27.4 |
| Cowpeas | 18 | 11,471,533 | 3,117,621 | 27.2 |
| Pearl millet | 5 | 14,089,940 | 2,552,121 | 18.1 |
| Chickpea | 3 | 249,632 | 37,438 | 15.0 |
| Faba bean | 2 | 614,606 | 85,806 | 14.0 |
| Lentils | 1 | 94,946 | 9,874 | 10.4 |
| Sweetpotato | 5 | 1,478,086 | 102,143 | 6.9 |
| Banana | 1 | 915,877 | 56,784 | 6.2 |
| Field peas | 1 | 230,749 | 3,461 | 1.5 |
| **Total/weighted average** | **152** | **107,721,630** | **37,469,577** | **34.78** |

of West Africa. All three crops share the same poor country-specific outcomes in terms of adoption – negligible diffusion of improved varieties in Burkina Faso and no recorded adoption in Senegal where varietal output has paled in comparison to the robust performance in Mali (Ndjeunga et al., 2012).

Scientists in West Africa have also gone down some blind alleys. For example, sorghum breeding overemphasized *Caudatum* types that could not compete with the dominant Guinean materials prevalent in the region (Ndjeunga et al., 2012). Photoperiod-insensitive, short-duration *Caudatum* materials were high yielding, but they were susceptible to pests, disease, and bird damage and did not measure up to the consumption expectations of semi-subsistence producers who also consume a sizeable share of their output.

Additionally, groundnut crop improvement scientists in the Francophone countries have to compete with old improved cultivars grown prior to Independence. The aforementioned groundnut variety 55-437, released some 40 years ago, is still the dominant variety in Senegal and even in Anglophone Nigeria (Ndjeunga et al., 2012). In Mali, groundnut varieties 47-10 and 28-206 released in the 1950s are the most popular cultivars.

In spite of the dearth of investment in the improvement of these crops in West Africa as well as scientists' ageing profiles, some progress has occurred which has been below the radar for some time. SOSAT C88 – an improved, ICRISAT-related short-duration pearl millet variety released in 1988 in Mali and Niger, and in 2000 in Nigeria – lays claim to an area slightly exceeding 1 million ha. This variety is grown in a larger area than any of the over 1,000 improved adopted cultivars listed in the DIIVA database. Varietal change in groundnut in East Africa, especially in Uganda, is another success story that was stimulated by an impressive partnership between NARO, ICRISAT, and USAID's Peanut CRSP.

Barley, cowpea, and yams also appear in the lower half of Table 4.2. Starting from a very low base of 11% in 1998, the uptake of improved barley varieties in Ethiopia has slowly but steadily increased over time. Both improved food and malting barleys have contributed substantially to MV adoption (Yigezu et al., 2012b).

Cowpea adoption outcomes are dominated by the performance of crop improvement research in Niger and Nigeria which, when combined, have a harvested area of over 8 million ha. Niger is characterized by a harsh production environment and unstable crop research featuring a high level of donor instability. These conditions have resulted in an adoption estimate of 9% that has kept cowpea from entering the top half of Table 4.2.

According to FAO production data, yams have the highest calculated value of production of any crop, including cassava and maize, in SSA. This fact seems incredible because maize and cassava are usually considered the staple food crops in SSA, but an absence of crop improvement research targeted on a species as spatially concentrated as yams does not seem surprising. The 30% adoption estimate for yams in Table 4.2 is attributed to a 75% outcome for improved varieties in Côte d'Ivoire, the second largest producer in West Africa. C18 is the prevalent variety. Following its introduction in Côte d'Ivoire in 1992, C18 expanded rapidly, covering large areas of yam cultivation where it sometimes represents 100% of the area cultivated to *Dioscorea Alata* – otherwise known as 'yellow' or 'water' yam – one of six economically important yam species. C18 is known for making tasty yellow porridge.

Both beans and sweetpotato partially owe their position in the lower half of Table 4.2 (page 40) to this study's stance on excluding released local landraces from the definition of MVs. The adoption level for beans would rise to 50% with a broadening of this definition, while the adoption level of improved varieties of sweetpotato would triple to 24%.

Among grain legumes in Table 4.2, improved varieties of beans rank third in the adoption outcomes. Bean MVs are characterized by a substantially higher uptake in Ethiopia than MVs for any other grain legume in the DIIVA Project; presumably because Ethiopia has developed a vibrant export industry for haricot beans.

In 1984, a regional breeding program was established in the Great Lakes region of SSA. It focused on breeding for resistance to bean pests and diseases in conditions of low and declining soil fertility typical of small rural household production. To meet this challenge, PABRA was launched as a CIAT project in 1996. It now consists of three regional genetic improvement networks – the Eastern and Central Africa Bean Research Network (ECABREN), the Southern Africa Bean Research Network (SABRN) and West and Central Africa Bean Research Network (WECABREN) – and encompasses 29 countries in SSA. PABRA has a record of sustainability and growth that is matched only by a few other regional IARC-related crop improvement networks (Lynam, 2010).

The sustainability of the PABRA umbrella network has strongly influenced these positive outcomes for adoption in a crop that is often characterized by niche specificity in terms of production conditions and market preferences. Identification of improved bean varieties in farmers' fields is an onerous undertaking. With a few notable exceptions, improved bean varieties are believed to account for only small areas in most countries, thereby making the validation of such spatially fragmented expert opinion a difficult task.

In the 1970s and 1980s, little research was conducted on sweetpotato in SSA. Sweetpotato owes its rather modest position in Table 4.2 to a stable and sustained breeding effort in Uganda and Mozambique (Labarta, 2012). Interest in orange-fleshed sweetpotato for its high beta-carotene content has also helped to stimulate and marshal investment in what was once a relatively neglected secondary food crop in SSA. The adoption of improved varieties in Table 4.2 is split about equally between white- and orange-fleshed varieties.

Adoption of potato MVs are at the mean level in Table 4.2. Given the crop's market orientation and rapidly increasing growth rate in SSA over the past two decades, an adoption level that approaches the mean value across all crops could not be termed superior performance. Following a longer-term CIP presence, Malawi has only recently released improved varieties that are now in the very early phase of adoption. The greater uptake of improved clones in Ethiopia and Kenya has not compensated for the sharp downturn in the use of improved materials in Rwanda since the 1994 genocide which destroyed not only the potato improvement program in Ruhengeri – the hub of CIP activities in the Great Lakes region (Rueda et al., 1996) – but also devastated an effective seed program. Although potato is a priority food crop, recovery in Rwanda has been slow for improved clones, which were believed to be close to full adoption in the early 1990s, prior to civil war.

Cassava is perhaps the most surprising member of the set of seven crops with above-average adoption in Table 4.2. In spite of low levels of research intensity documented in Section 2 of this paper, the performance of cassava crop improvement has been solid and steady with regard to adoption outcomes. The majority of the countries included in this study have substantially higher levels of uptake of improved varieties now compared to the late 1990s (Alene and Mwalughali, 2012a). A strategy that has emphasized high yield combined with disease resistance in a mostly sweet, rather than bitter, background seems to have yielded good dividends in many countries. Additionally, donors have actively supported programs to propagate and widely distribute improved planting materials.

The location of pigeonpea in the top half of Table 4.2 was also expected. All three study countries in East Africa have a commercial demand for high-yielding medium-duration types that are well adapted to bi-modal seasonal rainfall in Kenya, Malawi, and Tanzania (Simtowe and Mausch, 2012).

Maize in ESA benefited from the large number of released varieties stimulated by liberalization policies and private sector investment in maize breeding. As discussed in the previous section, varietal output borders on prodigious in some countries, such as Zambia, which has enacted policies strongly favoring maize production. However, excellent performance in Zambia and Malawi has not compensated for the lack of tangible progress in Angola and Mozambique. In Angola, the dominant released cultivars only account for about 5% of the area planted and date from the mid- to late-1960s prior to Independence.

Adoption outcomes seem to be at a moderately high level for rice, which is grown in well-defined agro-ecological settings throughout SSA. Aggregate adoption levels still depend heavily on what happens in Nigeria and Madagascar, countries that together account for more than half of the rice-growing area in the 14 countries studied that had data available on this aspect. Aggregate adoption levels also hinge on adoption outcomes in the rainfed lowlands and the uplands. The aggregate level is also sensitive to adoption outcomes in Guinea, which arguably has released more varieties with less ensuing adoption than any other of the 152 crop-by-country national adoption observations. Recent gains in adoption in several countries appear to have been driven by a positive response from farmers to the NERICA varieties (Diagne et al., 2012). More than any other crop, rice was negatively affected by the decision to define MVs from 1970 – an earlier starting date in 1960 would have led to higher adoption levels, but this points to the continued use of very old varieties.

Maize in WCA secures the second spot in adoption performance in Table 4.2. Improved maize varieties in WCA gained more ground in adoption than any other crop in SSA between 1998 and 2010. These gains were accomplished without significant private sector input (Alene and Mwalughali, 2012a). Most of these gains were recorded via the adoption of OPVs. Some of these are getting older and undoubtedly not all farmers renew seed in a timely fashion, raising questions about the sensitivity of our definition of improved varieties. Factoring in seed renewal rates would lead to a lower adoption estimate, but the uptake of improved maize varieties would still be very impressive (Alene et al., 2009).

Wheat topped the crop adoption table in 1998. The increasing transition in area from durum to spring bread wheat was one of the factors leading to the higher adoption of improved varieties in Ethiopia – by far the largest producer in SSA. Wheat would be likely to occupy a higher position in Table 4.2 if reliable data on adoption had been collected for Kenya, Tanzania, Zambia, and Zimbabwe. These countries were at the level of full adoption of wheat MVs in 1998. Assuming full adoption in 2010 is eminently plausible, as wheat in these four countries is mainly produced in large farms with irrigation. The inclusion of these four countries results in a rise in the adoption estimate to 70%, which is still substantially lower than that for soybean in Table 4.2. The limited penetration of improved Durum varieties into farmers' fields in Ethiopia is a major constraint to full adoption of wheat HYVs in SSA.

Soybean ranks first in our crop adoption table. Soybean is a new crop characterized by strong market demand. Genetic materials are mostly imported from abroad; sufficient time has not elapsed to allow many local landrace materials to develop. Although improved soybean adoption levels are not surprising, their varietal age is – as discussed in Section 5. Given soybeans' scope for global expansion, the crop seems to be taking its time in finding a home in farmers' fields in SSA. Nigeria still harvests more soybean area than the other 12 countries in Table 4.2 combined.

## Adoption rates by country

Aside from the Central African Republic's second place ranking – attributed to the adoption of rice MVs – there are relatively few counterintuitive findings in the adoption estimate by country rankings (Table 4.3, overleaf). One is the relatively high placing of the Democratic Republic of the Congo in achieving an above-average adoption outcome across all crops in spite of stagnating institutional and economic development.

The five countries at the bottom of Table 4.3 all have a weighted adoption estimate below 15%. Burkina Faso is the outlier with a high adoption performance in maize and rice. Burkina Faso is also the first adopter of *Bacillus thuringiensis* (Bt) cotton varieties aside from South Africa. Burkina Faso's position is attributed to negligible adoption of groundnut, sorghum, and pearl millet

**Table 4.3. Weighted area adoption levels by country in SSA in 2010**

| Country | MV adoption % | Number of crop observations |
|---|---|---|
| Zimbabwe | 92 | 4 |
| Central African Republic | 72 | 1 |
| Cameroon | 68 | 6 |
| Zambia | 67 | 6 |
| Kenya | 63 | 8 |
| The Gambia | 56 | 1 |
| Côte d'Ivoire | 55 | 6 |
| Ghana | 53 | 6 |
| Benin | 52 | 6 |
| Malawi | 47 | 8 |
| Senegal | 45 | 6 |
| Sudan | 41 | 4 |
| Nigeria | 41 | 9 |
| DR Congo | 36 | 6 |
| Madagascar | 35 | 1 |
| Mali | 35 | 6 |
| Ethiopia | 33 | 9 |
| Uganda | 33 | 11 |
| Tanzania | 32 | 10 |
| Guinea | 29 | 5 |
| Togo | 22 | 6 |
| Rwanda | 21 | 4 |
| Angola | 17 | 2 |
| Sierra Leone | 16 | 1 |
| Burundi | 14 | 4 |
| Niger | 14 | 4 |
| Eritrea | 13 | 2 |
| Burkina Faso | 13 | 6 |
| Mozambique | 13 | 5 |

MVs. Other countries, like Angola, Mozambique, and Niger, have uniformly low rates of adoption of improved cultivars across all crops.

Optimism is warranted about the prospects for enhancing adoption in such countries as Ethiopia, Mali, and Uganda that are now characterized by average levels for SSA as a whole. However, attaining a moderately high adoption rate of 50% as a hypothetical development goal by 2020 will be a daunting challenge, unless adoption prospects improve markedly for countries in the bottom half of the table.

## Named MVs in the adoption database

About 87% of the MV adopted area is associated with detailed data containing regional and cultivar-specific information. The other 13% refers to aggregate adoption only at the national level.

The regional and cultivar-specific database accounts for slightly over 33 million ha. Adopted area is attributed to named and unnamed varieties where they are available. Unnamed varieties are aggregated into a category called 'other'. Every effort was made to minimize the number of varieties in the 'other' category. Most of the specific entries come from survey data and refer to names that are believed to be MVs, but that could not be linked to a specific released variety. A few of the observations based on expert opinion also have a small residual 'other' category.

There are 1173 named releases in the cultivar-specific database. They account for

98% of the 33 million ha described above. The size distribution of area planted with these varieties is heavily skewed, consistent with previous findings in the "1998 Initiative" for maize in ESA, potato, rice, and wheat. Most of the varieties are grown on small areas, whereas the median-sized variety distribution is cultivated on about 7000 ha. In total, 250 entries were adopted on less than 1000 ha. The 75$^{th}$ percentile of the cumulative distribution occurs at about 22,000 ha. Only 76 varieties exceed 100,000 ha of adopted area.

Few, if any, of these varieties could be called mega-varieties with potential to cover tens of millions of ha, such as the rice variety Swarna (also Sona Masoori and Samba Masuri, among other names) that is grown in South Asia. The most extensively grown variety is SOSAT C88 – the leading pearl millet cultivar in Nigeria and the second-ranking improved variety in Mali. It is one of the subjects of impact assessment in the DIIVA Project (Ndjeunga et al., 2011).

Most of the more extensively grown or more economically valuable improved varieties are concentrated in a small subset of crops and countries. The value of production estimates complement harvested area in describing the economic importance of adopted varieties. Value of production adjusts for heavier yields leading to the more attractive prices of some crops. Value of production is an important criterion because varietal change in crops with more attractive prices and/or higher base yields has the potential to generate greater net benefits per ha of adopted area. By either criterion, the top 100 varieties account for about 60–65% of the total adopted area and value of production of all adopted varieties.

Based on a value criterion, the share of cereals in the top 100 falls and the share of vegetatively propagated crops rises dramatically. According to FAO production data, one ha of cooking banana, yams, or potato can be worth the equivalent of 25–30 ha of sorghum and pearl millet in value. Therefore, it is not surprising to see relatively small areas of improved clones of these crops claim a larger share in the top 100, when value of production is the criterion. Indeed, a small majority of the varieties in the top-value 100 are vegetatively propagated.

The top ten ranking varieties are listed in Table 4.4 (below). Cereals dominate the area classification. Only SOSAT C88 makes it into the top 10 when the categorization is based on value. Under either criterion, Nigeria contributes more varieties than all other countries combined. Aspects of several of these economically important varieties are described in the next section on spillovers.

