Towards appraising the impact of legume research: A synthesis of evidence

Standing Panel on Impact Assessment (SPIA)

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Foreword

Legume crops play an important role in farming systems and were among the earliest crops to be domesticated by humans, over 10,000 years BP. Their contributions to farming systems and human well-being are clear and well-documented. Legumes fill temporal and spatial gaps in cropping systems – through rotations and intercropping, respectively. By fixing atmospheric nitrogen, they improve soils and increase the productivity of other crops. Many legumes can also be fed to livestock, allowing for value addition within farming systems. For humans, legumes offer a valuable source of dietary protein. The rationale for CGIAR's long-standing investments in legume research is often argued along these lines; that is, there are important properties, unique to legumes, that cereals and other staples simply do not possess. These reasons are sufficient to explain why CGIAR has chosen over the years to pursue research on legumes.

While the arguments for the importance of legume crops are persuasive, they do not necessarily imply that agricultural research on legumes has been successful in the past or that continued research on legumes is likely to generate high returns. Addressing these questions requires much more information. What do we know about the impacts of past agricultural research on legume crop improvement and crop management? What are the problems in legume production for which agricultural technologies have been developed? Where have these legume technologies been adopted? Can we say anything about the impacts of legume technologies, where adopted, on productivity, incomes, nutrition, poverty or environmental sustainability? These were the broad questions that the Standing Panel on Impact Assessment (SPIA) set out to answer in 2010 when it launched a study on legumes research impact.

Aggregate global data from the last 20 years show that legume yields have grown at only about 0.5 percent per year, which compares quite poorly to growth rates in yields of cereals over the same period (roughly 1.5 percent per year). This simple comparison is, of course, unfair. Legumes are often grown on more marginal land, sometimes on small areas. They are also frequently intercropped with cereals or used as short-duration rotation crops in what are largely cereal-based systems. In either of these cases, the management of legumes is often given secondary importance relative to the main cereal crop. Indeed, there is some evidence that introducing legumes in a rotation has the effect of increasing the yield of the subsequent cereal crop via its impact on soil fertility. These considerations should certainly inform expectations about the adoption and impact of legume technology, and they suggest that it is overly simplistic to focus solely on legume yields and productivity to assess the impact of research. Instead, research impact should properly be assessed by looking at its effects on the entire farming system – and indeed on the entire farm household enterprise, not to mention more distant effects on the well-being of non-farm consumers.

As a starting point, SPIA sought to identify the set of CGIAR legume technologies that have moved from research stations to farmers' fields and beyond. Our goal at the outset of this study was to document adoption and diffusion of CGIAR legume technologies. We expected that this initial study would lead to a series of SPIA initiatives to evaluate more comprehensively the impacts – economic, social and environmental – of CGIAR legume research. We began by commissioning work that would focus on the presumed strong dietary, gender and soil fertility dimensions of legume research. Our idea was to start with a review of the available literature that would make sense of the existing studies, providing critiques and highlighting good practice where appropriate. As will become clear, our plans have not been realized: we have had to scale back our ambitions.

Within CGIAR, four centers – the International Center for Tropical Agriculture (CIAT), the International Center for Agricultural Research in the Dry Areas (ICARDA), the International Crops Research Institute for the

Semi-Arid Tropics (ICRISAT), and the International Institute of Tropical Agriculture (IITA) – have mandates for productivity improvement for specific crops in the legume family. Their research brief includes crop germplasm improvement and productivity-enhancing natural resource management. But, surprisingly, there have been relatively few studies providing *ex-post* impact assessments of legume research in CGIAR. This SPIA study started with a desk-based scoping phase in 2010, led by Robert Tripp, which reviewed the existing evidence of documented impacts from CGIAR legume research and drew on consultations with management and senior scientists at CIAT, ICARDA, ICRISAT and IITA. That report[1] looked at the main legume crop varietal releases of CGIAR and national agricultural research systems (NARS) partners and provided an overview and critique of the set of adoption studies carried out by CGIAR – for which well-documented cases were relatively few up to that time.

Given the paucity of evidence found by Tripp in 2010, SPIA launched a second phase of investigation in 2011, with the goal of assembling credible evidence about the broadest possible impacts from legumes research across the CGIAR system.[2] SPIA recognized that, given limited basic information even about adoption, this study was not in a position to generate rigorous estimates of the poverty and nutritional impacts from legumes research (although a few ongoing studies were trying to move in this direction). This second phase of SPIA's effort, then, focused on identifying three to six 'best bets' of country–crop cases where the initial evidence suggested that there could be an important impact story, but for which the existing evidence base was insufficiently well-developed. This study was again led by Tripp; he, along with SPIA Secretariat members and other consultants, made a number of reconnaissance visits to CGIAR centers and field sites in India (for chickpea, pigeonpea and lentil), Nepal (for lentil), Nigeria (cowpea), Syria (chickpea), Turkey (chickpea), Tanzania (pigeonpea) and Kenya (pigeonpea) in the first half of 2011 to explore the potential for developing specific case studies that could provide more than simply 'anecdotal evidence'.

While SPIA learned a tremendous amount throughout this process of consultation with CGIAR and national scientists, the major constraint to the identification of 'best bets' remained the lack of availability of unbiased, large-scale adoption data. When CGIAR scientists were asked about the lack of such data, one of the most common explanations offered was the inherent difficulty associated with identifying specific legume varieties in the field setting – either as part of adoption surveys or as part of a process of expert opinion elicitation. Neither farmers nor independent experts (e.g. legume breeders or extension workers) were able to confidently identify varieties of a number of legume crops based on phenotypic characteristics, and there was no consistent mapping of local names to specific varietal names.[3] As the costs of DNA fingerprinting analysis continues to fall, SPIA believes that future impact studies, for legumes and for other crops, may soon be able to make use of this technology for routine identification of varieties in farm household surveys. While DNA fingerprinting costs are currently relatively high, the costs of getting bad data are in reality much higher.

In the meantime, SPIA has identified the following cases as 'best bets' for identifying significant impacts from CGIAR legume research: chickpea in Andhra Pradesh, Madhya Pradesh, Turkey and Syria; common bean in East Africa; pigeonpea in Tanzania; cowpea in Nigeria and Niger; and groundnut in West Africa.