**Table 4.4. Top-ranked varieties by commodity and country by area and value of production**

| | Area | | | Value | | |
|---|---|---|---|---|---|---|
| Rank | Name | Crop | Country | Name | Crop | Country |
| 1 | SOSAT C88 | Pearl millet | Nigeria | TMS 30572 (Nicass 1) | Cassava | Nigeria |
| 2 | Wad Ahmed | Sorghum | Sudan | C18 | Yams | Cote d'Ivoire |
| 3 | Oba 98 | Maize | Nigeria | TDr 89/02660 | Yams | Nigeria |
| 4 | TMS 30572 (Nicass 1) | Cassava | Nigeria | TMS 4(2)1425 (Nicass 2) | Cassava | Nigeria |
| 5 | ICSV 111 | Sorghum | Nigeria | NR 8082 (Nicass 14) | Cassava | Nigeria |
| 6 | Kubsa | Bread wheat | Ethiopia | TDr 89/02602 | Yams | Nigeria |
| 7 | ICSV 400 | Sorghum | Nigeria | TDr 89/02665 | Yams | Nigeria |
| 8 | Suwan 1-SR | Maize | Nigeria | SOSAT C88 | Pearl millet | Nigeria |
| 9 | Tabat | Sorghum | Sudan | Sadisa (91/203) | Cassava | DR Congo |
| 10 | C18 | Yams | Côte d'Ivoire | Afisiafi (TMS 30572) | Cassava | Ghana |

## Spillovers in adoption

Although the history of crop improvement research is marked by spillovers in adoption in SSA, spillovers are not the first thing that comes to mind when thinking of adoption outcomes in the harsh rainfed production environments of Africa. Adaptability appears to be restricted by low fertility in environments characterized by seemingly high levels of location specificity.

Positive evidence for spillover outcomes was well documented in the colonial era in SSA. For example, in collaboration with the British, scientists in Sierra Leone had been working to increase regional rice production in the difficult mangrove agro-ecology since 1934. The locus of their activities – curtailed in the 1990s because of the civil war – was the Rokupr Rice Research Station. Before Independence this was known as the West African Rice Research Institute and its mandate was to promote spillovers. Several of the released ROK rice varieties became popular, not only in Sierra Leone but also in Guinea and Guinea Bissau. They have also been the subject of adoption studies and impact assessments (Adesina and Zinnah, 1993; Edwin and Masters, 1998).

The case of the high-yielding, late-maturing maize hybrid SR 52 – the world's first triple-cross hybrid grown commercially – released in the early 1960s in Rhodesia is a well-known example of varietal output that generated benefits to neighboring countries in southern Africa (Eicher, 1995). A lesser known example after Independence focused on late blight-resistant potato cultivars in the Great Lakes region of East Africa. In the early 1970s, three late blight-resistant varieties – at the time, recently released from Mexico – were imported into Uganda and Kenya via the Rockefeller Foundation. Although these varieties never laid claim to a significant area in Mexico, they quickly became popular in several smaller countries in East Africa. Before the 1994 genocide in Rwanda, Sangema was the dominant variety in Rwanda and was arguably the most economically important in the ESA region in the 1970s and early 1980s. Even today, Rosita, a synonym for Sangema, is the prevailing potato variety in Malawi and Mozambique.

Confirming the potential for spillovers, the products of older regional crop improvement programs are still visible in their respective geographical sphere of influence. The Armani Regional Station, now in Tanzania but at one time covering all East Africa, has been the location for research that has led to long-term spillovers since the 1950s and 1960s in cassava and sweetpotato materials as progenitors and in a few cases as finished elite clones. Researchers at Armani developed the sweetpotato variety known as 'Tanzania' in Uganda and Rwanda, as 'Sinama' in Tanzania, as 'Enaironi' in Kenya, as 'Kenya' in Malawi, as 'ADMARC' in central Mozambique, and 'Chingovwa' in Zambia (Labarta, 2012). In the five countries included in the CIP study, this variety is estimated to be cultivated on an area approaching 200,000 ha, equivalent to 13% of the total sweetpotato area. (Because of its age, 'Tanzania' is not considered in the set of improved varieties.) It combines high dry matter and a marked preference in East Africa with a strong background of virus-resistance in the Great Lakes Region.

In many of the study crops within the DIIVA Project, researchers have been able to identify more recent examples of spillovers, where investing in varietal improvement in one country has benefited neighboring countries or other countries in SSA. Spillovers in adoption are not as common as spillovers in releases, but they are very visible when they occur.

IITA researchers were able to describe in detail the occurrences of spillovers in adoption for all five of their mandated crops in the DIIVA Project (Alene and Mwalughali, 2012a). In cassava, TMS 30573 occupies 17.8% of the total cassava area in Nigeria, 17.5% in Uganda, 7% in Benin, and 3.2% in Guinea. Though not officially released, the same clone is also being grown extensively in Kenya, where it covers 24% of the cassava area and, to a much lesser extent, is produced in Côte d'Ivoire. In cowpea, popular multi-country varieties include: IT82E-32, covering 23% of the total cowpea area in Ghana, 11% in Benin, and 2% in Cameroon. This is followed by VITA-7, accounting for 22% of total cowpea area in Guinea, and 13% in DR Congo (Alene and Mwalughali, 2012a). The adoption level for variety IT81D-1137 is estimated at 17% in DR Congo and 14% in Benin. These varieties are attractive to farmers because they feature high yield potential, good disease tolerance and short duration.

In maize, Obatanpa – derived from quality protein maize (QPM) materials – and TZEE-Y fit the description of spillover varieties that have crossed over the borders of several countries in WCA (Alene and Mwalughali, 2012a). Two improved soybean varieties are also widely cultivated in the region. Firstly, TGx 1448-2E – a shattering and frog-eye, leaf-spot resistant IITA-bred variety – is sown on more than 60% of soybean area in Nigeria and on more than 20% of harvested area in Cameroon and Ghana. Secondly, TGx 1835-10E – another IITA-developed variety that is desired for its early maturity and resistance to soybean rust, pod shattering and lodging – dominates soybean areas in Uganda (50%) and covers 26% of soybean area in Kenya as well as 6% in Nigeria.

In yams, examples of large spillover effects are harder to find, but a few improved cultivars are found in two countries. Florido is planted in Benin and Togo, and TDr 89/02665 is propagated in Ghana and Nigeria in 5–10% of the total planted area.

Groundnut seems to be the exception to the finding that the prevalence of wide adaptability and spillover varieties is uncommon in ESA. Similarities in the results were less numerous than contrasts between the two regions. In four of the five groundnut study countries in the ESA region, rosette-resistant ICGV-SM 90704 and drought-tolerant ICGV 83708 ranked first or second in the adoption of improved varieties.

Finally, in rice, NERICA 1 is presently grown in five of the 12 producing countries with cultivar-specific information in the DIIVA adoption database. Earlier, BG 90-2 from Sri Lanka was a commonly introduced cultivar that was released by the majority of rice-producing countries in West Africa and later became popular in several countries.

The incidence of spillover varieties appears to be higher in West Africa than in East Africa. The Sahelian, Sudanian and Guinean zones of West Africa cut across broad swathes of several countries. This makes for more homogeneous agro-ecological conditions going from west to east across countries than from north to south within the same country. The incidence and size of spillovers also varies by crop and is lower in beans and higher in potatoes in East Africa. In ESA, spillover events in maize were not as large; although they were probably underestimated because of incomplete and low-quality data. SC 627 is a hybrid that scores well on wider adaptation and is grown extensively in Tanzania and Malawi (De Groote et al., 2011).

In West Africa, the incidence of spillovers also varies from crop to crop. Spillover varieties are readily visible in pearl millet and groundnut but less so in sorghum. The pearl millet variety SOSAT C88 mentioned previously has been adopted in four West African countries. Similarly, the groundnut variety Fleur 11 is also spreading in West Africa from Senegal to Mali and Niger (Ndjuenga et al., 2012).

The emphasis on spillover varieties in this subsection does not detract from the empirical fact that the varieties selected and used solely within a country are likely to contribute far more to total adopted area in SSA than multi-country varieties. Moreover, as pointed out earlier in this section, none of the identified spillover varieties can yet be called mega-varieties, such as the rice variety Swarna Masuri sown on millions of hectares in South Asia.

The identification of definite spillover varieties serves mainly as a reminder that small NARS can still reap some benefits from national and international research. A stable crop improvement presence in the region can generate returns that far exceed national benefits for the investing country.

## IARC-related adoption

Most IARCs have been heavy contributors to the varietal change that has taken place in their mandated crops in SSA (Table 4.5, overleaf) – about 22% of the area harvested is in IARC-related genetic materials. The relative importance of those materials approaches two-thirds of total area in improved varieties.

The crops in Table 4.5 are ordered by the difference between their estimated share in varietal output and adoption. It is refreshing to see sorghum, pearl millet, and groundnut at the head of this table. Released varieties of these crops may have had somewhat limited acceptance by farmers (see Table 4.2 on page 40), but IARC-related cultivars have had better adoption outcomes than most in a difficult rainfed production environment.

The mean weighted difference between the adoption and release shares is 20%, which is higher than expected. The crops towards to bottom of Table 4.5 are relatively new to crop improvement research in the CGIAR, so we did not anticipate having high shares of IARC-partnered adoption.

Perhaps more than any other international non-CG institution and in any crop in the DIIVA Project, CIRAD (IRAT) has had a marked impact on the adoption of rice MVs in several countries of Francophone Africa, including Madagascar. This important institutional connection is a plausible explanation for why rice does not rank higher in Table 4.5. Likewise, the small negative value of maize in ESA could be attributed to the late start by CIMMYT in the region, and to alternative suppliers in the burgeoning private sector.

## Comparing adoption levels between 1998 and 2010

The 1998 benchmark provides a basis for carrying out a before-and-after comparison of the level of varietal adoption for the ten continuing crops in the DIIVA Project (Table 4.6, overleaf).

On average, the 61 observations represent

**Table 4.5. The contribution of the CG Centers to MV adoption in SSA in 2010**

| Crop | Adoption | | | Release | Difference between adoption and release shares (%) |
|---|---|---|---|---|---|
| | Estimated adoption (%) | IARC-related (%) | Share IARC (%) | Share IARC (%) | |
| Sorghum | 27.4 | 20.6 | 75.0 | 24.8 | 50.2 |
| Pearl millet | 18.1 | 15.7 | 86.6 | 40.2 | 46.4 |
| Groundnut | 29.2 | 25.0 | 85.8 | 43.6 | 42.2 |
| Bean | 29.0 | 23.5 | 81.0 | 39.1 | 41.9 |
| Wheat | 58.5 | 37.7 | 64.5 | 45.0 | 19.5 |
| Banana | 6.2 | 2.2 | 34.9 | 16.7 | 18.2 |
| Potato | 34.4 | 31.2 | 90.8 | 75.0 | 15.8 |
| Sweetpotato | 6.9 | 5.6 | 81.3 | 66.3 | 15.0 |
| Cassava | 39.7 | 32.7 | 82.5 | 68.1 | 14.4 |
| Soybean | 87.9 | 55.6 | 63.2 | 48.9 | 14.3 |
| Lentil | 10.4 | 10.4 | 100.0 | 86.7 | 13.3 |
| Cowpea | 27.2 | 18.1 | 66.7 | 57.5 | 9.2 |
| Maize–WCA | 65.7 | 53.0 | 80.6 | 74.2 | 6.4 |
| Chickpea | 15.0 | 15.0 | 100.0 | 95.8 | 4.2 |
| Barley | 32.7 | 7.5 | 23.0 | 21.1 | 1.9 |
| Pigeonpea | 49.9 | 41.8 | 83.9 | 82.4 | 1.5 |
| Rice | 38.0 | 19.2 | 50.6 | 51.4 | -0.8 |
| Maize–ESA | 44.0 | 12.9 | 29.4 | 30.3 | -0.9 |
| Field pea | 1.5 | 0.0 | 0 | 16.7 | -16.7 |
| Yams | 30.2 | 15.1 | 50.0 | 74.3 | -24.3 |
| Faba bean | 14.0 | 0.5 | 3.7 | 40.0 | -36.3 |
| Weighted average[a] | 35.25 | 23 | 65.6 | 45.5 | 20.0 |

a Weighted by total area, except the share in adoption estimates that are weighted by total adopted area in each crop

**Table 4.6. Change in MV adoption between 1998 and 2010 in ten food crops in SSA**

| Crop | Number of paired observations | 1998 | | 2010 | | Relative importance in 2010 (% area coverage of paired observations) |
|---|---|---|---|---|---|---|
| | | Area (ha) | MV adoption (%) | Area (ha) | MV adoption (%) | |
| Barley | 1 | 897,360 | 11.0 | 91,3863 | 33.8 | 86 |
| Bean | 6 | 1,738,000 | 14.6 | 1,903,964 | 35.1 | 45 |
| Cassava | 15 | 8,777,800 | 21.0 | 10,033,995 | 42.0 | 81 |
| Groundnut | 3 | 496,517 | 12.6 | 724,019 | 56.7 | 7 |
| Maize | 19 | 18,566,300 | 25.6 | 24,366,088 | 52.8 | 91 |
| Pearl Millet | 1 | 1,285,540 | 22.0 | 1,520,440 | 31.1 | 9 |
| Potatoes | 4 | 353,852 | 49.2 | 569,921 | 37.1 | 60 |
| Rice | 7 | 3,639,110 | 48.4 | 3,787,146 | 36.5 | 44 |
| Sorghum | 4 | 12,711,129 | 19.3 | 13,354,489 | 32.4 | 58 |
| Wheat | 1 | 1,330,000 | 56.0 | 1,453,820 | 63.5 | 84 |
| Total/weighted average | 61 | 49,795,608 | 25.0 | 58,627,745 | 43.9 | 55 |

about 55% of the area of the crops grown in SSA. Coverage is adequate in eight of the ten crops to draw inferences about varietal change between 1998 and 2010. However, coverage is too scanty to make inferences about progress in varietal uptake in groundnut and pearl millet.

Two important empirical facts emerge from Table 4.6 (above). First, the level of varietal adoption was 25% in 1998. Secondly, and more importantly, MV adoption increased at a rate equivalent to a linear annual gain of 1.45 percentage points over the 13-year period.

With the exception of rice and potatoes, all crops experienced an expansion in the use of MVs. Uptake was especially robust in barley, beans, cassava, and maize, with adoption levels doubling during the period.

The before-and-after data points for the primary staples, maize and cassava, are arrayed in Figure 4.1 (overleaf) where the balloons in the droplines are weighted by area in 2010. Maize in DR Congo was the only crop-by-country observation to experience a steep decline in the estimated adoption rate between 1998 and 2010. Gains in the uptake of maize hybrids were significant in Zambia and Malawi. Hybrids also played an important role in Ethiopia. Increases in the West African countries and in Tanzania and Uganda were almost entirely fueled by the spread of improved OPVs. In general, the cassava-growing countries were characterized by lower adoption levels in 1998 than the maize-producing countries; but, aside from Tanzania, every cassava-producing country displayed a propensity for the greater uptake of improved clones in 2010 than in 1998.

A potentially relevant aspect of this before-and-after comparison centers on the accrual of adoption gains by level of adoption in 1998. The difference in adoption between the two periods is negatively associated with the magnitude of adoption in 1998. Countries that commenced with levels of adoption equal to, or below, 40% tended to accrue more increments in adoption. Those that started with moderately high rates of adoption of improved varieties were hard pressed to achieve even more positive outcomes in adoption. We expect this type of behavior when a country approaches full adoption, but not when it is at such a moderate to high level of MV acceptance as improved maize cultivars were in Burkina Faso, Ghana, and Kenya in 1998.

Lack of progress in countries with already moderately high rates of adoption indicates the existence of marginal production regions where MVs do not compete favor-

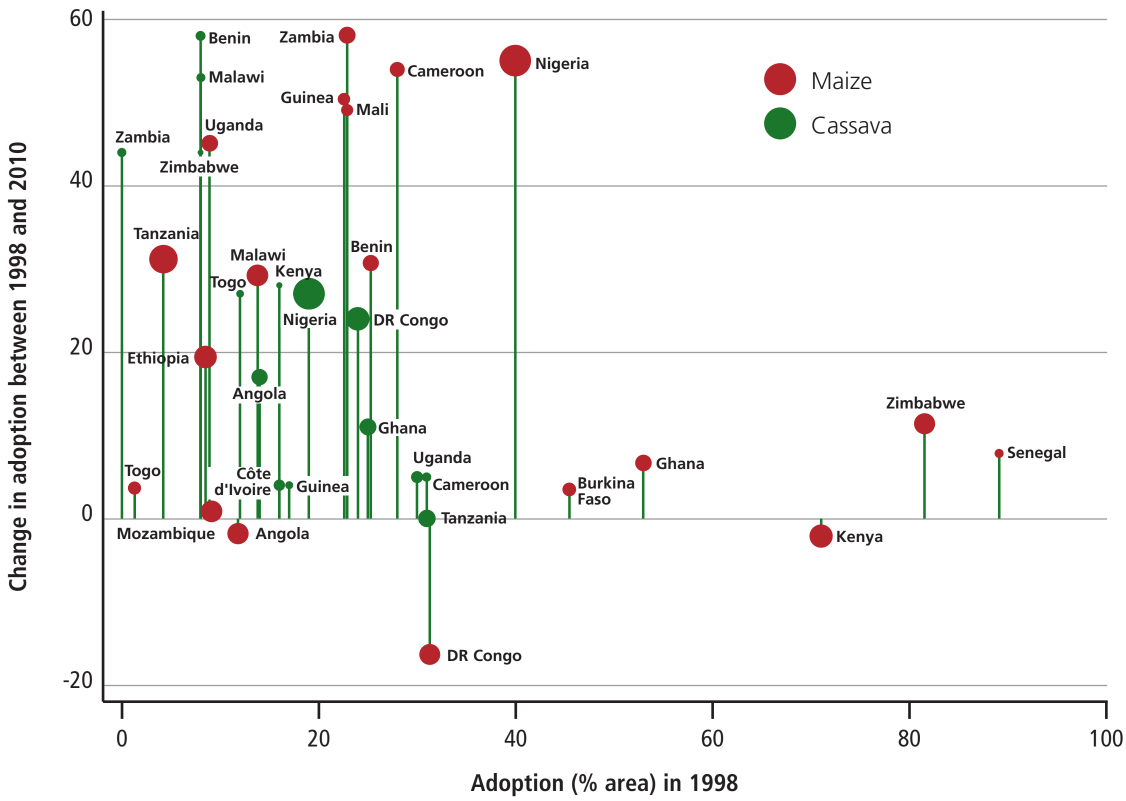



**Figure 4.1. Change in the estimated level of adoption of improved maize and cassava varieties between 1998 and 2010**

ably with traditional varieties on a few important characteristics. It will be interesting to see if the new entrants in moderate-to-high adoption group in Figure 4.1 (above) will be able to consolidate and expand on their gains in the next version of the DIIVA Project.

Comparable before-and-after data on the remaining crop in Table 4.6 (on page 49) are presented in Figure 4.2 (overleaf). Many relatively small producing countries made relatively large gains in the adoption of beans and groundnut. Sorghum in the Sudan was the largest crop-by-country combination to register appreciable gains in adoption.

Unlike cassava and maize in Figure 4.1, the relative importance of MVs declined in several countries between the 1990s and 2010. In particular, the adoption estimate for improved clones of potato decreased sharply from 97% of the harvested area in 1993 to 35% in 2010. As discussed, potato MVs became less important because of the devastation in Rwanda caused by the 1994 genocide, which did not predate the '1998 Initiative' because the adoption estimates for Rwanda referred to 1993.

In contrast, the estimated deteriorating position of MVs in rice could be attributed to a change in methods. Expert opinion panels were used to generate all the estimates for rice MVs in 1998. Surveys funded by the Japan International Cooperation Agency (JICA) were deployed by researchers in AfricaRice to arrive at nationally representative estimates of MV adoption in 20 African countries from 2008 to 2011.

If progress in MV adoption was slow, switching methods could be sufficient to change a small positive outcome to a meager negative consequence.

Similar to the evidence presented in Figure 4.1, countries characterized by moderately high levels of adoption in 1998 had a hard time maintaining these levels, let alone achieving gains in adoption. Rice

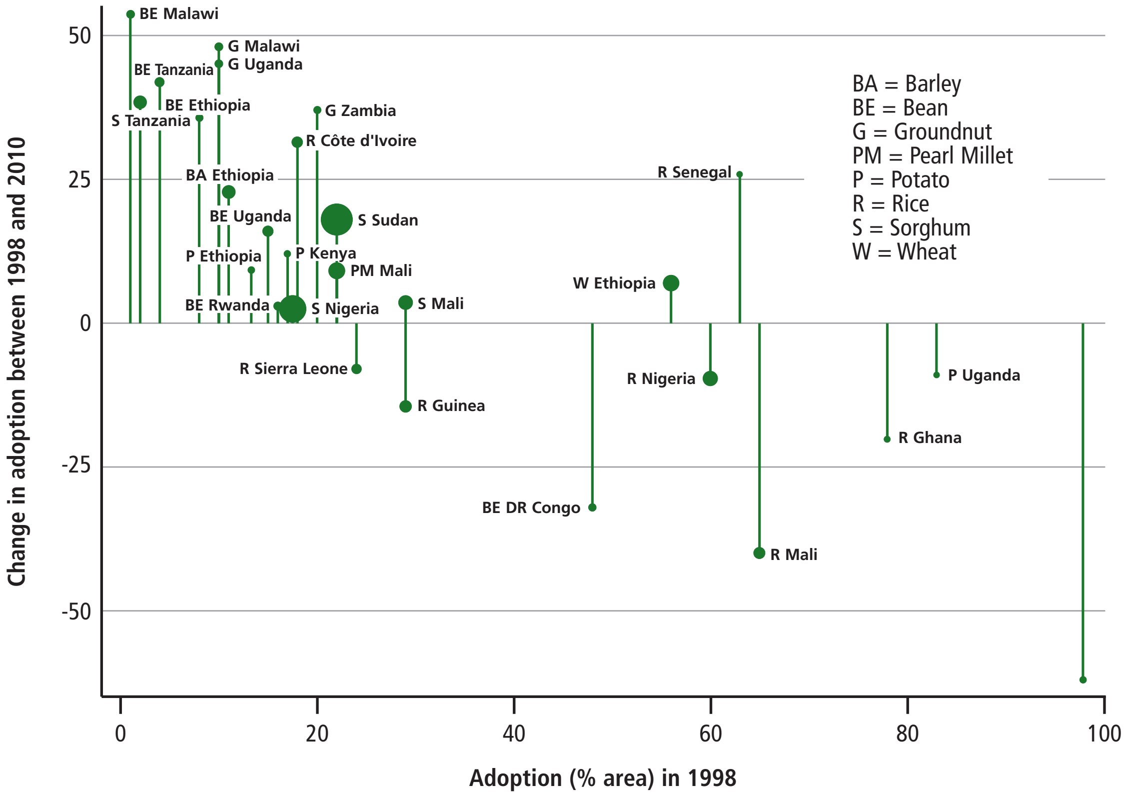



**Figure 4.2. Change in the estimated level of adoption of improved bean, groundnut, pearl millet, potato, rice, sorghum, and wheat varieties between 1998 and 2010**

in Senegal and, to a lesser extent, wheat in Ethiopia are the only two crop-by-country observations that exhibited substantial gains in adoption from 'moderate' to 'high'. Gains in adoption were concentrated at the lower end of the x axis in Figure 4.2 in much the same manner as very positive outcomes were clustered in the same region of Figure 4.1.

About 90% of the paired observations in Table 4.6 on page 49 showed an increase in the uptake of improved varieties (Figures 4.1 and 4.2). Again, disadoption and/or overestimation of MV adoption levels in 1998 occurred mainly in potatoes and rice. The finding of a few cases of disadoption is unexpected because the ending of fertilizer subsidies is frequently mentioned as a motivation for reversion to local varieties. The evidence for disadoption is sparse, particularly for maize, which is a relatively intensive user of fertilizer among the food crops in the DIIVA Project.

## Summary

The area-weighted grand mean adoption level of improved varieties across the 20 crops is 35%. The distribution of adoption of improved varieties is skewed as 14 of the crops are characterized by a mean adoption level that falls below 35%. Crops with an estimated adoption performance superior to the overall average included soybean, wheat, maize, pigeonpea, cassava, and rice. About 23% of the 35%, i.e., a share of 65% of MV adopted area is related to IARC-contributed genetic materials. The IARC-related share in adoption is about 20% higher than its 45% contribution to released varieties.

The problem of lagging countries was also evident in the cross-sectional adoption estimates based on 152 crop-by-country observations. Adoption of modern varieties was uniformly low in Angola, Mozambique, and Niger across all crops.

Spillover varieties were prevalent, but, unlike in South Asia, so-called mega-varieties that claimed millions of hectares of arable land were not found. Of the over 1000 improved varieties listed in the DIIVA adoption database, SOSAT C88, a short-duration pearl millet variety, was the most extensively cultivated on just over one million ha in Nigeria, Mali, Niger, and Burkina Faso. In maize, Obatanpa, derived from QPM materials, and TZEE-Y, an IITA-bred variety, fit the description of spillover varieties that have crossed over the borders of several countries in WCA. The incidence of spillover varieties appears to be higher in WCA than in ESA and in groundnut than in other crops.

The paired comparison of 61 crop-by-country observations for the 10 continuing crops showed that area-weighted adoption was 27% in 1998 and 44% in 2010. The 95% confidence interval for the 17.6% gain in adoption was 12.3%–22.9%. Over 90% of the observations experienced a rise in MV adoption, which increased at a rate equivalent to a linear annual gain of 1.45 percentage points over the 13-year period. With the exception of rice and potatoes, all crops experienced an expansion in the use of modern varieties. Uptake was especially robust in barley, cassava, and maize with adoption levels more than doubling during the period. Civil war and changing methods in measuring adoption loom large as plausible explanations for why improved varieties lost ground in a few countries and a few crops. Crop-by-country observations with a low level of MV adoption in 1998 were more likely to experience positive outcomes in adoption than those with moderate levels of adoption in 1998.

# 5. Varietal change

## The importance of estimating varietal change

The level of adoption of improved cultivars only tells part of the story about the results of investment in crop improvement. The velocity of varietal change is an equally important aspect, especially for countries where levels of adoption are already high. The rate of change or the replacement of old varieties by new ones says a lot about the effectiveness of genetic improvement programs. Past research suggests that if newer materials are not replacing their older counterparts, returns to genetic improvement stagnate (Brennan and Byerlee, 1991). Simply put, the permanency of first-generation improved varieties in farmers' fields points to a problem of declining productivity in the search for, and release of, new varieties in crop improvement.

Varietal turnover is measured by the age of varieties against their area in production. The date of release usually initiates a variety's age calculation – i.e. when it became available to the public for adoption. Therefore, age is measured from the year of release to the current year, unless farmers had access to the variety many years prior to the date of release. Only improved varieties are calculated irrespective of their adoption level. The appropriate measure is the area of variety, x or y, in the total area of improved varieties. The results show that varietal age will fall irrespective of whether younger varieties replace older improved varieties or traditional varieties, because the share of younger varieties will increase in the group of improved varieties.

Area-weighted age estimates under 10 years indicate rapid varietal change and steady progress in plant breeding from an economic perspective. Estimates of varietal turnover that exceed 20 years indicate that more recent materials are having a hard time competing with earlier materials. Rising varietal age is associated with declining marginal returns to plant breeding. However, the adoption level also needs to be factored into the evaluation. Having rapid varietal turnover with less than 10% adoption does not imply significant economic progress in plant breeding.

Past studies have documented large disparities in varietal turnover rates in different agricultural settings. Farmers growing irrigated wheat in the Yaqui Valley of Mexico replace their varieties every three to four years. The breaking down of disease resistance and the steady increase in yield gains are positive incentives for rapid varietal change. In the corn belt of the USA, farmers switch to newer hybrids every two to three years. In contrast, potato growers in specialized compact regions of outstanding production potential in the USA have limited incentives to replace the Russet Burbank potato with newer varieties. Russet Burbank is difficult to grow, but it is highly productive and has strong market demand. For potato growers in Canada and the USA, estimated varietal age has fluctuated between 40 and 50 years since the 1990s indicating a low rate of return to most state and national potato improvement programs in North America (Walker, 1994, Walker et al., 2011b).

## The velocity of varietal turnover in 2010 by crop

The estimated average weighted age is presented in Table 5.1 (overleaf) by crop for 117 country observations where crop-specific

Farmers in Benin celebrate a bumper crop of NERICA rice. Velocity of varietal turnover is as important as adoption level in assessing plant-breeding importance adoption and varietal release information were available. The average results by crop are tightly clustered in the range of 10–20 years. This means that there may be few, if any, crops where older adopted improved materials have substantially eroded the profitability of plant breeding. But, by the same token, there was also little evidence that rapid varietal change is taking place. The area-weighted grand mean is 14 years indicating that the average MV in farmers' fields in 2010 dated from 1996.

The results in Table 5.1 (below) are somewhat counterintuitive because crops such as sweetpotato and banana, with high multiplication ratios, are characterized by a younger portfolio of varieties compared with several propagated crops with stronger market demand. However, this is not surprising because of the dearth of earlier research on these clonal crops that translated into few, if any, releases in the 1980s and 1990s.

Table 5.1 does contain a few surprises. For example, soybeans should have performed better on this criterion given its emerging and expanding cultivation in SSA. However, the youngest soybean varieties in farmers' fields in Nigeria are 'old' as they were released in the early 1990s.

**Table 5.1. The velocity of varietal turnover of improved varieties in farmers' fields in SSA by crop**

| Crop | Varietal age (yrs) | Number |
|---|---|---|
| Banana | 10.2 | 1 |
| Sweetpotato | 10.3 | 5 |
| Groundnut | 11.7 | 5 |
| Chickpea | 11.9 | 2 |
| Cowpea | 11.9 | 16 |
| Lentil | 12.5 | 1 |
| Maize–WCA | 12.8 | 11 |
| Wheat | 12.8 | 1 |
| Maize–ESA | 13.0 | 8 |
| Beans | 13.8 | 9 |
| Cassava | 14.1 | 17 |
| Soybean | 14.2 | 11 |
| Pearl millet | 14.8 | 3 |
| Rice | 15.8 | 4 |
| Sorghum | 17.4 | 6 |
| Pigeonpea | 17.9 | 2 |
| Yams | 18.4 | 5 |
| Barley | 18.5 | 2 |
| Field pea | 18.9 | 1 |
| Potato | 19.4 | 5 |
| Faba bean | 20.7 | 2 |
| Weighted mean/Total | 14.0 | 117 |

The lack of difference in varietal age between maize in WCA and ESA is also unexpected. Improved cultivars in WCA are OPVs; hybrids dominate maize production in ESA. Historically and, especially in the last decade, many more hybrids have been released in ESA than OPVs in WCA. Yet, the genetic and seed market-related differences between these two contrasting types of material have not translated into substantial differences in varietal turnover. H-614 is the dominant hybrid in Kenya. It was released in 1986. HB-660 is less dominant, but it is the leading improved cultivar in Ethiopia. Both hybrids are closely related with the same parental materials. They trace their roots to the Kitale Station in Kenya from crosses between Kitale Synthetic and Ecuador 573, a landrace from the Andean Highlands collected by the Rockefeller Foundation in 1953 (De Groote, personal communication, 2013). In Kenya, the mean varietal age of hybrids and improved OPVs across the six maize producing agro-ecologies was 24 years in a nationally representative adoption survey in 2010 (Swanckaert et al., 2012).

One way to shed more light on the performance of crop improvement across crops is to combine the information on varietal adoption and age. Mean levels of both variables are drawn in Figure 5.1 (overleaf) to identify different combinations of outcomes for varietal adoption and change. This delineation results in four quadrants that are roughly indicative of the comparative profitability of investments in crop improvement. Programs in the upper left-hand quadrant are characterized by poor outcomes in both varietal adoption and change; commodities in the lower left-hand quadrant are problematic in terms of adoption levels; and those in the upper right-hand quadrant are problematic in terms of the velocity of varietal change. Only maize and wheat are clearly placed in the positive outcome space of both criteria in the lower right-hand quadrant. Cassava, beans, and soybean border on the positive outcome space, suggesting that they are superior to most crops on one criterion and are average on the other.