1 Tripp, R. 2011. *The Impacts of Food Legume Research in the CGIAR: A Scoping Study*. Rome, Italy, Standing Panel on Impact Assessment (SPIA), CGIAR Independent Science and Partnership Council (ISPC) (available at http://impact.cgiar.org/sites/default/files/images/LegumeScoping2011.pdf).

2 Tripp identified the following long-list of potential impact case-studies: Chickpea in India, Syria, Turkey and Ethiopia; Cowpea in Nigeria and Niger; Soybean in Nigeria; Pigeonpea in India, Tanzania, Kenya, Malawi and Uganda; Lentil in Ethiopia, Nepal and Bangladesh; Faba bean in Egypt and Ethiopia; Groundnut in Mali, Nigeria, India, Uganda and Malawi; and, Common Bean in Rwanda, Uganda, Tanzania, Kenya and Malawi.

3 Early results from DNA fingerprinting work currently being carried out on cereal and root crops in East Africa, overseen by the Bill & Melinda Gates Foundation, suggest that this is an issue that is not unique to legumes, but certainly the problem would seem to be most acute for open-pollinated or partly open-pollinated crops such as pigeonpea (Mine, 2012).

Given the above-mentioned data problems, in mid-2011 SPIA launched a mixed portfolio of small projects to follow up on these prospects, with the goal of incrementally improving the evidence base on adoption. For chickpea, SPIA commissioned studies by ICRISAT in Andra Pradesh and by the National Centre for Agricultural Economics and Policy Research (NCAP) in Madhya Pradesh. SPIA also asked ICARDA to invest in their own studies for Syria and Turkey. For cowpea, SPIA worked with IITA scientists to develop a varietal identification protocol that could identify improved cowpea varieties as a class, based on phenotypic characteristics. This protocol was then used by the World Bank's Living Standards Measurement Study (LSMS), which assisted in designing an Integrated Survey of Agriculture (LSMS-ISA) in Nigeria in 2012. For pigeonpea, Sarah Mine was hired as a consultant to visit Tanzania and test whether a similar phenotypic protocol could work. For common bean, data from the SPIA-coordinated project on Diffusion and Impact of Improved Varieties in Africa (DIIVA) were used; this project compiled adoption data for all relevant countries in East Africa, as well as an impact assessment study looking at improved bean in Rwanda and Uganda. For groundnut, the DIIVA data sets were again drawn on for relevant countries in West Africa.

In August 2013, the assembled studies and surveys from SPIA's legume work were handed over to Douglas Pachico, an agricultural economist with extensive experience of legume programs in CGIAR. He was assigned the task of assembling an overall synthesis report. We are grateful to him for taking on this challenging task and for the clarity with which he has summarized the main issues. It is heartening to note Pachico's main conclusion – that research results from over 30 adoption surveys conducted in more than 20 countries provides evidence that farmers are growing improved legume varieties in many developing countries and regions. In particular, there is ample evidence of widespread adoption of improved bean varieties in Sub-Saharan Africa and improved chickpea varieties in southern India. There is also evidence for modest adoption of improved chickpea in the Horn of Africa and improved cowpea varieties in West Africa. At the same time, the Pachico report emphasizes the need for more adoption studies to fill critical gaps in knowledge. Most striking is the lack of data on adoption of improved varieties across large areas targeted by CGIAR research – for example, cowpea in many parts of West Africa and lentil in India, Turkey and Iran. Pachico concludes by identifying an even greater challenge facing CGIAR – going beyond simple adoption estimates to more meaningful examination of impacts on CGIAR system-level objectives such as poverty reduction (especially for women), increased food security, improved nutrition and health, and enhanced management of natural resources. The evidence base for these impacts is very limited, with few rigorous studies.

Beyond adoption and impact assessment, the Pachico report also highlights a number of other important issues that can emerge from the body of literature compiled for the study. One is the inadequacy of seed systems in many countries, meaning that farmers have relatively few options for acquiring high-quality seed. The report suggests there is clear evidence that seed supplies are a constraint and that there is a need to move towards documentation of best practices and changes in policy. The report also finds: "apart from improved varieties, there has been little evidence of adoption of other improved legume technologies." This includes a variety of management practices that have been promoted at various times by different CGIAR research programs. Another important point from the study is that the promotion of improved legume varieties is likely to have relatively modest impacts on natural resources (e.g. soil quality) in places where improved legumes are replacing existing varieties; instead, the bigger impacts will come when improved varieties allow more significant changes in farming systems.

Although this review finds substantial gaps in the evidence for adoption and impact of CGIAR legume research, there is also clear evidence of research successes. Extending and improving the evidence base remains a priority for SPIA and should remain even more of a priority for the relevant CGIAR Research Programs (CRPs). We hope that this report will be of use to donors and CGIAR management alike by elucidating the current state of the evidence base for impacts of legume research.

The Standing Panel on Impact Assessment (SPIA) would like to thank Douglas Pachico for his thoughtful and comprehensive report. SPIA also thanks Robert Tripp, Sarah Mine, Timothy Dalton, Ramesh Chand, Mywish Maredia and Sitou Akibode for their contributions as consultants to background work that fed into this report. SPIA gratefully acknowledges the collaboration of a number of CGIAR scientists, particularly Arega Alene, Tahirou Abdoulaye, Ousmane Boukar, Aden Aw-Hassan, Said Silim and Yigezu Yigezu, as well as a large number of their colleagues from NARS in countries included in this report. Although the report points to gaps in the literature, we note that in many cases these gaps reflect the intrinsic difficulty of impact assessment for legume research, as well as the relatively low institutional priorities and modest resources devoted to this area of research.

Contents

Acronyms and abbreviations

2SLS	Two-Stage-Least-Squared
BP	Before Present
CIAT	International Center for Tropical Agriculture
CRP	CGIAR Research Program
DIIVA	Diffusion and Impact of Improved Varieties in Africa
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
LSMS	Living Standards Measurement Study
LSMS-ISA	Living Standards Measurement Study Integrated Survey of Agriculture
NARS	National Agricultural Research System
NCAP	National Centre for Agricultural Economics and Policy Research
SLO	system-level outcome

Executive summary

This paper reviews research results from over 30 adoption surveys conducted in more than 20 developing countries, which provide evidence that farmers are growing improved legume varieties in many regions. There is ample evidence of widespread adoption of improved bean varieties in Sub-Saharan Africa, chickpea varieties in southern India and cowpea varieties in West Africa, as well as small-scale adoption of improved chickpea varieties in the Horn of Africa.

Key findings on adoption for six major legume crops are as follows:

Chickpea: Recent surveys conducted in India find that improved chickpea varieties have been adopted across large swathes of the country, particularly in southern and central regions, where rapid expansion of area under chickpea can be attributed to the availability of improved short-duration varieties.

Groundnut: There has been a recent surge in the uptake of improved groundnut varieties in Africa, particularly in East Africa rather than the traditionally high-producing regions of West Africa. Nearly two-thirds of reported adoption is for varieties released before 1990.

Bean: Over three million farmers in Sub-Saharan Africa have adopted improved bean varieties, and more improved varieties of bean have been released than for any other legume in Africa. Earlier studies have already documented the widespread adoption of improved bean varieties in Latin America.

Cowpea: Although recent survey evidence is scarce, expert opinion suggests that there has been widespread adoption of new varieties in West Africa. The area planted with improved cowpea varieties is estimated to exceed 3 million ha – a far greater area than for any other grain legume – and two-thirds of the area under these improved varieties is based on material produced in collaboration with CGIAR.

Pigeonpea: Recent surveys find evidence of pockets of adoption of improved varieties in a few countries in East and Southern Africa, while recent expert elicitations confirmed earlier surveys that had indicated wide adoption of improved varieties in India.

Lentil: There is survey evidence showing adoption of improved lentil varieties in Bangladesh and Ethiopia, but evidence of adoption is still lacking from the most important lentil-producing countries, which include China, India, Iran, Nepal and Turkey.

Apart from improved varieties, there has been little evidence of adoption of other improved legume technologies. With respect to new varieties, the current body of literature suggests that there is great diversity in their suitability and uptake in different parts of the world. There are opportunities for new adoption studies to fill gaps in knowledge or data. For example, surveys of cowpea in West Africa or of lentil in India, Turkey or Iran might offer prospects for documenting adoption. Nevertheless, the critical challenge now for assessing the impact of grain legume research is to better ascertain how far adoption has influenced CGIAR system-level outcomes (SLOs): poverty reduction, especially for women; increased food security; improved nutrition and health; and enhanced management of natural resources, about which relatively little is known.

Current evidence makes clear that the adoption and performance of new varieties among resource-poor farmers is variable, depending on the particular circumstances involved. Sometimes, the adoption rates for poor farmers are as high or higher than the adoption rates of wealthier farmers; in other cases, adoption is skewed towards the wealthier farmers. In interpreting these findings, however, it is important to recall that in low-income communities, ‘wealthier farmers’ are themselves poor by most standards, and the findings of technology bias in favor of the wealthier farmers may not be as undesirable as it would seem. Furthermore, legumes occupy different proportions of cultivated land on poor farms compared to better-off farms. As a result, they have differential effects on farm productivity and profitability.

Where grain legumes are a secondary crop in the farm system – which is often the case – and contribute a relatively modest share of total household income (many poor people may depend more on selling labor than on productivity of their small landholdings), the effects of adoption on poverty are also likely to be modest.

Although it appears logical that improved crop production should lead to increased food security, and improved nutrition and health, there is very little empirical evidence about the impacts of new varieties on these objectives. However, a recent study found that improved bean varieties in Uganda had a much greater impact on food security than they did on poverty (Larochelle *et al.*, 2013). This is a rare result; and there is almost no evidence of the impact of legume research on health. Remedying this gap involves assessment of evidence from studies on SLOs 2 and 3, and even undertaking new (potentially expensive) data collection. It is unlikely that this would become a routine dimension of all future adoption and impact studies, but a few well-targeted studies are called for.

Likewise, while there is extensive on-station experimental evidence showing that the presence of grain legumes in the cropping system significantly increases the yields of the subsequent crop in the rotation, the existing body of adoption surveys adds little empirical farmer field evidence showing the natural resource impacts of improved varietal adoption.

With respect to assessing gender-differentiated outcomes in past adoption studies, some initial steps have been made, but the opportunity to go into greater depth on this issue remains to be fully exploited. A minimum set of gender-related data for adoption studies could be useful, but just as important would be some in-depth studies.

Resources to assess these diverse types of impacts are going to remain limited. The value of the information being obtained always has to be considered in terms of its opportunity cost. In particular cases where only the most advanced methods will be effective, the cost of collecting additional information has to be weighed against the operational utility of additional precision.

Although there is substantial evidence for widespread adoption of some improved grain legume varieties, the evidence almost always indicates that adoption is far from universal, even for varieties that have had several years to diffuse. Understanding the factors that constrain adoption is important. This is an especially critical issue for groundnut, both in Africa and India, where despite high levels of adoption, the adoption of varieties released during the last 25–30 years is modest at best. While surveys have been useful in measuring the extent of adoption, few studies provide compelling explanations of what limits adoption in a particular situation. Further research is also necessary to understand theories of change and the extent to which adoption of improved varieties facilitates achievement of the CGIAR SLOs.

Ample evidence exists about the importance of seed systems in adoption. Further research on this topic in the context of adoption surveys is unlikely to add much. The emphasis now should be on identifying best practices for grain legume seed systems to guide implementation. Farmer characteristics like education, age or resource endowments have especially important effects on the earliness of adoption, but they are often less important in differentiating between adopters and non-adopters once peak levels of adoption are reached. This is a well-studied topic and it is not clear that further research will contribute much.

Varietal characteristics that impede adoption are an extremely important constraint, and one that depends on the particular crop variety and its target growing conditions, including socioeconomic constraints. Research systems need to have effective feedback on variety performance at an early stage of development, as it is highly inefficient to become aware of such issues only at the adoption study stage. Approaches such as participatory research can be effective at an earlier stage.

Keywords: legumes, improved varieties, impact, poverty, rural

1. Introduction

CGIAR has made significant investments in legume improvement research over four decades, recently contributing to a Grain Legume Research Program (CGIAR, 2012) and formerly through four international agricultural research centers: the International Center for Tropical Agriculture (CIAT) for bean; the International Center for Agricultural Research in Dry Areas (ICARDA) for lentil; the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for chickpea, groundnut and pigeonpea; and the International Institute of Tropical Agriculture (IITA) for cowpea. However, the impacts of legume research are far less well documented than for cereals (Tripp, 2011a). Appraising impacts can help investors ensure accountability and, to a lesser extent, inform future research activity (Kelly *et al.*, 2008).