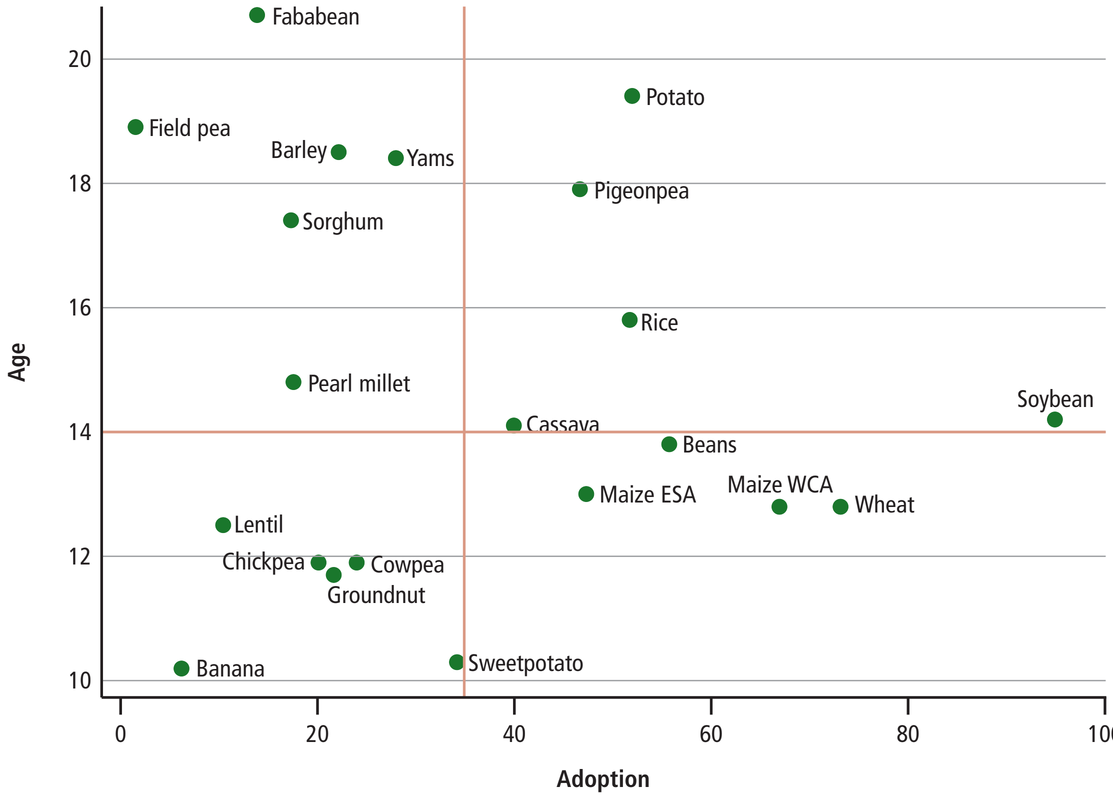



**Figure 5.1. Distribution of crops by adoption level and percent and varietal age in years. Note: reference lines index the mean level of varietal adoption and age**

## Varietal change and adoption by crop-by-country observations

The same analytical format can be used to array adoption and age information for all of the 117 observations for which there is complete information on cultivar-specific adoption and on the date of varietal release. These unlabeled results are presented in Figure 5.2 (overleaf). Sixteen programs are located in a favorable position in the lower right-hand quadrant, showing better than average adoption of improved varieties with younger varietal age (less than or roughly equal to 10 years).

A quick inspection of Table 5.2 (page 57) shows that these better-performing crop-by-country entries are a blend of larger-area programs in maize, cassava, and cowpea with several very small programs in soybean and rice. But, on average, these 16 programs are not significantly different from the mean size of the crop-by-country observations in Table 5.1 (page 54) and Figure 5.2. Several of the programs in Table 5.1 were described in Section 4 as success stories in the discussion on adoption levels by crop.

The composition of country and crop programs in Table 5.2 also begs some questions, such as:

- How has DR Congo managed to attain better than average estimates in varietal adoption and varietal change in cassava in the presence of severe institutional and economic constraints? This remains a question that requires further research.
- Why do Burkina Faso and Senegal have desirable outcomes for diffusion and varietal age in maize but also have negligible results in varietal releases and adoption in sorghum, pearl millet, and groundnut? Apparently, maize is a new crop in Burkina Faso and Senegal and is expanding rapidly in terms of area.

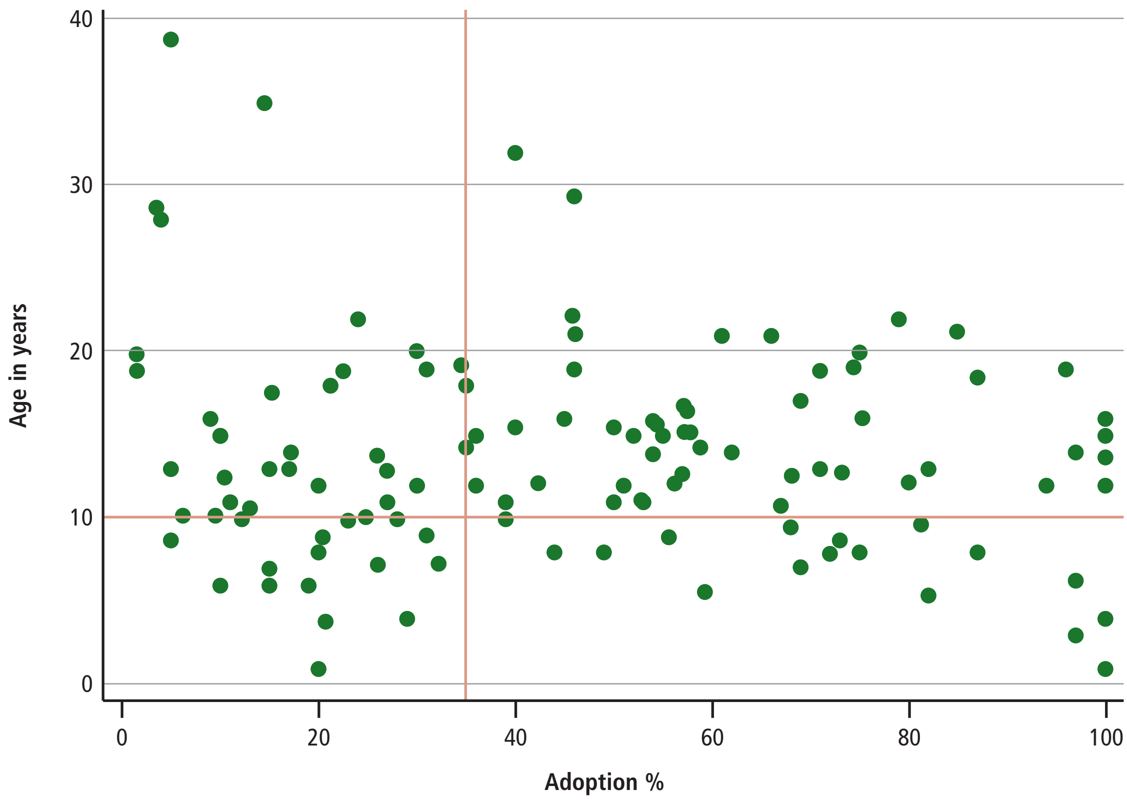



**Figure 5.2. Distribution of crop-by-country improvement level of adoption and the mean age of varieties in farmers' fields. Note: benchmark lines are set at the mean adoption level and 10 years of adoption age**

Returning to Figure 5.2, programs located in the top-left quadrant with unfavorable readings on both varietal adoption and varietal change are larger than average. Their mean area is about 1 million ha greater than the mean of all 117 crop-by-country observations. These lagging programs in both varietal adoption and turnover are critical to attaining dynamism in varietal diffusion as well as development in the medium and longer term in SSA. They risk being bypassed by their crop and country neighbors that are located in the other three quadrants of Figure 5.2.

## The vintage of adopted varieties

A small majority of the 1145 cultivars in the adopted variety database carry information on the date of release. These varieties account for about 80% of the adopted area and value of production. Their age distribution is presented in Table 5.3 (overleaf). The largest area and value share come from the cohort of varieties that were released in the late 1990s. This finding is not necessarily surprising, but it does show that CG Centers were able to supply materials for release by their NARS partners during a time of financial crisis in the late 1990s and early 2000s. From this, it is possible to infer that financial constraints did not entirely stop the flow of materials in the pipeline. A 15% value share for varieties released between 2006 and 2011 is encouraging and indicates that materials in the pipeline are finding a home in farmers' fields. A sizeable chunk of the recent difference between the area and value share has been attributed to the release of two promising improved yam clones in Nigeria.

The share estimates in Table 5.3 also hint at the longer term impact of varietal change. Improved varieties in the early 1980s are still making a substantive contribution that cannot be ignored.

**Table 5.2. Genetic improvement programs with higher adoption and more rapid varietal turnover by crop and country[a]**

| Crop | Country | Adoption of improved varieties (%) | Varietal age (yrs) | Total area ('000 ha) |
|---|---|---|---|---|
| Cassava | Kenya | 44 | 8 | 60 |
| Cassava | DR Congo | 49 | 8 | 1850 |
| Cowpea | Nigeria | 39 | 10 | 3768 |
| Cowpea | DR Congo | 87 | 8 | 96 |
| Groundnut | Uganda | 56 | 9 | 239 |
| Maize | Senegal | 97 | 6 | 191 |
| Maize | Burkina Faso | 49 | 8 | 555 |
| Maize | Cameroon | 82 | 5 | 686 |
| Maize | Malawi | 68 | 10 | 1655 |
| Maize | Zambia | 73 | 9 | 1081 |
| Rice | Rwanda | 69 | 7 | 13 |
| Rice | Uganda | 81 | 10 | 120 |
| Soybean | Zambia | 100 | 1 | 45 |
| Soybean | Zimbabwe | 100 | 4 | 67 |
| Soybean | Uganda | 97 | 3 | 148 |
| Soybean | Cameroon | 75 | 8 | 13 |

a Observations in Table 5.1 with better than average adoption and age <= 10 years

A case in point is IITA's release of its important cassava variety TMS 30572 in 1984. In contrast, materials released prior to 1980 in the early years of the CGIAR were relatively limited in number and their impact has eroded over time.

**Table 5.3. The vintage of varieties contributing to adoption in 2010 by criterion and by release period**

| Release period | Criterion | |
|---|---|---|
| | Area share (%) | Value share (%) |
| 1970–1975 | 1.7 | 1.1 |
| 1976–1980 | 2.7 | 2.9 |
| 1981–1985 | 8.3 | 10.6 |
| 1986–1990 | 12.7 | 12.8 |
| 1991–1995 | 19.4 | 15.6 |
| 1996–2000 | 27.1 | 23.9 |
| 2001–2005 | 17.7 | 17.4 |
| 2006–2011 | 10.3 | 15.2 |
| **Total Area ('000 ha)** | **27,477.4** | |
| **Total Value in US$ (million)** | | **12,095.20** |

Note: Based on 590 varieties that account for 80–85% of total area and value of production of all varieties in the database

## Comparing levels of varietal change in 1998 and 2010

Information is sparse for comparing aspects of varietal change between 1998 and 2010. In 1998, cultivar-specific profiles at the national level could only be constructed for maize in ESA, wheat, rice, and potato. Varieties were younger in wheat and potato and older in maize and rice. The average age ranged from about 10 years in potato to 18 in rice.

Heisey and Lantican (2000) estimated weighted average varietal age for improved wheat varieties from the 1998 dataset for seven countries in SSA. Estimated age varied from a low of 2.5 in Zimbabwe to 15.9 in Ethiopia. Estimated varietal age for six of the seven countries ranged from 10–16 years. Those estimates were roughly the same for comparable data in 1990 indicating stagnant progress in varietal turnover. In Zimbabwe, varietal turnover was very rapid because several large homogeneous wheat producers were effective in realizing their demands for varietal change.

Comparing the 1998 estimates to those in Table 5.1 (page 54) for 2010 suggests that improved varieties are not getting any younger in farmers' fields. For maize and wheat, age is roughly the same as 14 years ago. For three of the four countries producing potatoes, varieties are becoming older. For rice, the average age of MVs was the highest of the four crops in both 1998 and 2010. Returning to maize in Kenya, varietal age has increased steadily from 17 years in 1992 to 22 years in 2001 to 24 years in 2010 (Swanckaert et al., 2012). Although age has fallen markedly in the dry transitional zone in response to rapid varietal adoption and change, new private sector seed suppliers have not been able to penetrate into other zones where adoption levels are stagnating.

## Summary

The velocity of varietal change is as important as the adoption level of MVs in assessing plant-breeding performance especially for countries approaching moderate to full adoption. Varietal turnover is measured by the age of improved varieties weighted by their area in production.

The area-weighted mean age was 14 years, indicating that the average MV in farmers' fields was released in 1996. The average age-related results by crop were tightly clustered in the range of 10–20 years. This means that there may be few, if any, crops where older adopted improved materials have substantially eroded the profitability of plant breeding. But, by the same token, there was also little evidence that rapid varietal change is taking place. Some crops and important producing countries are characterized by older than expected improved varieties. For a new expanding crop, the youngest soybean varieties in farmers' fields in Nigeria are 'old' as they were released in the early 1990s.

Sixteen crop-by-country programs scored well on both varietal adoption and turnover. These better performing crop-by-country entries combined larger area programs in maize, cassava, and cowpea with several smaller programs in soybean and rice.

The largest area and value shares came from varieties that were released in the late 1990s, suggesting that CGIAR Centers were able to supply materials for release by their NARS partners during a time of financial crisis. The 15% value share for varieties released in 2006–2011 is encouraging and indicates that materials continue to find a home in farmers' fields. Materials released prior to 1980 in the early years of the CGIAR were comparatively limited and their impact has eroded over time. In contrast, those produced in the 1980s account for more than 20% of the area and value resulting from MV adoption.

Comparing the 1998 estimates to those in 2010 suggests that improved varieties are not getting any younger in farmers' fields. For maize and wheat, age is roughly the same as 12 years ago. For three of the four countries producing potatoes, varieties are becoming older. For rice, the average age of modern varieties was the highest of the four crops in both 1998 and 2010.

# 6. Validating adoption estimates generated by expert opinion from survey estimates

What did we learn from the DIIVA Project that will improve the accuracy, precision and cost-effectiveness of future estimation?

Shedding light on the major issues and arriving at orders of magnitude is the intent of this section that is based on three further questions:

1. Were there systematic differences between adoption estimates from the expert panel and survey sources?
2. Do we need to revise the estimate of 35% of MV adoption for 2010 in light of the validation results?
3. What were the main weaknesses in using expert panels and surveys in estimating MV adoption?

Prior to describing the validation surveys and analyzing systematic differences, we begin with a brief review of the literature and the protocol for eliciting expert opinion.

## Validating expert opinion on adoption and the protocol used to elicit estimates from experts

The DIIVA Project was not the first to compare subjective estimates on adoption from expert panels with more objective data. In the spirit of the '1998 Initiative', CIMMYT economists assessed the congruence between expert opinion from NARS scientists, mainly plant breeders, and aggregate adoption estimates from data on seed sales of hybrids and OPVs for maize-growing countries in southern and East Africa (Hassan et al., 2001). Their assessment showed that expert opinion on adoption in countries where hybrids were popular and approaching full adoption were very consistent with estimates derived from seed production data. In contrast, estimates from the two sources diverged as the importance of OPVs increased. Expert opinion in Uganda and Tanzania resulted in markedly higher estimates than those inferred from annual seed-related data.