There is a substantial and growing body of literature on the adoption of improved legume varieties. There is, though, great diversity in the suitability and uptake of food grain legumes in different parts of the world. For example, cowpea is an important staple in West Africa; as is bean in East Africa and Latin America; lentil in West Asia and North Africa; and chickpea and pigeonpea in South Asia. Moreover, within each of these broad regions, legumes occupy diverse roles in the cropping systems. Consequently, legume research generally does not lead to mega-varieties that are grown over millions of hectares across the world, as has been the case with some wheat and rice varieties.

The Standing Panel on Impact Assessment (SPIA) of CGIAR has been documenting the most important cases of the adoption and impact of legume technologies, commissioning: a scoping study (Tripp, 2011a); an overview of global and regional trends in production, trade and consumption (Akibode & Maredia, 2011); a study of adoption in 20 crops in Africa (Walker *et al.*, 2014); and a methodological study of varietal identification of pigeonpea in Tanzania (Mine, 2012). This paper is an updated review of recent evidence of grain legume impacts, taking into account studies by SPIA and others. While impacts dating back to the 1990s and before are not completely ignored, the focus here is on more recent impacts.

This paper also assesses the impact of legume research in terms of the CGIAR system-level outcomes (SLOs): reducing rural poverty, increasing food security, improving nutrition and health, and managing natural resources more sustainably. Gender equity is treated as a crosscutting theme.

Our process of assessing the impact of research activity uses indicators that measure progress towards achieving CGIAR goals (Kelley *et al.*, 2008) and this paper focuses on one set of outputs of CGIAR research: varieties developed in collaboration with countries' national agricultural research systems (NARS). Improved varieties include both selections from landraces as well as breeding lines.

The adoption of new varieties of legumes is the main outcome considered in this paper. This is usually measured as the area sown to new varieties, but also sometimes as the percentage of farmers growing new varieties. Although adoption is a process that occurs over time, this paper attempts to record the latest snapshot based on current knowledge.

Many adoption studies also examine the immediate results of adoption (e.g. changes in yield, production cost, value and profits) and these too are examined in this paper. Where possible, information on the impacts of legume research on poverty, food security, nutrition, sustainability and gender equity are noted. Most of the studies reported in this paper are based on either expert opinion or household surveys; they do not take full advantage of the latest thinking on methodology and the inherent selection bias and endogeniety problems associated with many cross-sectional data analyses (de Janvry *et al.*, 2010). Nonetheless, this review reflects the current state of knowledge and reaches some broad conclusions.

This paper is organized as follows: first, progress in generating the most important outputs of legume research – improved varieties – is reviewed; next, some methodological issues in measuring the adoption of improved legume varieties are considered; third, the available evidence on the adoption of improved legume varieties is summarized crop by crop; fourth, some of the most significant constraints to the adoption of legume varieties are noted; fifth, the paper discusses briefly some of the consequences of adopting improved legumes, i.e. impacts on productivity, farming systems, rural poverty, food security/nutrition, natural resources and gender relations; finally, there is a brief summary and some suggestions for future research.

2. Outputs of legume research

There is considerable evidence that CGIAR food legume research has produced a significant number of outputs in Sub-Saharan Africa. Although focusing on release data from Africa alone overlooks substantial legume research targeted at Asia and Latin America (which lack any recent cumulative review of legume varietal releases), it does give useful performance indicators for a priority region of CGIAR. As of 2010, research by CGIAR and NARS partners had led to the release of 850 improved legume varieties (Table 1). Moreover, the rate of varietal release has increased over time.

With the exception of groundnut – a priority of colonial research systems – there were practically no legume varietal releases prior to the 1970s. By the 1980s, national programs, with the support of CGIAR, were active in the release of new varieties of bean and cowpea as well as groundnut, while there were also many releases of soybean varieties. Table 1 shows the number of new varietal releases for different legumes in Sub-Saharan Africa during successive decades; the total also includes undated releases. Total varietal releases have grown consistently over the last four decades.

There has been a steady rise over the last 40 years in the output of varieties of bean and chickpea, while there has been a surge in varietal releases of groundnut and pigeonpea since 2000. In the last three decades there has also been a steady output of lentil varieties – almost all in a single country, Ethiopia – of which about 85 percent are derived from the efforts of CGIAR and its partners. The output of soybean varieties appears to have plateaued in the last 20 years, while the release of cowpea varieties seems to have fallen sharply in the last decade.

There are notable differences in the intensity of output of new varieties across different legumes (Table 2). Varietal release per area harvested is highest for soybean which, as a new crop in most of Sub-Saharan Africa, started off with a low area of production. Likewise, there has been a high intensity of varietal release of lentil, but this is essentially a result of such a small area being planted to lentil that the release of even a few varieties has led to a high ratio of releases to area planted.

The intensity of varietal output is also high in bean and chickpea, which contrasts with the relatively modest output of cowpea and groundnut. This is, perhaps, a reflection of the natural adaptability of cowpea and groundnut, which also tend to be grown in homogenous zones around the world.

Table 1. Legume research outputs in Sub-Saharan Africa: varietal releases

	Pre-1970	1970s	1980s	1990s	2000s	Total[1]
Bean	1	6	22	73	130	250
Chickpea	0	3	2	9	12	27
Cowpea	3	8	49	65	32	200
Groundnut	20	23	25	21	48	140
Lentil	0	0	4	5	5	15
Pigeonpea	0	0	3	2	12	17
Soybean	2	13	32	52	57	201
All legumes	26	53	137	227	296	850

Source: Walker *et al.* (2014)
1 Total includes undated releases

Table 2. Intensity and CGIAR share of legume varietal releases in Sub-Saharan Africa

	Output intensity (releases/million ha)	Releases/year per country, 1999–2011	CGIAR share (%)
Bean	100	1.4	39
Chickpea	108	1.0	96
Cowpea	17	0.5	58
Groundnut	22	0.4	44
Lentil	158	0.3	87
Pigeonpea	46	0.4	82
Soybean	170	0.4	49

Source: Walker *et al.* (2014)

By comparison, the high number of releases per area planted to bean is almost certainly due, in part, to the crop being grown in highly diverse environments, so that bean research has had an explicit aim of taking advantage of local adaptation. This has led to an increase in the apparent output intensity of bean, as measured by varietal releases per million hectares (ha). The apparently low output intensity of cowpea and groundnut could therefore be due to the opposite circumstances of bean, but it might also reflect further as yet unrealized opportunities to increase the development of improved varieties of these two crops.

CGIAR makes a major contribution to the output of new varieties (Table 2), notably in chickpea (96 percent), lentil (87 percent) and pigeonpea (82 percent). To some extent, this may be because these are less important crops in Sub-Saharan Africa compared to bean, cowpea or groundnut. NARS might rationally be less inclined to invest scarce research resources in crops that are less widely grown, and choose to rely on CGIAR research activities instead. Meanwhile, bean, cowpea and groundnut are all grown on much larger areas therefore attracting more national attention to their improvement, including seeking a wider range of providers of germplasm beyond CGIAR.

3. Some methodological issues in legume adoption studies

Since it is clear that legume research has been effective in producing a wide range of improved varieties, the next step is to assess the extent and impact of adopting these new varieties. Measuring adoption levels of any variety of crop is almost commonplace in agricultural economics, yet there are a number of methodological issues that impede an accurate estimation of adoption and other relevant variables such as changes in yields. Some of these issues are outlined below.

The first is how to measure adoption. In many studies, adoption is measured by the number or percentage of farmers growing a particular variety. While this has some relevance as an indicator of the extent of adoption, farmers grow different amounts and, often, more than one variety of a particular crop. Therefore, the preferred adoption measure is the total area grown to a variety, or that area expressed as a percentage of the total area in the crop (Tripp, 2011a).

The area grown to a variety can be estimated by many methods. In regions where all farmers purchase seed and there is a well-organized seed system, seed sales data can provide a useful indicator of the areas planted to different varieties. Having said that, grain legume farmers tend to purchase only a small proportion of the seed that is planted. Most legume seed is either saved by the farmer from an earlier crop or acquired by exchanging seed with or purchasing from another farmer or local grain dealer (Rubyogo *et al.*, 2007; Sperling & McGuire, 2010; Simtowe *et al.*, 2010). Consequently, seed sales are almost never a reliable indicator of the amount of seed planted to different legume varieties.

Expert opinion, for example, from extension agents, researchers or lead farmers is often the first step towards measuring adoption, and these results are often reported in various media as adoption estimates. Internal reports and initial scoping studies often involve interviewing key informants to identify where adoption is most likely to be taking place. These surveys then go on to assess, say, regions where chickpea adoption studies might be worthwhile (Tripp, 2011a). This is a relatively inexpensive approach that can provide useful general information, but again may not give an accurate measure of the extent of adoption. Possible reasons for this are that expert knowledge is limited (e.g. the experts are only familiar with one region where the crop is grown) or their knowledge is systematically biased (e.g. researchers or extensionists may report high adoption of improved varieties because it reflects better on their own performance).

In general, it is to be expected (although it is not always certain) that more accurate estimates of varietal adoption can be obtained by gathering data directly from farmers; typically through a statistically representative survey. However, it is expensive to conduct surveys that interview individual farmers over widespread and often relatively inaccessible regions. Such surveys are reported to cost an average of US$100,000 (Walker *et al.*, 2014). Expert opinion is therefore an attractive method from the point of view of information costs.

In order to develop a cost-effective system for the routine collection of adoption data covering 20 crops across Sub-Saharan Africa, the DIIVA study attempted to validate estimates from expert panels with the results of nationally representative surveys on the adoption of improved varieties (Walker *et al.*, 2014). This study found a statistically significant difference between survey measurements of adoption and expert estimates, with surveys generating estimates that were, on average, seven-eighths of expert estimates. While expert data do tend to yield higher adoption estimates than surveys, when carefully done, expert opinion can generate results that are fairly consistent with survey data – although that is not always the case. Despite higher information costs, surveys of farmers are frequently preferred to relying on expert opinion because they are believed to be less subject to measurement error and consequently more credible. However, it is entirely plausible that expert opinion could be more accurate in cases where farmers themselves may not be very reliable sources of information about the varieties they are growing.

Use of focus groups at the community level is an approach that should be less costly than surveys of individual farmers. Analysis of the results of focus groups, compared with surveys or experts, is forthcoming (Walker *et al.*, 2014). However, farmer surveys, aside from their higher costs, are not without problems. The representativeness of surveys can be a troubling issue (Tripp, 2011a). Studies of adoption are in practice often conducted only in areas that have been subject to intense research efforts and are rarely undertaken without some expectation – typically based on expert opinion – that adoption has taken place. In a sense, it is logical to invest in conducting an adoption survey only when and where there is good reason to think there has been some adoption. However, the sampling frame must be representative of the population of interest, so care must be taken not to extrapolate the findings of such studies more broadly by, for example, assuming that survey statistics from a project area also apply to adoption at national level. Even where studies are careful not to extrapolate results to wider populations (Mazid *et al.*, 2009), poor sample design can mean that surveys are not always representative of farmers in general. These are problems that careful survey design can address. The methodologies involved are well understood but lie outside the scope of this paper.

The appropriate definition and identification of 'improved' or 'modern' varieties are also issues in surveys as well as with expert panels (Tripp, 2011a; Mine, 2012; Walker *et al.*, 2014). Definitions of improved varieties are inconsistent across adoption studies. In some cases selections from landraces or germplasm bank accessions are considered improved, but in other studies they are not. Sometimes decades' old varieties are considered modern as long as they are the products of formal research, such as chickpea in India (Bantilan *et al.*, 2014) or groundnut in Africa (Ndjeunga *et al.*, 2012). But, in other cases, more recent cut-off dates are applied to qualify as improved varieties, for example, bean in Africa (Walker *et al.*, 2014). In a sense, such definitions are arbitrary and can be adapted to the needs at hand, but inconsistencies in definitions can impede comparisons across countries, regions or crops.