Using genomic techniques in marker-assisted selection to incorporate striga resistance in sorghum cultivars that farmers are already growing in the Sudan

In the DIIVA Project Implementation Workshop held in Addis Ababa, Ethiopia in February 2010, a 13-step protocol was described for eliciting expert opinion on the adoption of improved cultivars (Walker 2010):

1. Ensure that the historical information on varietal release has been updated and is available. In other words, the varietal release database precedes and lays the foundation for the assessment of adoption perceptions.
2. Canvass background evidence on recent adoption studies and variety-specific seed distribution and sales.
3. Convene an expert panel (usually NARS crop improvement scientists of the commodity of interest and other experts with extensive field-level knowledge of varietal adoption).
4. Divide the country into sub-regions or recommendation domains that the experts are most comfortable with (as few as two or three or as many as 10 or more). These sub-regions should be as fully described as possible in the form of a map or a listing of sub-national administrative units.
5. Assign relative areas to each sub-region from the sub-national Harvest Choice database from the most recent year or a three-year average of recent years.
6. Assess the correspondence between the Harvest Choice agro-ecological,

socioeconomic classification and the experts' description of sub-regions.
7. Elicit perceptions on the rank of specific improved varieties and local varieties as a group in descending order of popularity in each sub-region. The reference point for the ranking is 100% of the crop's area in the sub-region.
8. Check the congruence between varieties in the expert adoption schedule and the release list.
9. Elicit descriptive information on non-local varieties that are sub-regionally important (they are on the expert perception adoption schedule) but are not on the release list. Such information relates to the date of first use, institutionally specific classification in the release database, distinguishing characteristics, etc.
10. Translate the cultivar-specific perceptions on ranks into perceptions of a percent (%) of area for each ranked category. Do this for each sub-region and for the most recent cropping year, say 2009–2010. The easiest way to do this may be to start with the aggregate category group of local varieties for a percent (%) area estimate and then estimate percent (%) area for the dominant MV, the second most dominate MV, the third ranked MV, etc.
11. Highlight issues of greatest uncertainty in the perceptions of percent (%) area; note ranges where uncertainty is greatest.
12. Discuss areas of discrepancies between the background information and the elicited perception and revise the perceptions if the discrepancies are large and if revisions are warranted.
13. Draft a brief one- to two-page report documenting the substance and the process (composition of the expert panel; a description of the sub-regions; background information on adoption; details on how perceptions were assessed; a description of the varieties included in the adoption perception schedule that were not on the release list; and magnitude and reasons for any revisions to expert opinion) for each priority crop-by-country combination.

Some of these steps were viewed as less essential than others. For example, the Harvest Choice database in Steps 5–6 was optional, depending on circumstances. Through trial and error, the Project's Coordinator and its Steering Committee Members expected that some CG Center participants would arrive at an assessment process that was superior to this one in terms of cost-effectiveness and precision.

It is too early to tell if this hope of superiority in methods-related adaptation will become a reality, but a review of methods deployed by the CG Centers shows several concrete examples of adaptation (J. Stevenson and J. Burgess, 2013, personal communication):

- CIAT used a very inclusive approach to conduct its 13 expert panels that were widely attended by knowledgeable people from over 150 institutions, including the private sector and NGOs (Muthoni and Andrade, 2012).
- Several CG Centers, including CIP and ICRISAT, adapted the process when they saw that progress depended on increasing the level of hands-on management by conducting more in-country visits, complemented by a GIS-orientation to build estimates from the ground up (Ndjeunga et al., 2013).
- IITA created teams in Francophone and Anglophone SSA to hold workshops, assemble data and canvass information. Wisely, IITA staff discouraged the review of adoption studies because such research could unduly influence the thinking of participants and keep them from reflecting on their personal experience.

It was also apparent what did not work: mailing out questionnaires to key collaborators and hoping for responses and delegating the lion's share of responsibility to in-country consultants. These approaches resulted in considerable e-mail fatigue but little in the way of reliable information. Because US$6,000–7,000 was allocated for each crop-by-country observation, a more aggressive supervisory approach could be pursued. That approach usually bore fruit.

Participants now agree that a more geographically decentralized process, featuring wider participation by different institutional actors in society, is needed to arrive at more precise and accurate expert opinion estimates of MV adoption. Balancing knowledgeable experts with representation from a wider sectorial audience is a challenge when seeking expert opinion on progress in varietal research.

In some contexts, other methods would be eminently more suitable than expert opinion. But what is frequently overlooked is the fact that, to arrive at a significantly better outcome, alternative methods require relatively sophisticated skills in application and energetic, persistent interviewers.

## Describing the validation surveys on the diffusion of MVs

Nine large-scale adoption surveys were funded and undertaken by the DIIVA Project. Their coverage and sampling features are described in Table 6.1 (overleaf). Although multi-purpose in nature, their primary intent was to validate the adoption estimates generated by the national expert panels. Eight of the nine surveys were nationally representative; cassava's inquiry was regional for Southwest Nigeria.

Previous adoption surveys, if they existed, were largely restricted to small project areas in the other crop and country settings. Both NARS and IARC participants requested a national survey to complement their project-specific inquiries that often addressed only the initial uptake and very early adoption of well-defined introduced materials.

The average cost of the nine surveys was about US$100,000. During the Project Implementation Workshop, project participants were encouraged to pool their resources and canvass joint surveys. They were reluctant to do so initially. But the reality of a fixed budget for survey work, combined with the desire for greater country coverage in their crops of interest, subsequently spawned a more collaborative approach. ICARDA and CIP worked together with the Ethiopian national program to carry out a survey on MVs of barley, faba bean, and potatoes in Ethiopia in mostly shared agro-ecologies across the three crops. CIP and CIAT jointly undertook surveys with their NARS partners in Rwanda on beans, potatoes, and sweetpotatoes and in Uganda on beans and sweetpotatoes. ICRISAT also carried out a multi-crop survey in Tanzania on groundnut, pigeonpea, and sorghum.

The guidelines for the survey recommended a stratified cluster sampling (Walker and Adam, 2011). Most of the participants followed this recommended framework. Sample size varied from 841 households in the cassava survey in five states of southwestern Nigeria, to 5445 households in the rice survey also in Nigeria where all 36 states were covered. Households interviewed per village ranged from 10–18. Community interviews based on focus groups preceded the household interviews in most of the surveys.

Oral responses on seed usage and on area planted to specific varieties provided the raw material for the subsequent calculation of adoption estimates. The cassava survey team complemented their household interviews with field measurements that featured varietal photographs using mobile phones (Alene and Mwalughali, 2012b). These were analyzed by research scientists who were able to assess varietal identity from the pictures displaying morphological plant characteristics. Without high resolution photographs from mobile phones, identification of specific varieties would have been impossible.

The 15 crop observations in the surveys described in Table 6.1 were complemented by a more limited survey that canvassed four regions in Uganda to assess adoption of recently released clonal material in banana (Kagezi et al., 2012). We also used output from a recent IFPRI–Council for Scientific and Industrial Research, Ghana (CSIR) survey on adoption of maize and rice MVs in Ghana (Ragasa et al., 2013a and 2013b).

Because of the lack of close supervision and the existence of recent survey estimates on adoption, cultivar-specific estimates could not be elicited from expert panels for rice in Nigeria; therefore, the validation exercise for this survey focuses on the aggregate

**Table 6.1. Description of the sampling features of the diffusion MV validation surveys conducted by participants in the DIIVA Project**

| Crop | Country | Geographic basis for sampling | Sample size: Primary Sampling Unit (PSU) | Sample size: House-holds per PSU | Number of households[a] | Community survey |
|---|---|---|---|---|---|---|
| Barley | Ethiopia | The 3 major regions where barley is grown | 123 Kebeles | 12 | 1,469 (1,280) | Yes |
| Bean | Rwanda | 10 major agro-ecological regions | 80 communities | 18 | 1,440 | Yes |
| Bean | Uganda | 4 major geographic regions | 19 districts, 108 communities | 18 | 1,908 | Yes |
| Cassava | Nigeria | All 5 States in Southwest Nigeria | 80 Enumeration Areas | 10–12 | 841 | Yes |
| Groundnut | Nigeria | 10 major groundnut-producing States | 243 villages | 10 | 2,739 | Yes |
| Groundnut | Tanzania | 7 main producing regions | 77 Wards, 104 villages | 15–16 | 1,622 (1,046) | Yes |
| Maize | Ethiopia | Production potential from 118 maize-growing districts | 156 Kebeles | 15–16 | 2,455 | No |
| Pigeonpea | Tanzania | 7 main producing regions | 77 Wards, 104 villages | 15–16 | 1,622 (816) | Yes |
| Potato | Ethiopia | The 3 major regions where potato is grown | 123 Kebeles | 12 | 1,469 | Yes |
| Potato | Rwanda | 10 major agro-ecological regions | 80 communities | 18 | 1,440 | Yes |
| Rice | Nigeria | All 36 States in Nigeria | 589 Enumeration Areas | 10 | 5,445 | Yes |
| Sorghum | Tanzania | 7 main producing regions | 77 Wards, 104 villages | 15–16 | 1,622 (902) | Yes |
| Sweetpotato | Rwanda | 10 major agro-ecological regions | 80 communities | 18 | 1,440 | Yes |
| Sweetpotato | Uganda | 4 major geographic regions in Uganda | 19 districts, 108 communities | 18 | 1,908 | Yes |
| Wheat | Ethiopia | 8 wheat-growing agro-ecologies | 125 Kebeles | 15–18 | 2,096 (1,839) | No |

a First number denotes total sample size; numbers in ( ) are households growing the crop.

adoption of MVs as a group in relation to local varieties. AfricaRice also undertook a similar national survey in 2009. If the expert panel had had access to those results, its responses could have been contaminated by that information.

## Validating expert opinion with the survey estimates

Three small national, regional, and cultivar-specific databases were available for matching adoption estimates from different sources. Congruence between national estimates is described in Table 6.2 (overleaf) where the 18 matching observations in the database are ordered according to Mean Absolute Percentage Error (MAPE). In appraising congruence, both the percentage differences in column 5 and MAPE in column 6 provide complementary information.

The estimated adoption levels in Table 6.2 are based on what experts stated were improved varieties during the elicitation exercise. For beans and sweetpotato in Rwanda and Uganda, released local landraces were included in the set of improved varieties.

For groundnuts in Nigeria, 55-437, described in Section 4, was included as an improved variety. The definition of improved varieties needs to be constant across all sources in comparing estimates. In most contexts, reviewing the national release list was the basis for defining MVs.

Adoption estimates elicited by IITA from NARS participants in Ghana closely matched the results of the IFPRI national survey on maize adoption. The fit is also reasonably good for the next 10 observations in Table 6.2. MAPEs are less than 30%, and differences are under 10% with the borderline exception of pigeonpea in Tanzania. In contrast, a lack of agreement is apparent in the last seven observations.

Arguably, the most egregious mismatch between expert opinion and survey estimates centers on sweetpotato in Uganda. Estimates were elicited for the four main geographic regions of the country and were aggregated to generate a national estimate. The discrepancy between sources of estimates was most marked in the eastern and northern regions with differences exceeding 75%. Labarta et al. (2012) give two plausible reasons for the wide divergence between the expert opinion and the survey estimates. Large quantities of improved sweetpotato vines were transferred to the northern region in response to relief programs. Interest in orange-fleshed sweetpotatoes has also sparked a massive transfer of planting material in selected districts. Historically, drought tolerance of planting material is a known weakness of improved varieties and improving tolerance is a primary breeding objective. It appears that transfer of large quantities of planting material fueled exuberance and optimism about the prospects for adoption that departed sharply from the reality of propagating sweetpotato in a drought-prone environment where a few well-defined local varieties reign.

The second explanation focuses on varietal invisibility in the sweetpotato crop, which seldom exceeds 0.5 ha, is often planted in association with other crops, and usually is harvested piecemeal. It is a crop characterized by poor road visibility that leads to blurred perceptions in identifying varieties that farmers are growing. As a result, varietal identity and diversity is not apparent without taking the time and effort to make field visits, especially at flowering.

**Table 6.2. Validating adoption estimates from expert opinion with survey results by crop**

| Crop | Country/ region | Estimate of MV Adoption (%) | | | |
|---|---|---|---|---|---|
| | | Expert opinion | National survey | Difference (%) | Mean Absolute Percent Error (MAPE) |
| Maize | Ghana | 57.0 | 59.6 | -2.6 | 4 |
| Maize | Ethiopia | 26.5 | 27.9 | -1.4 | 5 |
| Sorghum | Tanzania | 42.3 | 38.7 | 3.6 | 9 |
| Rice | Nigeria | 50.4 | 56.2 | -5.8 | 10 |
| Bread wheat | Ethiopia | 87.7 | 77.8 | 9.9 | 13 |
| Groundnut | Tanzania | 32.2 | 28.4 | 3.8 | 13 |
| Beans | Rwanda | 68.2 | 60.1 | 8.1 | 13 |
| Potato | Ethiopia | 25.2 | 22.2 | 3.0 | 14 |
| Barley | Ethiopia | 29.2 | 33.8 | -4.7 | 14 |
| Pigeonpea | Tanzania | 39.5 | 49.7 | -10.2 | 21 |
| Banana | Uganda | 8.0 | 6.2 | 1.8 | 29 |
| Cassava | SW Nigeria | 68.0 | 52.0 | 16.0 | 31 |
| Sweetpotato | Rwanda | 41.6 | 27.9 | 13.7 | 49 |
| Beans | Uganda | 60.0 | 40.0 | 20.0 | 50 |
| Groundnut | Nigeria | 51.2 | 31.0 | 20.2 | 65 |
| Potato | Rwanda | 84.9 | 35.6 | 49.3 | 138 |
| Sweetpotato | Uganda | 78.8 | 17.9 | 60.9 | 340 |
| Durum wheat | Ethiopia | 13.0 | 0.5 | 12.5 | 2,500 |

Inspection of the regional and cultivar-specific databases also provides clues about the likely reasons for the poor congruence between the estimate sources for the other six observations. Although problematic regions and cultivars can be identified, explanations for what led to these large order of magnitude disparities are mostly speculative. Nevertheless, based on these seven cases, we can say that over-optimism about technology transfer programs can result in substantial overestimates of technology adoption. The case of potato in Rwanda shows that civil war may lead to the collapse of MV varietal adoption. These are two contextual situations that analysts need to be aware of in measuring the long-term uptake of improved varieties.

Knowing what is going on in farmers' fields is desirable when scientists give expert opinion on adoption. But such knowledge is not always recorded at the main research station. The elicitation process of expert opinion also does not seem to play a significant role in understanding variations in congruence. Nor does more prestigious science make for more congruent estimates.

As mentioned earlier, NARO's sweetpotato breeding program in Uganda is highly respected and is the hub of sweetpotato improvement in the Great Lakes region. IITA's Center is located in Southwest Nigeria where the cassava survey was conducted. The same people and the same process generated the congruent estimates for maize in Ghana and the rather 'disagreeable' estimates for cassava in southwestern Nigeria. With the same elicitation process, CIP was responsible for congruent estimates for potato in Ethiopia and divergent estimates for potato in Rwanda.

Likewise, differences in crops and countries do not seem to feature as explanations of the variation in types of estimates. Ethiopia was associated with convergent estimates for barley, maize, and potato, and divergent estimates for durum wheat (Yigezu et al., 2012b; Jaleta et al., 2013; Labarta et al., 2012). Adoption estimates for bread wheat in Ethiopia did not vary much by source but, in relative terms, the estimates for durum wheat were substantially different (Yirba et al., 2012). These estimates were elicited from the same group of wheat improvement scientists.

The simple mean MV adoption level was 48% for expert perceptions and 36.5% for survey estimations. The 11% mean difference in a paired t-test is statistically significant at the 5% level. If we designate sweetpotato in Uganda and potato in Rwanda as outliers because of their changing contextual situations and re-estimate the means for the remaining 16 observations (see Table 6.2), the mean difference between the two estimation methods narrows to 5.5% and is, again, significant statistically at 0.05. Proportionally, the survey estimate is seven-eighths the size of the expert opinion estimate. Reducing our 35% estimate for aggregate adoption of MVs in SSA in Table 4.1 on page 39 by the same proportion yields a revised estimate that approaches 31%. This revised estimate incorporates a correction from the finding that expert opinion tends to generate somewhat higher levels of adoption than properly conducted survey estimation.

Redoing the above calculation on the regional dataset of 34 observations (excluding potato in Rwanda and sweetpotato in Uganda) gives identical results. The simple-mean, expert-opinion estimate of 36.4% is 4% higher than the survey estimate of 32.4%.

The mean adoption estimate of 36.5% in the national surveys was made up of 26.5% from MVs named by the panel and 10% from unnamed or other named materials believed to be MVs. The size of the second component varies from survey to survey, but it is usually sizeable as there is always a leftover quantity of MV area that cannot be assigned to a specific cultivar. For this reason, the area of specific MVs will typically be proportionally less than total adoption levels. Because the ability to designate specific areas to MVs is imperfect, survey-specific cultivar estimates will often be substantially lower than comparable estimates from expert panels.