Field identification of improved varieties can also be challenging in surveys (Tripp, 2011a; Tripp, 2011b). Several factors contribute to this difficulty. Farmers may use a wide array of names for the same variety; others may plant a mixture of a number of distinct genotypes without distinguishing between them. It can be especially difficult to discriminate among varieties when they differ by subtle traits, like improved nutritional content or resistance to pests, and this may become an increasing problem as new genes are incorporated into desirable backgrounds.

A study of pigeonpea in Tanzania attempted to overcome this varietal identification problem by developing a thorough identification protocol – a series of step-wise questions aimed at distinguishing between different varieties (Mine, 2012). While such careful methods to identify varieties may reduce the problem of varietal identification to some extent, they do not always eliminate this source of measurement error completely. In particular, pigeonpea experts were unable to generate consistent results using the identification protocol. Farmers had difficulty quantifying the maturation time of different varieties; planting dates varied according to altitude as well as variety; and descriptions of flower color needed greater precision (Mine, 2012). Of course, in many situations farmers are quite capable of distinguishing between improved types and landraces; especially when the improved varieties are relatively new and have easily observable physiological differences.

The seriousness of these methodological problems with surveys (e.g. research costs, representativeness of samples, definition of modern varieties, and field identification of modern varieties) depends on how critical precision is for operational purposes. Critical decisions may not depend upon whether adoption is precisely 30 percent or 45 percent. An approximate measurement from a representative sample may be enough to inform decision-makers whether the outcomes of investments in research programs are making enough of a difference, even if precise adoption levels are unknown.

After measuring adoption, estimating the effect of new technology on productivity becomes the next key question in impact assessments. It is not enough to know who is using the new varieties; it is also critical to find out how these new varieties affect productivity. This is often measured through yields (production per unit of land). Many studies use the impacts of improved varieties on yields to estimate the value of production due to the new varieties, either at individual farm level or aggregated across farms (e.g. Bantilan *et al.*, 2014; Asfaw *et al.*, 2010).

The use of experimental data, either from research stations or via farm trials, attempts to get a precise measurement of yield differences by controlling other factors. However, the very existence of a high level of control may render experimental data unrepresentative of varietal performance in real-life situations. More commonly, adoption studies use survey data to calculate differences in yields between 'adopters' and 'non-adopters', as a way of measuring the impact of new varieties. In some cases, regression analysis is used to estimate a varietal effect free of the influence of other variables.

Farmers' decisions to adopt, however, are not driven simply by yields but by profits (revenue minus costs). Estimating the profitability of new varieties takes into account both potential price differences among varieties as well as input differences (e.g. varying amounts of fertilizer, labor and seed costs). Consequently, many adoption studies include a profitability analysis, typically through partial budgeting (e.g. Bantilan *et al.*, 2014). Results from such analyses can be translated into unit cost reductions and used in partial equilibrium models to estimate the market effects of new varieties on producers and consumers.

However, a more fundamental methodological problem is that adopters will differ from non-adopters in both observed and unobserved variables (e.g. individual farmer's ability, soil quality). Consequently, using yield or profit differences between adopters and non-adopters results in biased estimates of what adopters would have experienced in the absence of adoption (de Janvry *et al.*, 2010). The extent of this bias depends on the importance of non-observable variables in the adoption decision and their correlation with other variables. Moreover, the population of adopters grows over time during the diffusion process, and the way adopters use the new varieties changes as they learn more about the new technology. Therefore, differences in profitability or yields between improved and 'traditional' or 'local' varieties are not constant but vary over time through the diffusion process (de Janvry *et al.*, 2010).

Propensity score matching (PSM) attempts to resolve the issue of selecting an appropriate control group by matching adopters and non-adopters on the basis of a propensity score derived from a first stage logit or probit model. This approach has been used to study groundnut adoption in Uganda (Kassie *et al.*, 2010). Nevertheless, to the degree that PSM first stage equations do not fully explain the adoption decision, unobserved variables remain an impediment to identifying an appropriate counterfactual non-adopting group (de Janvry *et al.*, 2010).

Perhaps the most straightforward way of dealing with this issue is by treating the village or community as the element of randomization rather than the individual. This approach typically requires the inclusion of many villages in the study and substantially increases research costs (de Janvry *et al.*, 2010). Whether taking this more costly approach to adoption studies in order to eliminate bias in the statistical estimates actually produces results that are substantially different remains to be seen. Meanwhile, as scarcity of resources already causes major projects to rely more heavily on expert opinion than farmer surveys, it is far from clear that randomization by village – which requires even greater resources than conventional farm surveys – will be adopted any time soon as the standard methodology.

4. Evidence of adoption of improved varieties

While some surveys have a sampling framework that is constructed carefully to be representative, others are complemented by expert opinion. A large number of these dual surveys provide considerable evidence to suggest that substantial adoption of improved varieties has occurred in some legume crops in some countries. This evidence is briefly reviewed here by crop, with a focus on recent studies.

4.1 Chickpea

With some three-quarters of the world's crop produced in South Asia, chickpea is the world's third most important grain legume crop (Akibode & Maredia, 2011). Chickpea production has undergone a massive transformation in India – the world's largest producer – and recent surveys provide evidence that improved varieties are being adopted across large swathes of the continent (Chand *et al.*, 2013; Bantilan *et al.*, 2014).

In northern India, chickpea was formerly a major winter rotation crop that followed monsoon rice. However, the widespread adoption of Green Revolution high-yielding dwarf varieties of wheat and other cash crops, such as oilseed rape, coupled with an expansion in irrigation, displaced the role of chickpea in the region substantially. In 1964/65 chickpea was sown on 5.14 million ha in northern India, but by 2010/11 this had fallen to 0.73 million ha (Bantilan *et al.*, 2014). Growth in chickpea production lagged behind growth in demand and India became a major importer of chickpea over this period (Rao *et al.*, 2010).

Researchers at ICRISAT worked with national partners to develop high-yielding, short season varieties that are resistant to fusarium wilt and root-rot disease. As successful CGIAR research in wheat displaced traditional legumes like chickpea in northern India, availability of shorter-season varieties led to a massive expansion of chickpea cultivation in southern India – a result that was not fully expected. From 1964/65 to 2010/11 the chickpea area of southern India increased from 2.1 million ha to 5.6 million ha. Simultaneously, yields rose dramatically, for example, increasing from 853 kg/ha in Andhra Pradesh in 1996–1998 to 1,317 kg/ha in 2008–2010.

Short duration is the outstanding trait of the new varieties that farmers cited in focus group interviews (FAO–ICRISAT). Compared to the alternative crops that chickpea is replacing, the improved varieties require less investment, less labor and fewer mechanical operations, and they are in high demand at market. Overall, they are a less risky option for farmers.

The introduction of short-duration chickpea varieties has led to a dramatic increase in the area sown to chickpea in southern India; consequently reducing the areas of alternative crops including sorghum, millet, sunflower, groundnut, cotton and tobacco. Chickpea now accounts for 67 percent of cropped land. As its area expands, tractors are replacing bullocks.

Several chickpea varieties bred by NARS and ICRISAT were released by the 1990s, and by 2000 adoption had taken off in most districts of Andhra Pradesh, according to a survey of 810 chickpea farmers (Bantilan *et al.*, 2014). Five of the six varieties reported to have been released in the 1990s had CGIAR input to their development. This survey is particularly useful because it developed a careful protocol for varietal identification and complemented its interviews with focus group discussions to gain a deeper understanding (Bantilan *et al.*, 2014). The survey found improved chickpea varieties on 98 percent of the area studied, along with a single improved variety (JG11) – a true short-duration cultivar – on 84 percent of the chickpea area.

Like Andhra Pradesh, the chickpea area in Madhya Pradesh has expanded rapidly since the mid-1990s. A recent survey of 1,000 farmers in three major chickpea-growing areas of the state found that virtually all of them were growing improved or imported chickpea varieties (Chand *et al.*, 2013). These findings for Andhra Pradesh and Madhya Pradesh are confirmed by similar results in a recent study that used expert elicitation methods (Charyulu *et al.*, 2013). It estimated adoption levels of improved chickpea varieties in Rajasthan (68 percent), Uttar Pradesh (65 percent) and Karnataka (48 percent).

However, in Madhya Pradesh 8 of the 10 varieties in use were products of the national/international breeding program; none had been released in the past decade (Chand *et al.*, 2013). Indeed, one of the most popular varieties, JG315, is a selection that was released in 1984. Another was introduced from Mexico in the early 1990s. Although these are clearly not traditional landraces, and the surveys documenting their adoption are recent, it might be more appropriate to label them earlier improved varieties, since they were released some 25–30 years ago.

While the area planted to chickpea in Sub-Saharan Africa is still growing, Africa accounts for less than 5 percent of global chickpea plantings (Rao *et al.*, 2010). Chickpea is concentrated in three countries in the Horn of Africa: Eritrea, Ethiopia and Sudan; with Ethiopia alone accounting for over 90 percent of the region's chickpea production.

The improved varieties in Ethiopia all have CGIAR content in their pedigrees and, based on expert opinion, are estimated to cover nearly 30,000 ha in the rainfed highlands, representing about 13 percent of the national chickpea area (Yigezu *et al.*, 2012: Table 10). Some insights into the performance of, and outcomes due to, the adoption of improved chickpea varieties are provided in a survey of 700 farmers in the chickpea-growing districts of the central highlands, which have been served by relevant development projects (Afsaw *et al.*, 2010). Because the survey was conducted in project districts, the 46 percent of area reported in improved chickpea varieties exceeds estimates of adoption at national level.

Chickpea in Sudan – cultivated in the irrigated lowlands – is notable for being the only crop in Sub-Saharan Africa where 100 percent of the crop area in a particular country is improved varieties, according to expert opinion (Walker *et al.*, 2014; Yigezu *et al.*, 2012). Of course, this is grown on a relatively small acreage, and thus pales in comparison with the chickpea area in India.

Another sample of 470 chickpea farmers in Syria includes those who have grown improved winter-sown chickpea varieties. This study does not provide a representative sample to measure adoption, but instead is designed to investigate the on-farm performance of the new technology. Despite this shortcoming in the sample, the study is strong on using statistical methods to assess the influences on adoption and the effects on productivity of the new technology (Mazid *et al.*, 2009).

4.2 Groundnut

Unlike other crops considered in this report that are food grain legumes, groundnut is principally an oilseed crop with animal feed as an important by-product. China contributes approximately 40 percent of global groundnut production; India supplies roughly 15 percent; while Africa produces about 25 percent (FAOSTAT, 2012 data). Groundnut is a former mainstay of many economies in West Africa (Ndjeunga *et al.*, 2008). Since CGIAR groundnut efforts have focused on Africa and South Asia, this paper concentrates on evidence of adoption from these regions.

As a commercial oilseed crop, groundnut received important research attention during colonial times, and in Africa many improved groundnut varieties were available in the 1970s or earlier – before any significant research effort in other food grain legumes (see Table 2). Varieties released prior to independence remain the most widely grown cultivars in countries like Nigeria and Mali. Recently, there has been an upsurge in the output of improved groundnut varieties in Africa, but these releases have been concentrated in the smaller producers in East Africa rather than in the major groundnut countries of West Africa (Walker *et al.*, 2014).

Data from expert opinion suggest that 1.8 million ha are sown to modern groundnut varieties in Sub-Saharan Africa, thereby covering some 29 percent of the total area. The reach of improved groundnut varieties is reduced, in part, by the fact that some countries (e.g. Burkina Faso and Senegal) report absolutely no adoption (Walker *et al.*, 2014). Moreover, in countries where adoption has occurred, nearly two-thirds of reported adoption arises from varieties released before 1990 (Ndjeunga *et al.*, 2013).

Nigeria is the largest groundnut producer in West Africa, accounting for two-fifths of African production and 10 percent of global production (Ndjeunga *et al.*, 2013).

A systematic approach was taken to draw an appropriately sized random sample of 2,739 groundnut farmers in the semi-arid Sahelian and Sudanian savannas of Nigeria (Ndjeunga *et al.*, 2013). A rigorous statistical approach was used to match adopters and non-adopters who have similar propensities to adopt, in order to control for differences between the two groups that can affect key relations, for example, the effects of new variety adoption on household income.

The household survey indicated that 31 percent of groundnut area is planted with improved varieties; notably less than the 51 percent adoption estimated by experts and 53 percent adoption elicited in community level group interviews (Ndjeunga *et al.*, 2013).