Thus far, we have presented comparative results from the 18-observation national database. Similar differences in MV adoption between expert opinion and household surveys were also found in the 34-observation regional database. Findings for the 274-cultivar specific database are presented in Table 6.3 (below), which divides the varieties into four categories depending on the level of perceived adoption by experts. For example, of the 279 varieties from the national comparisons in Table 6.3, experts perceived that 44 had a level of adoption that exceeded 10% of cultivated area of the crop. Experts believed that, on average, these were sown on 24% of the area available; the mean survey estimate for the same 44 varieties was about 13%, resulting in a difference between the two sources of about 11%. From the previous discussion of the national and regional data, it was likely that expert estimates were higher than the survey estimates at all levels, except the lowest estimates.

This tendency for systematic differences to emerge between the two sources of estimates applies to all levels of estimates, but figures most prominently for expert estimates in the range of 5–10% (Table 6.3). For the lowest level of adoption in the MV cultivar database, the survey estimates are higher than expert opinion, which to some extent neglected these varieties. Restricting the analysis to only positive observations for expert opinion in this lowest interval does not reverse the finding that the survey estimates are higher than those for expert panels.

Soon after values greater than one are reached, the difference between the two sources of estimates widens as expert estimates become significantly higher than survey estimates (Table 6.3). Proportionally, the gap is widest for the interval 5–10%. The mean expert estimate of 8% is matched by a survey estimate of only 2.8%. Congruence is a little better for the leading varieties that were expected to account for more than 10% of the area. For these dominant cultivars, the simple mean survey estimate rises to 50% of the expert estimates.

The message conveyed in Table 6.3 is that probably neither surveys nor expert panels can do a good job in delivering accurate estimates of cultivar-specific adoption. Expert panels will most likely overestimate the importance of specific varieties; surveys will understate their relevance. Although skillful use of both methods may suffice for our purposes, we should be aware of the sources of bias when the focus is on MV-specific adoption. Accuracy in survey estimates depends heavily on whether or not a plethora of names can be identified reliably with specific varieties.

Of the DIIVA-funded surveys, bean researchers in Rwanda worked hardest in tracing the identities of farmers and their crop varieties in many locations. They assigned successfully (with an 88% certainty) the area available to local, selected, and improved varieties of bean (Katungi and Larochelle, 2012). CIAT researchers and their partners had considerable experience in the counting of bean varieties. Their work in the DIIVA Project built on interviews with village focus groups carried out in 2000 and 2005 when respondents ranked the importance of different varieties. With the addition of data from 2010, patterns emerging over time could be seen.

On the other hand, expert opinion tends to focus on a subset of varieties while ignoring the relative importance of other MVs. The otherwise excellent survey work in southwest Nigeria was an apt example of not being inclusive enough in eliciting estimates from experts – the elicitation did not mention the leading MV found in the household survey, apparently because it did not appear on the release list.

Being too inclusive can also prove to be a risky strategy. Returning to beans in Rwanda, experts allocated very small areas

**Table 6.3. Agreement between expert and survey estimates of specific varieties by expert interval**

| Estimate (%) | 0–1 | 1.01–5 | 5.01–10 | >10 |
|---|---|---|---|---|
| Expert | 0.39 | 2.97 | 8.02 | 24.12 |
| Survey | 0.70 | 1.15 | 2.84 | 12.86 |
| Difference | -0.30 | 1.82 | 5.18 | 11.27 |
| Number of observations | 105 | 100 | 30 | 44 |

to 22 improved varieties. Sixteen of these had negligible adoption outcomes in the household survey results. An additional 25 MVs accounted for about 10% of the area. These did not receive an area allocation by the expert panel.

## Focusing on challenges in nationally representative adoption surveys

Two challenges have been highlighted in arriving at cost-effective MV adoption levels from survey data. The first is responding to the need to save resources by covering multiple crops in shared agro-ecologies. There are usually tradeoffs between the potential for cost saving and the reliability of estimates (C. Ragosa, 2013, personal communication). The other is the aforementioned problem of identifying a specific MV from a multiplicity of names that exhibit widespread spatial variation. Judging whether a cultivar is or is not an MV is a corollary to the identification problem. The recycling of seed in cross-pollinated crops is another difficult issue that calls for standardization.

Levels of MV adoption can vary widely even in well-conducted surveys. Based on a national-level survey of rice in Ghana in 2012, researchers estimated aggregate MV adoption approaching 60% (Table 6.4, overleaf). However, researchers from an earlier national survey carried out in 2009 arrived at a comparable estimate exceeding 80% (Diagne et al., 2012). The difference is not attributable to the differing survey years – the disparity in estimates emanates from decisions researchers had taken in classifying varieties as 'improved' or 'traditional'.

In both surveys, the leading variety was Jasmine 85, an IRRI variety bred in Thailand in the 1960s (Table 6.4). (Jasmine 85 was officially released in Ghana in 2009 after it had already been adopted widely by farmers.) But the key question is: What to do about Mandii, the second leading variety laying claim to 19% of area? Researchers in the 2012 survey classified it as a 'local variety' in Table 6.4, while researchers in the 2009 survey designated it as 'improved'. Their list of improved varieties contains 104 names with only 7 dated released varieties with adopted area.

Mandii seems to be expanding – its area in 2009 was estimated at 7%. Given the uncertainty about its origins, the 'What to do about Mandii?' question can most likely only be addressed by DNA analysis.

The DIIVA Project has also reconfirmed the need for field measurement in cases where varieties are difficult to distinguish morphologically. The survey of cassava in southwestern Nigeria epitomizes this case (Alene and Mwalughali, 2012b). Farmers knew improved varieties by a group name but could not distinguish relatively small morphological and phenotypic differences that allowed for the elicitation of reliable data on specific MV cultivars. In this case, there was no substitute for field measurement, which is more doable in cassava because it is in the field for a longer time in a mature state.

Survey performance could be improved if focus groups generated reliable information on varietal adoption. The use of focus group interviews in a community questionnaire was one of the features of the surveys supported by the DIIVA Project (Table 6.1, page 62). In their validation reports, project participants formally compared responses from focus groups and household questionnaires. Although these results have yet to be analysed, reading the reports suggests that focus groups can provide useful information about the relative importance of the variety in the village and the adoption levels of individual farmers; but household data are strongly preferred if cultivar-specific area estimation is the goal (Mausch and Simtowe, 2012).

Researchers from AfricaRice were more optimistic about the use of community-based instruments than most researchers from other CG Centers (Diagne et al., 2013). They still opted for household schedules over focus group interviews, where it was necessary to collect cultivar-specific information. They also found ways to collect area data at the community level which compared favorably with information gathered from household interviews (Table 6.5, page 68).

Although there is an 11% gap between the two estimates on the level of adoption of MVs as a whole, the matched ranking between community and household surveys

**Table 6.4. Distribution of rice by variety planted during the major growing season in 2012**

| Varieties | Area (%) |
|---|---|
| **CSIR-released varieties** | **34** |
| JASMINE 85/Gbewaa/Lapez (2009) | 27 |
| Digang (also called Abirikukuo or Aberikukugu) (2002) | 3 |
| GR 18 (Afife) (1986) | 2 |
| GR 21 (1986) | 1 |
| Sikamu/TOX 3108 (1997) | 1 |
| NERICA 1 (2009) | 1 |
| FARO 15 (1970s) | 0 |
| Bodia (2010) | 0 |
| **Other promising varieties being evaluated (already with certified seed production)** | **19** |
| Togo Marshall | 11 |
| Jet 3 | 4 |
| Aromatic Short | 2 |
| IR20 | 1 |
| TOX 3107/Bumbaz | 1 |
| NERICA 14 | 0 |
| NERICA 9 | 0 |
| WITA 7 | 1 |
| **Other varieties that came from MOFA but cannot be named** | **5** |
| **Indigenous/traditional/local varieties** | **40** |
| Mandii (originally from Sierra Leone, introduced by MOFA in the 1970s) | 19 |
| **Farmers did not know variety** | **2** |
| **Total** | **100** |

MOFA = Ministry of Food and Agriculture, Ghana.
Source: Ragasa et al., 2013b, CRI/SARI/IFPRI survey (November 2012–February 2013).

is characterized by widespread agreement on the relative importance of specific cultivars. The simple correlation between the community and the household rankings approaches 0.80 in Table 6.5.

Common bean cultivars show even stronger agreement in Rwanda and Uganda between a community estimate in the percentage of villages where a cultivar was mentioned in a focus group and the percentage area of the same cultivar from the household survey. For 67 common cultivars in Rwanda, the estimated correlation coefficient exceeds 0.80; for the leading 19 common varieties in Uganda, the estimated correlation coefficient exceeds 0.95. In both of these meticulously carried out surveys, the community survey focused on the top three cultivars at three points in time. All the cited focus group varieties could be paired up with household responses, but not all the household responses could be matched to the top varieties perceived by focus group respondents. More than 100 varietal names generated in the household survey could not find an identical partner in the community focus group inquiries which also embraced a relatively large set of varieties. Most of these unmatched household varieties were planted in very small areas.

The high estimated correlation coefficients for bean cultivars in Rwanda and Uganda suggests that well-constructed community focus groups can provide valuable information on the relative importance of leading varieties in a well-defined regional setting. Therefore, community focus groups could provide a valuable means to ground truth expert opinion in a rapid rural appraisal format. This finding raises several important issues, such as the number of communities that is sufficient for the generation of significant and positive associations under different variance-related conditions. Given that travel to the community is usually the largest cost component of any rural survey in SSA, the issue of relative costs is relevant.

**Table 6.5. Comparison of village-level and household-level interview data on varietal adoption using area grown under these varieties for rice in Nigeria**

| Variety | Village interview | | Household interview (2009) | | Gap |
|---|---|---|---|---|---|
| | Percentage | Rank | Percentage | Rank | |
| **Traditional** | **54.75** | **1** | **43.73** | **1** | **11.02** |
| **Modern** | **45.25** | **2** | **56.27** | **2** | **-11.02** |
| FARO 44 / SIPI 4 | 8.04 | 1 | 12.35 | 1 | -4.31 |
| CHINA | 7.03 | 2 | 8.76 | 2 | -1.73 |
| IMPROVED | 3.48 | 3 | 4.83 | 3 | -1.35 |
| NERICA (Others) | 2.94 | 4 | 4.36 | 4 | -1.42 |
| FARO 15 | 2.80 | 5 | 4.03 | 5 | -1.23 |
| FARO 46 / WITA 1 | 2.39 | 7 | 2.77 | 6 | -0.38 |
| FARO 52 / WITA 4 | 2.68 | 6 | 2.45 | 7 | 0.23 |
| FARO 55 / NERICA | 1.77 | 8 | 2.15 | 8 | -0.38 |
| FARO 37 / WITA 3 | 1.59 | 9 | 2.01 | 9 | -0.42 |
| FARO 29 / BG 90- | 1.48 | 10 | 1.58 | 10 | -0.10 |
| FARO 54 / WAB 18 | 1.38 | 11 | 1.32 | 11 | 0.06 |
| BUTUKA | 0.17 | 31 | 1.20 | 12 | -1.03 |
| FARO 51 / CISADA | 0.95 | 12 | 1.09 | 13 | -0.14 |
| TURN 2 | 0.53 | 14 | 1.07 | 14 | -0.54 |
| ECWA | 0.28 | 21 | 1.03 | 15 | -0.75 |
| IR 8 | 0.57 | 13 | 0.71 | 16 | -0.14 |
| CAROLINA | 0.50 | 16 | 0.66 | 17 | -0.16 |
| WILLY RICE | 0.33 | 20 | 0.59 | 18 | -0.26 |
| FARO 21 | 0.34 | 17 | 0.55 | 19 | -0.21 |
| FARO 35 / WITA 2 | 0.52 | 15 | 0.38 | 20 | 0.14 |
| YARJOHN | 0.27 | 22 | 0.28 | 21 | -0.01 |
| FADAMA2 | 0.06 | 52 | 0.27 | 22 | -0.21 |
| Other Improved | 5.15 | | 1.83 | | |

Source: Diagne et al., 2013

Nonetheless, in the next phase of DIIVA, we need to find a cost-effective alternative to the 500–700 representative household surveys in order to validate expert opinion from the more qualitative perspective of 'Do the elicited estimates roughly reflect reality or not?' Well-structured, community focus group discussions combined with field visits could be one such alternative.

## Summary

About one-third of the resources of the DIIVA project were invested in nine nationally representative adoption surveys that were designed to validate the estimates from expert panels and provide raw material for impact assessment. In carrying out the process of estimate elicitation from a standardized protocol, participants also generated considerable anecdotal evidence on what worked. The protocol was adapted to regional and crop-specific circumstances that featured a considerable amount of 'learning by doing' by CG Center staff conducting the expert panels. In general, more effective elicitation was characterized by:

- close and intensive supervision of CG project-related staff;
- organization of and attendance at time-bound workshops with direct interaction with expert panel members;
- greater spatial resolution in the elicitation of estimates that were subsequently aggregated to regional and national levels;
- including more members from the informal sector and from NGOs with geographic-specific expertise in technology transfer on the panels; and
- feedback from CG Center breeders in the final stages of the process.

Lessons on what did not work were transparent. The CG Center that relied solely on NARS scientists as consultants to carry out expert elicitation was only able to provide quality cultivar-specific adoption estimates for two of their 14 assigned crop-by-country observations. Much more intensive supervision was needed.

Survey estimates and those from expert opinion panels were within ten percentage points for ten of the 18 observations suitable for validation. Survey estimates were lower for the other eight observations, and for two of these they were markedly lower. Ignoring these two outliers, survey estimates were about seven-eighths the size of expert elicitations. Therefore, the mean value of 35% for MVs for SSA as a whole is likely to be overestimated because the majority of estimates came from expert opinion. Applying the seven-eighths finding from the validation exercise gives a more conservative estimate of about 31% for MV adoption if surveys had replaced expert opinion panels.

Higher mean absolute percentage errors between the two sources did not seem to be associated with variations in the elicitation approach or specific to a crop or country. They had more to do with the extenuating circumstances of rapid change or disruption associated with rampant over-optimism about the prospects for large technology transfer efforts and with civil war that also can be devastating for the applicability of prior knowledge in circumstances where confirmation is difficult.

Slightly over 70% of the mean adoption estimates in the national surveys were composed of MVs for which the panel held positive adoption beliefs; the other 30% came from unnamed or other named materials believed to be MVs. The size of the second component varies from survey to survey, but it is usually sizeable as there is always a leftover quantity of MV area that cannot be assigned to a specific cultivar. For this reason, the summed area of specific MVs will typically be less than an aggregate adoption level. Surveys are likely to understate the importance of specific improved cultivars; detailed estimates from expert opinion that feature few, if any, varieties in a residual 'other' category are likely to overemphasize the uptake of specific MVs. Accuracy in survey estimates depends heavily on whether or not numerous regional- and location-specific names can reliably be assigned to specific varieties.

# 7. Conclusions

This Synthesis Report on the first two objectives of the DIIVA Project is laden with numbers. Some are more important than others. We estimate that MVs of food crops in SSA in 2010 covered slightly more than 35% of the total harvested area. Between 1998 and 2010, uptake of MVs increased at a pace equivalent to a linear annual gain of 1.45%.

Incorporating the adoption of improved varieties as a MDG would be desirable for economic development in general and agricultural development in particular. Although there are still several methods-related and semantic issues to resolve, the results of the DIIVA Project show that it is possible to make a timely and concerted effort to measure the diffusion of MVs for a relatively small quantity of resources. Extrapolating the past performance to the future would establish a target of about 50% for MV adoption by 2020. Continuation of a trend may seem like a pedestrian target, but this level of adoption is ambitious because scientists working on several crops in the DIIVA initiative have little research or basic knowledge on which to found improvements.

Realizing outcomes consistent with this solid trend in performance will require several changes. Lagging crops and/or lagging countries or both were identified as an area of concern, particularly for sorghum, pearl millet, and groundnut in West Africa where scientists' advancing age and low levels of research intensity are important issues that threaten enhanced varietal output and adoption. Efforts will have to be redoubled in West Africa if a goal of 50% coverage in improved varieties for SSA is to be attained by 2020. Some 'out-of-the-box' thinking may be required to address the problem of stagnating and eroding scientific capacity in several West African crop improvement programs on coarse cereals and grain legumes. Performance also has to improve in Angola and Mozambique, the only two countries in Southern Africa where adoption of MVs is low for all primary and secondary food crops.

For some crops, leveraging adoption in one country is the key to significant progress. For cowpea, that country is Niger. If an improved cowpea variety could reach a 20% adoption level in Niger, it would become one of the very few food-crop varieties to cover 1 million ha in Africa. Presently, cowpea varieties planted on only 3–4% of the total area make the crop eligible for membership in the group of the 100 most extensively grown food-crop varieties in SSA.

For other crops, enhancing the adoption prospects in a single agro-ecology of just one country would make a difference. For rice, that agro-ecology is the rainfed lowlands of Madagascar.

Meeting this proposed MDG also means that varieties should turn over faster in farmers' fields. We documented that the weighted average age of improved varieties in farmers' fields is 14 years since release. This rather mediocre estimate for varietal turnover could have been considerably worse. However, a slender body of evidence suggests that it also has not improved over time. Improved varieties in farmers' fields today are not getting any younger for most crops and countries. The potential of biotechnology to increase varietal turnover through techniques such as MAS is still largely a promise that needs to come to fruition.

The analysis also underscores the importance of the IARCs of the CGIAR in supplying material to, and sharing of material with the NARS. About 65% of the varietal adoption originated in IARC-related materials. The CG Centers contribution for 10 of the 20 crops was above 80%. Their share in adoption was also substantially higher than their share in varietal output for most crops.

In the proposal for the DIIVA Project, over 30 hypotheses were specified for testing on the strength of NARS, varietal output, adoption and change, and exchange of materials between CG Centers and NARS.

Some of these hypotheses, such as equal shares in varietal releases and adoption from the contributions of the CGIAR to varietal change, were rejected; others were broadly confirmed; and others still could not be tested as data were insufficient or incomplete mainly in the area of the germplasm exchange of materials.

Findings from the DIIVA Project also show that output in the form of released varieties is increasing for most crops, but is still characterized by a high level of instability from year to year. Part of this instability is attributed to donor programs that periodically reinforce public sector research because governments do not have the resources or political will to invest in poor people's crops. Estimated research intensities, i.e. the relationship between size of country production and investment in research scientists, has not changed over time for most crops. The input of university research in varietal release is still negligible in most crops and countries.

During the discussion of substantive results in the sections on varietal output, adoption, and change, the DIIVA Project has also had its share of surprises. Prominent among these unexpected findings were the increasing demand for maize OPVs in West Africa, the steady productivity record of cassava in the face of well-documented resource scarcity, and the advanced age of cultivars in the expanding soybean crop in Nigeria.

The prolificacy of the private sector in producing new maize hybrids in ESA is not surprising, but the observation that varietal age has not yet started a downward trend is. The slow pace of private sector development in maize research in West Africa was also unanticipated. The moderately high adoption performance in DR Congo across several food crops was an unexpected achievement that warrants more careful monitoring when varietal adoption is next updated.

The continuing emphasis on the release of purified landrace materials in the very recent past for some countries in some crops and the central role of adaptive breeding in most national crop improvement programs point to rejection of the hypothesis that applied plant breeding by national crop improvement programs in the form of crossing and selection was increasingly evident. That hypothesis was broadly confirmed in the global '1998 Initiative'. However, this scenario on the development of national plant breeding in SSA does not even apply to rice, which was the crop that was its 'poster child' in Asia and Latin America (Evenson and Gollin, 2003a).

The descriptive research in this Synthesis Report clearly does not begin to exhaust the relevant themes that can be explored via the DIIVA 1998 and 2010 databases. The relationships among scientific capacity, varietal output, and varietal adoption need to be explored in a more rigorous analytical manner. The data can also be integrated with other datasets to shed light on recent tendencies in, and determinants of, productivity growth in African agriculture.

Indeed, documenting productivity growth from adoption is an equally challenging proposition. The genetic contribution to yield growth is low in marginal production environments characterized by erratic rainfall and declining soil fertility. In the companion Green Cover Report that presents the impact assessment research in the DIIVA Project, large and statistically significant yield effects from improved varietal adoption were found in maize in regions of relatively high production potential. However, comparable productivity impacts for improved varieties of bean in Rwanda and Uganda and improved sorghum and pearl millet cultivars in Northern Nigeria were considerably lower. Measuring the genetic contribution from improvement in traits that do not reflect higher yield potential – such as short duration for drought, escape or varietal disease-resistance – is likely to understate the size of these effects, unless highly focused and intensive data collection is pursued.

A 35% share in MVs for food crops in SSA in 2010 is roughly the level Asia was at in the early 1970s, that Latin America attained in the mid-1980s, and that the Middle East and North Africa reached in the early 1990s (FARA, 2006, as cited in Lynam, 2010). But this comparison that relies on aggregate old data is flawed, because it is not adjusted for the reality of rainfed agriculture in SSA.

The findings on adoption in SSA need to be compared to complementary studies that are now nearing completion by IRRI and ICRISAT on the adoption of rice, sorghum, pearl millet, and groundnut improved varieties in South Asia; and by CIAT on the diffusion of rice, bean, and cassava MVs in Latin America. These investigations were inspired by, and follow the pattern of, the DIIVA Project.

From the perspective of SSA, their findings on rainfed agriculture are especially relevant, so that progress can be assessed and realistic targets established on performance. Unless basic knowledge changes the yield distribution of basic food crops in rainfed agriculture, the evidence from South Asia suggests that program results (even well-developed crop improvement initiatives) can fall considerably short of full adoption and rapid varietal turnover for some crops in difficult agro-ecologies.

For example, the dominant cultivar in post-rainy season sorghum production in peninsular India is still M35-1, a variety released in the late 1930s about 10 years prior to Independence. Both groundnut in peninsular India and rice in East India are characterized by slow rates of varietal turnover because of the permanency of first-generation MVs in farmers' fields. Nevertheless, adoption of improved cultivars is substantially lower in SSA than in roughly comparable agro-ecologies in South Asia and Latin America. Questions of 'How much lower?' and 'What are reasonable targets?' are researchable issues that need to be addressed using comparative evidence on varietal uptake and turnover in South Asia and Latin America.

During the discussion of results, several priorities for research were implicitly identified (see Sections 2–6). For example, documented budgetary shortfalls at the CG Centers implied a significant contraction in the flow of germplasm to the NARS via donor-funded plant breeding networks. Had tightening budgets for germplasm enhancement and development not been less in evidence in the 1990s and into the early 2000s for the CGIAR crop improvement programs, the pace of varietal change could have accelerated faster than 1.45% per annum.

Regional commodity networks are often seen as critical institutions for generating varietal output and subsequent adoption and change in developing countries, especially in SSA. Largely anecdotal evidence suggests that few of these organizations survived intact from the budgetary restrictions of the 1990s and early 2000s. These multinational networks have been heavily dependent on funding from donors and technical leadership from the CGIAR. Quantitative information and analysis is needed to test the early evidence that these genetic improvement networks were seriously damaged by the budgetary crisis of the 1990s and early 2000s, and that the exchange of germplasm was severely reduced because of funding shortfalls caused by donor withdrawal.

Most of the above research priorities are easy to visualize. Years from now they should pale in comparison to output stimulated by making the database accessible to the public. Providing access is past due and is critical for generating timely and wider research results for, and by, a larger audience who are aware of the project and have expressed a firm demand for its use. Analytically, this study does not break new ground. Its novelty and value stems from its wide scope in terms of crops and countries with intensive data collection via the same protocols with an emphasis on validation.

The achievements of the DIIVA Project are more substantive than methodological. We did confirm the differences between the estimates obtained from expert opinion and from surveys. The results of the validation comparisons suggest that our 35% adoption estimate could decline to about 31% if we had the resources and the capacity to substitute national representative surveys for expert opinion panels.

We also conducted a thorough assessment of the availability of experimental data for undertaking an ex-post rate of returns analysis. However, these data were not available and their quality appears to have deteriorated since the 1980s when Farming Systems Research figured prominently in several CG Centers. On the other hand, CG Center scientists made unforeseen project-related contributions in the conduct of multi-crop surveys in shared agro-ecologies and in field measurement that permitted the used of highly trained technical assistants in a cost-effective manner.

We also acquired more awareness about the magnitude of some of the problems associated with measuring varietal adoption. Foremost among these is the issue of varietal identification, which could be welcomed by anthropologists. Investing in the development and maintenance of pilot varietal name registries over an extensive, but well-defined, geographic area could be a productive undertaking. Learning from pilot studies with DNA fingerprinting remains a priority for the next phase of this project. If Dana Dalrymple was charged with evaluating the DIIVA Project, he would be impressed with the comprehensive coverage of the endeavor, but would probably say that not much has changed in the way we chronicle varietal adoption.

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## Annex 1. Summary data on FTE scientists, varietal release, and adoption of improved varieties by crop and country[a]

| Crops | Country | FTE Scientists in 2009 | Released varieties by time period if dated: Before 1970 | 1970–1989 | 1990–2010 | Undated entries[b] | Adoption of improved varieties by characteristic: Total crop area (ha) | Adoption (% area) | Year | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Banana | Uganda | 42 | 0 | 0 | 6 | 7 | 915,877 | 6 | 2010 | Survey |
| Barley | Eritrea | 1 | 0 | 0 | 3 | 0 | 56,857 | 15 | 2009 | EO[d] |
| Barley | Ethiopia | 21.1 | 0 | 6 | 32 | 0 | 945,559 | 34 | 2010 | Survey |
| Bean | Burundi | 2.6 | 0 | 5 | 25 | 5 | 410,100 | 8 | 2009 | EO |
| Bean | DR Congo | 5.1 | 0 | 2 | 26 | 7 | 224,584 | 16 | 2009 | EO |
| Bean | Ethiopia | 21.4 | 0 | 3 | 29 | 0 | 207,494 | 44 | 2009 | EO |
| Bean | Malawi | 6.4 | 0 | 0 | 15 | 0 | 260,287 | 55 | 2009 | EO |
| Bean | Mozambique | 5.1 | 0 | 2 | 12 | 1 | 108,000 | 13 | 2009 | EO |
| Bean | Rwanda | 14.5 | 0 | 12 | 45 | 4 | 285,000 | 19 | 2010 | Survey |
| Bean | Tanzania | 12.2 | 0 | 3 | 25 | 1 | 393,716 | 46 | 2009 | EO |
| Bean | Uganda | 8.7 | 1 | 0 | 17 | 0 | 532,883 | 31 | 2010 | Survey |
| Bean | Zambia | 5.2 | 0 | 1 | 9 | 0 | 75,145 | 9 | 2009 | EO |
| Bean | Zimbabwe | 5.3 | –[c] | – | – | – | – | – | – | – |
| Cassava | Angola | 9.4 | 0 | 0 | 14 | 0 | 839,000 | 31 | 2009 | EO |
| Cassava | Benin | 2.4 | 0 | 5 | 0 | 0 | 242,000 | 66 | 2009 | EO |
| Cassava | Burundi | 1 | 0 | 0 | 4 | 0 | 61,000 | 29 | 2009 | EO |
| Cassava | Cameroon | 11.5 | 0 | 0 | 0 | 28 | 205,000 | 36 | 2009 | EO |
| Cassava | Cote d'Ivoire | 5.1 | 0 | 0 | 0 | 17 | 349,000 | 20 | 2009 | EO |
| Cassava | DR Congo | 14.2 | 0 | 4 | 20 | 5 | 1,900,000 | 48 | 2009 | EO |
| Cassava | Ghana | 22.5 | 0 | 0 | 19 | 2 | 858,840 | 36 | 2009 | EO |
| Cassava | Guinea | 3 | 0 | 0 | 0 | 20 | 133,000 | 21 | 2009 | EO |
| Cassava | Kenya | 10.8 | 0 | 0 | 9 | 16 | 60,000 | 44 | 2009 | EO |
| Cassava | Malawi | 3.6 | 0 | 4 | 9 | 0 | 183,820 | 61 | 2009 | EO |
| Cassava | Mozambique | 8.9 | 0 | 2 | 17 | 5 | 941,000 | 19 | 2009 | EO |
| Cassava | Nigeria | 11 | 0 | 18 | 20 | 30 | 3,600,000 | 46 | 2009 | EO |
| Cassava | Tanzania | 2.2 | 0 | 0 | 16 | 10 | 921,475 | 31 | 2009 | EO |
| Cassava | Togo | 4 | 0 | 5 | 25 | 4 | 121,000 | 39 | 2009 | EO |
| Cassava | Uganda | 20.5 | 0 | 0 | 12 | 1 | 398,000 | 35 | 2009 | EO |
| Cassava | Zambia | 7.2 | 0 | 0 | 8 | 0 | 194,930 | 44 | 2009 | EO |
| Cassava | Zimbabwe | 1.5 | 0 | 0 | 2 | 4 | 49,000 | 52 | 2009 | EO |
| Chickpea | Eritrea | 0 | 0 | 0 | 0 | 0 | 9,525 | 2 | 2009 | EO |
| Chickpea | Ethiopia | 8.4 | 0 | 4 | 15 | 0 | 233,440 | 13 | 2009 | EO |
| Chickpea | Sudan | 18.6 | 0 | 1 | 7 | 0 | 6,667 | 100 | 2009 | EO |

a. References for and caveats about these data are given at http://www.asti.cgiar.org/diiva where the detailed dataset is stored
b. Undated entries refer to improved varieties that are not formally released
c. Indicates missing data
d. EO = Expert opinion

## (cont.) Annex 1. Summary data on FTE scientists, varietal release, and adoption of improved varieties by crop and country[a]

| Crops | Country | FTE Scientists in 2009 | Released varieties by time period if dated: Before 1970 | 1970–1989 | 1990–2010 | Undated entries[b] | Adoption of improved varieties by characteristic: Total crop area (ha) | Adoption (% area) | Year | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| Cowpea | Benin | 8.5 | 0 | 9 | 1 | 9 | 68,000 | 51 | 2009 | EO |
| Cowpea | Burkina Faso | 10.4 | 0 | 4 | 4 | 1 | 622,830 | 10 | 2009 | EO |
| Cowpea | Cameroon | 1.1 | 0 | 5 | 5 | 0 | 110,650 | 70 | 2009 | EO |
| Cowpea | Cote d'Ivoire | 4 | 0 | 7 | 1 | 0 | 3,000 | 27 | 2009 | EO |
| Cowpea | DR Congo | 0.8 | 0 | 4 | 4 | 0 | 128,000 | 44 | 2009 | EO |
| Cowpea | Ghana | 4.5 | 0 | 3 | 10 | 2 | 163,612 | 81 | 2009 | EO |
| Cowpea | Guinea | 2 | 0 | 0 | 12 | 0 | 3,900 | 63 | 2009 | EO |
| Cowpea | Malawi | 1.6 | 0 | 0 | 2 | 0 | 83,076 | 10 | 2009 | EO |
| Cowpea | Mali | 3.4 | 0 | 5 | 9 | 0 | 263,786 | 53 | 2009 | EO |
| Cowpea | Mozambique | 0.4 | 0 | 0 | 14 | 11 | 352,400 | 11 | 2009 | EO |
| Cowpea | Niger | 6.4 | 0 | 5 | 10 | 0 | 5,200,000 | 17 | 2009 | EO |
| Cowpea | Nigeria | 16 | 0 | 18 | 17 | 5 | 3,800,000 | 39 | 2009 | EO |
| Cowpea | Senegal | 4.8 | 3 | 2 | 3 | 0 | 218,904 | 27 | 2009 | EO |
| Cowpea | Tanzania | 2.4 | 0 | 3 | 3 | 0 | 147,721 | 31 | 2009 | EO |
| Cowpea | Togo | 5.2 | 0 | 3 | 0 | 0 | 178,707 | 40 | 2009 | EO |
| Cowpea | Uganda | 1.8 | – | – | – | – | 74,330 | 16 | 2009 | EO |
| Cowpea | Zambia | 1.9 | 0 | 2 | 3 | 0 | 74,000 | 17 | 2009 | EO |
| Cowpea | Zimbabwe | 1 | 0 | 0 | 1 | 0 | 4000 | 45 | 2009 | EO |
| Faba bean | Ethiopia | 6.85 | 0 | 4 | 17 | 0 | 537,606 | 4 | 2009 | EO |
| Faba bean | Sudan | 8.68 | 0 | 1 | 6 | 0 | 77,000 | 87 | 2009 | EO |
| Field pea | Ethiopia | 6.85 | 0 | 4 | 22 | 0 | 230,749 | 2 | 2009 | EO |
| Groundnut | Burkina Faso | 2.5 | 3 | 8 | 3 | 2 | 458,222 | 25 | 2010 | S |
| Groundnut | Kenya | 3 | 5 | 0 | 0 | 0 | 20,640 | 47 | 2010 | EO |
| Groundnut | Malawi | 1 | 0 | 0 | 6 | 0 | 266,946 | 58 | 2010 | EO |
| Groundnut | Mali | 2 | 2 | 6 | 17 | 0 | 335,031 | 20 | 2010 | EO |
| Groundnut | Niger | 2.25 | 0 | 8 | 5 | 0 | 588,651 | 12 | 2010 | EO |
| Groundnut | Nigeria | 1.55 | 2 | 16 | 6 | 0 | 2,600,000 | 19 | 2010 | S |
| Groundnut | Senegal | 1.6 | 4 | 6 | 7 | 1 | 1,100,000 | 47 | 2009 | EO |
| Groundnut | Tanzania | 3.83 | 0 | 3 | 7 | 0 | 535,000 | 32 | 2009 | EO |
| Groundnut | Uganda | 5 | 0 | 0 | 6 | 0 | 253,000 | 55 | 2009 | EO |
| Groundnut | Zambia | 1.15 | 4 | 1 | 12 | 0 | 204,073 | 57 | 2009 | EO |
| Lentil | Eritrea | 2 | 0 | 0 | 1 | 0 | – | – | – | – |
| Lentil | Ethiopia | 5.28 | 0 | 4 | 7 | 0 | 94,946 | 10 | 2009 | EO |

a. References for and caveats about these data are given at (website) where the detailed dataset is stored
b. Undated entries refer to improved varieties that are not formally released
c. Indicates missing data
d. EO = Expert opinion

## (cont.) Annex 1. Summary data on FTE scientists, varietal release, and adoption of improved varieties by crop and country[a]

| Crops | Country | FTE Scientists in 2009 | Released varieties by time period if dated | | | | Adoption of improved varieties by characteristic | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before 1970 | 1970–1989 | 1990–2010 | Undated entries[b] | Total crop area (ha) | Adoption (% area) | Year | Source |
| Maize–ESA | Angola | 12 | 0 | 0 | 0 | 24 | 1,600,000 | 10 | 2006 | Seed Sales |
| Maize–ESA | Ethiopia | 21.45 | 0 | 7 | 36 | 0 | 1,800,000 | 28 | 2009 | Survey |
| Maize–ESA | Kenya | 62 | 4 | 10 | 200 | 0 | 1,900,000 | 69 | 2009 | Survey |
| Maize–ESA | Malawi | 16 | 2 | 4 | 64 | 0 | 1,600,000 | 43 | 2008 | Survey |
| Maize–ESA | Mozambique | 12 | – | – | – | – | 1,600,000 | 10 | 2006 | Seed Sales |
| Maize–ESA | Tanzania | 30.75 | 0 | 9 | 82 | 0 | 3,000,000 | 35 | 2010 | Seed Sales |
| Maize–ESA | Uganda | 17 | 0 | 0 | 32 | 2 | 887,000 | 54 | 2006 | Seed Sales |
| Maize–ESA | Zambia | 13 | 0 | 11 | 194 | 0 | 911,942 | 81 | 2006 | Seed Sales |
| Maize–ESA | Zimbabwe | 59 | 1 | 3 | 73 | 0 | 1,500,000 | 93 | 2006 | Seed Sales |
| Maize–WCA | Benin | 4.35 | 2 | 16 | 7 | 11 | 830,000 | 54 | 2009 | EO |
| Maize–WCA | Burkina Faso | 3.7 | 0 | 13 | 19 | 0 | 555,175 | 49 | 2009 | EO |
| Maize–WCA | Cameroon | 17.5 | 0 | 9 | 31 | 5 | 693,027 | 82 | 2009 | EO |
| Maize–WCA | Cote d'Ivoire | 6.4 | 0 | 0 | 4 | 7 | 302,253 | 56 | 2009 | EO |
| Maize–WCA | DR Congo | 5 | 0 | 2 | 1 | 8 | 1,500,000 | 15 | 2009 | EO |
| Maize–WCA | Ghana | 7.1 | 1 | 9 | 15 | 2 | 863,577 | 60 | 2012 | Survey |
| Maize–WCA | Guinea | 2.93 | 1 | 2 | 8 | 1 | 440,000 | 73 | 2009 | EO |
| Maize–WCA | Mali | 3.4 | 0 | 8 | 10 | 3 | 408,606 | 72 | 2009 | EO |
| Maize–WCA | Nigeria | 77.5 | 8 | 38 | 44 | 21 | 3,700,000 | 95 | 2009 | EO |
| Maize–WCA | Senegal | 5.85 | 0 | 2 | 8 | 0 | 190,624 | 97 | 2009 | EO |
| Maize–WCA | Togo | 5.8 | 0 | 1 | 11 | 1 | 500,000 | 5 | 2009 | EO |
| Pearl millet | Burkina Faso | 4.46 | 0 | 11 | 15 | 0 | 1,300,000 | 3 | 2010 | EO |
| Pearl millet | Mali | 6.43 | 0 | 8 | 27 | 0 | 1,500,000 | 31 | 2010 | EO |
| Pearl millet | Niger | 5 | 0 | 22 | 15 | 0 | 6,500,000 | 11 | 2010 | EO |
| Pearl millet | Nigeria | 1.5 | 1 | 7 | 3 | 0 | 3,700,000 | 25 | 2009 | Survey |
| Pearl millet | Senegal | 3.2 | 0 | 5 | 6 | 1 | 1,100,000 | 35 | 2010 | EO |
| Pigeonpea | Kenya | 5 | 0 | 2 | 5 | 0 | 118,167 | 50 | 2009 | EO |
| Pigeonpea | Malawi | 0.67 | 0 | 1 | 6 | 0 | 175,734 | 50 | 2009 | EO |
| Pigeonpea | Tanzania | 1.2 | 0 | 0 | 3 | 0 | 72,000 | 50 | 2010 | Survey |
| Potato | Ethiopia | 16 | 0 | 2 | 30 | 0 | 164,146 | 23 | 2009 | Survey |
| Potato | Kenya | 30 | 3 | 10 | 10 | 0 | 152,998 | 29 | 2009 | EO |
| Potato | Malawi | 3 | 0 | 10 | 8 | 0 | 45,816 | 1 | 2009 | EO |
| Potato | Rwanda | 4.6 | 0 | 15 | 7 | 0 | 150,777 | 36 | 2009 | Survey |
| Potato | Uganda | 3.7 | 0 | 10 | 12 | 0 | 102,000 | 74 | 2009 | EO |

a. References for and caveats about these data are given at (website) where the detailed dataset is stored
b. Undated entries refer to improved varieties that are not formally released
c. Indicates missing data
d. EO = Expert opinion

## (cont.) Annex 1. Summary data on FTE scientists, varietal release and adoption of improved varieties by crop and country[a]

| Crops | Country | FTE Scientists in 2009 | Released varieties by time period if dated | | | | Adoption of improved varieties by characteristic | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before 1970 | 1970–1989 | 1990–2010 | Undated entries[b] | Total crop area (ha) | Adoption (% area) | Year | Source |
| Rice | Benin | – | – | – | – | – | 38,700 | 83 | 2009 | Survey |
| Rice | Burkina Faso | 7 | 1 | 14 | 9 | 0 | 92,243 | 71 | 2009 | Survey |
| Rice | CAR | 6.25 | – | – | – | – | 15,969 | 35 | 2009 | Survey |
| Rice | Cameroon | 8 | 0 | 16 | 11 | 4 | 99,653 | 52 | 2009 | Survey |
| Rice | Cote d'Ivoire | 12 | 2 | 20 | 26 | 0 | 569,000 | 33 | 2009 | Survey |
| Rice | DR Congo | 4.5 | – | – | – | – | 482,400 | 39 | 2009 | Survey |
| Rice | Ghana | – | 0 | 10 | 5 | 0 | 122,700 | 58 | 2009 | Survey |
| Rice | Guinea | 15.25 | 2 | 40 | 82 | 0 | 712,800 | 22 | 2009 | Survey |
| Rice | Kenya | 15.25 | – | – | – | – | 1065 | 85 | 2009 | Survey |
| Rice | Madagascar | 11.75 | 4 | 9 | 7 | 0 | 1,400,000 | 35 | 2009 | Experts |
| Rice | Mali | – | 4 | 10 | 16 | 0 | 646,100 | 25 | 2009 | Survey |
| Rice | Nigeria | 11 | 12 | 32 | 14 | 0 | 1,200,000 | 50 | 2010 | Survey |
| Rice | Rwanda | 8.25 | – | – | – | – | 12,775 | 69 | 2009 | Survey |
| Rice | Senegal | – | 0 | 10 | 35 | 0 | 101,000 | 43 | 2009 | Survey |
| Rice | Sierra Leone | 12 | 1 | 22 | 2 | 4 | 434,200 | 16 | 2009 | Survey |
| Rice | Tanzania | – | 1 | 3 | 8 | 0 | 627,600 | 13 | 2009 | Survey |
| Rice | The Gambia | 6.75 | – | – | – | – | 73,000 | 24 | 2009 | Survey |
| Rice | Togo | – | – | – | – | – | 36,492 | 59 | 2009 | Survey |
| Rice | Uganda | 7 | – | – | – | – | 120,000 | 46 | 2009 | Survey & EO |
| Sorghum | Burkina Faso | 2.96 | 0 | 2 | 25 | 2 | 1,700,000 | 3 | 2010 | EO |
| Sorghum | Kenya | 3 | 0 | 4 | 10 | 0 | 173,172 | 40 | 2009 | EO |
| Sorghum | Mali | 7.75 | 0 | 10 | 50 | 7 | 1,100,000 | 33 | 2010 | EO |
| Sorghum | Niger | 5.45 | 0 | 3 | 3 | 4 | 2,500,000 | 15 | 2010 | EO |
| Sorghum | Nigeria | 2.5 | 0 | 31 | 8 | 0 | 4,700,000 | 20 | 2009 | Survey |
| Sorghum | Senegal | 2.4 | 0 | 6 | 0 | 0 | 240,425 | 41 | 2010 | EO |
| Sorghum | Sudan | 18.2 | 1 | 6 | 16 | 0 | 6,700,000 | 40 | 2009 | EO |
| Sorghum | Tanzania | – | 1 | 1 | 5 | 0 | 874,219 | 38 | 2010 | Survey |
| Soybean | Benin | 1.55 | 0 | 3 | 7 | 2 | 38,000 | 50 | 2009 | EO |
| Soybean | Burundi | 3.2 | 0 | 1 | 3 | 7 | 2556 | 4 | 2009 | EO |
| Soybean | Cameroon | 2.6 | 0 | 1 | 7 | 2 | 13,000 | 75 | 2009 | EO |
| Soybean | Cote d'Ivoire | 4.5 | 0 | 3 | 15 | 0 | 1000 | 100 | 2009 | EO |
| Soybean | DR Congo | 0.8 | 0 | 3 | 2 | 0 | 35,000 | 100 | 2009 | EO |
| Soybean | Ghana | 1.9 | 0 | 0 | 7 | 0 | 70,000 | 94 | 2009 | EO |

a. References for and caveats about these data are given at (website) where the detailed dataset is stored
b. Undated entries refer to improved varieties that are not formally released
c. Indicates missing data
d. EO = Expert opinion

## (cont.) Annex 1. Summary data on FTE scientists, varietal release, and adoption of improved varieties by crop and country[a]

| Crops | Country | FTE Scientists in 2009 | Released varieties by time period if dated | | | | Adoption of improved varieties by characteristic | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before 1970 | 1970–1989 | 1990–2010 | Undated entries[b] | Total crop area (ha) | Adoption (% area) | Year | Source |
| Soybean | Kenya | 1 | 0 | 0 | 7 | 3 | 3000 | 74 | 2009 | EO |
| Soybean | Malawi | 2.1 | 0 | 5 | 10 | 0 | 80,000 | 100 | 2009 | EO |
| Soybean | Mozambique | – | 0 | 0 | 5 | 0 | – | – | – | – |
| Soybean | Nigeria | 14.6 | 1 | 8 | 11 | 0 | 613,000 | 92 | 2009 | EO |
| Soybean | Tanzania | 1 | 0 | 2 | 1 | 6 | 9000 | 79 | 2009 | EO |
| Soybean | Togo | 3.2 | 0 | 1 | 1 | 5 | 60,450 | 39 | 2009 | EO |
| Soybean | Uganda | 2.8 | 0 | 0 | 7 | 4 | 148,000 | 97 | 2009 | EO |
| Soybean | Zambia | 10.9 | 0 | 10 | 19 | 1 | 45,000 | 100 | 2009 | EO |
| Soybean | Zimbabwe | 2 | 1 | 9 | 7 | 14 | 67,300 | 100 | 2009 | EO |
| Sweetpotato | Burundi | 2 | 0 | 1 | 2 | 0 | 125,000 | 28 | 2010 | EO |
| Sweetpotato | Mozambique | 8.7 | 0 | 0 | 33 | 0 | 130,000 | 9 | 2010 | EO |
| Sweetpotato | Rwanda | 2.1 | 0 | 8 | 15 | 0 | 123,086 | 0 | 2010 | Survey |
| Sweetpotato | Tanzania | 15.9 | 0 | 0 | 10 | 0 | 480,000 | 0 | 2010 | EO |
| Sweetpotato | Uganda | 4 | 0 | 0 | 20 | 0 | 620,000 | 9 | 2010 | Survey |
| Wheat | Ethiopia | 18.05 | 0 | 7 | 66 | 0 | 1,490,764 | 63 | 2009 | Survey |
| Wheat | Kenya | 28 | 0 | 34 | 12 | 0 | 131,594 | 100 | 2009 | Assumed (1998 Results) |
| Wheat | Tanzania | – | 1 | 16 | 5 | 1 | 149,200 | 100 | 2009 | Assumed (1998 Results) |
| Wheat | Zambia | 12 | 0 | 16 | 29 | 0 | 34,296 | 100 | 2009 | Assumed (1998 Results) |
| Wheat | Zimbabwe | 12 | 19 | 13 | 25 | 0 | 13,000 | 100 | 2009 | Assumed (1998 Results) |
| Yams | Benin | 12.1 | 0 | 0 | 0 | 15 | 171,000 | 4 | 2009 | EO |
| Yams | Cameroon | 3.3 | 0 | 0 | 0 | 10 | 33,000 | 9 | 2009 | EO |
| Yams | Cote d'Ivoire | 7.1 | 0 | 0 | 5 | 0 | 758,000 | 75 | 2009 | EO |
| Yams | Ghana | 3 | 0 | 0 | 3 | 0 | 2000 | 10 | 2009 | EO |
| Yams | Guinea | 3.1 | 0 | 0 | 4 | 0 | 367,500 | 5 | 2009 | EO |
| Yams | Nigeria | 11.8 | 0 | 0 | 23 | 1 | 3,000,000 | 25 | 2009 | EO |
| Yams | Togo | 4.5 | 0 | 0 | 0 | 14 | 60,000 | 15 | 2009 | EO |
| Yams | Uganda | 4.6 | 0 | 0 | 0 | 3 | 254,000 | 14 | 2009 | EO |

a. References for and caveats about these data are given at (website) where the detailed dataset is stored
b. Undated entries refer to improved varieties that are not formally released
c. Indicates missing data
d. EO = Expert opinion

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Synthesis Report for Objectives 1 and 2 of Bill & Melinda Gates Foundation's DIIVA Project

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