In an earlier survey conducted by Ndjeunga (2008) of farmers participating in groundnut projects across Nigeria, Mali and Niger, the rate of adoption of improved cultivars in and around the pilot sites was reported to be 32 percent of the area in Nigeria (similar to a later, more representative, sample reported in Ndjeunga *et al.*, 2013); 44 percent of the area in Mali; and 14 percent of the groundnut area in Niger. As these estimates derive from selected 'project sites' they undoubtedly represent an upper limit on adoption at the national level.

Improved varieties of groundnut have been released in India too, and earlier studies provide some evidence of adoption (Deb *et al.*, 2005; Joshi and Bantilan, 1998). However, in these studies adoption is highly variable among locations and appears to be concentrated in areas where groundnut projects are active, making generalizations for India difficult. A more recent study featuring the elicitation of expert opinion finds near universal adoption of improved varieties in Gujarat and Maharashtra; significant adoption in Tamil Nadu (56 percent) and Andhra Pradesh (40 percent); and a low level of adoption in Karnataka (9 percent) (Charyulu *et al.*, 2013). While these are generally positive findings, "in spite of a solid and improving performance in varietal output, recent groundnut releases have not been widely adopted by farmers" (Charyulu *et al.*, 2013). Similar to the results noted earlier for Africa, the most widely grown improved varieties in India were released 20–35 years ago.

Therefore, the critical issue for groundnut adoption research is to understand the reasons for the low levels of planting of the more recently released varieties. It is essential to the effectiveness of investment in groundnut research to better understand whether the recent weak adoption of improved varieties is due to flaws in the diffusion process or in varietal characteristics. Based on this understanding, remedies could then be implemented. The evidence is strong that farmers will adopt improved groundnut varieties, but for some reason this has not taken place in the last couple of decades.

4.3 Bean

Bean is the most important food grain legume in Latin America – its region of origin – as well as in the highlands of eastern and Southern Africa. Bean typically thrives in reasonably well-watered upland regions.

Bean research has long emphasized disease-resistance because, not only is the crop susceptible to many diseases, the new technology means that resource-poor farmers can benefit without having to invest in additional inputs. More recently, increased attention has been paid to breeding for higher nutrient content and adaptability to climate stresses. But these new materials are largely in development and have yet to be diffused on a wide scale.

Widespread adoption of improved bean varieties has taken place in Latin America since the 1980s, with the impacts documented thoroughly (Johnson *et al.*, 2003). But there has been little activity to monitor the adoption of bean varieties since the 1990s. Consequently, there are no additional recent studies to cite in this paper. However, one study found that recently developed bean varieties in Central America continue to show productivity gains compared to the first generation of varieties released in the 1980s and 1990s (Reyes *et al.*, 2012).

The impacts of earlier bean research in Latin America derive from varieties developed around the same time as the varieties of chickpea and groundnut discussed in previous sections. The only difference is that the studies of chickpea and groundnut adoption are more recent. But since the vintage of the chickpea, groundnut and Latin American bean varieties are similar, for comparative purposes the previously documented adoption of bean varieties is described here.

By 2002 the largest adoption of improved bean varieties had occurred in Brazil, where some 1.5 million ha were estimated to have been sown. The rate of adoption was highest in Argentina, where a national survey found that 82 percent of bean cropping area was under improved varieties, most of which was large-scale commercial production for export. Substantial adoption was also found throughout Central America, where resistance to bean golden mosaic virus was an important development. However, in the Andean countries overall adoption levels were modest, especially among farmers growing climbing bean in higher altitude zones (Johnson *et al.*, 2003).

Latin America has large homogenous bean production zones in parts of Brazil, the central highlands of Mexico and northeast Argentina where bean is an important commercial crop. Smaller production niches prevail elsewhere, including throughout Central America and the Andes, typically due to the heterogeneity of most upland environments as well as greater variability in low-input production systems.

Bean adoption continues to be studied with care in Africa, where, as in Latin America, there continues to be a strong flow of varietal releases. Across the continent, more improved varieties of bean have been released than any other legume, and only maize has exceeded bean in the number of releases since 1999. The strong research output for bean in Africa is mostly due to a highly effective regional research network, the Pan-Africa Bean Research Alliance (PABRA) (Buruchara *et al.*, 2011; Walker *et al.*, 2014).

In general, Africa has not seen the kind of 'mega-varieties' that cover millions of hectares of rice and wheat in Asia and chickpea in South India. This is because niche specificity is especially intense in bean due to the diversity of environments and cropping systems in which it is grown, as well as the associated preferences of particular grain types. Consequently, a large number of bean varieties is needed to achieve adoption over a wide range of different roles in diverse cropping systems. Therefore, improved bean varieties have been developed in a decentralized network of breeding programs that focus on priority sub-regional biotic and abiotic traits while screening for particular 'market classes' (i.e. clusters of bean types sought in regional and export markets) (Rubyogo *et al.*, 2010; Buruchara *et al.*, 2011).

The significant output of improved bean varieties has been complemented by a concerted effort in seed production and distribution, in which African NARS have been proactive both at the country level and in long-running regional research networks. Through the work of over 120 partner organizations, bean seed has been distributed to 3.8 million households (Rubyogo *et al.*, 2010; Buruchara *et al.*, 2011).

These efforts have led to an adoption level of improved bean varieties that is conservatively estimated to cover at least 0.7 million ha, or about one-quarter of the bean area in the region (Walker *et al.*, 2014; CGIAR, 2012). The area of improved bean varieties comes from carefully elicited expert opinion that was found to give similar results to previous survey findings (Walker *et al.*, 2014). The 0.7 million ha figure excludes Kenya, however – one of the largest bean producers in Africa – where it is known there has been significant adoption. Unlike other grain legume data reported under the DIIVA study, the adoption figure for bean also excludes selections from landraces, some of which were introduced from Latin America to Africa by CGIAR (Muthoni & Andrade, 2012). It is estimated that broadening the definition of modern varieties to be in line with other crops would increase the bean adoption level by 50 percent (Walker *et al.*, 2014); if true, this would imply that adoption has reached about 1 million hectares of bean in Africa.

The initial impact of improved bean came with climbing bean in Rwanda. By the early 1990s climbing bean had spread to 40 percent of farmers in Rwanda (Sperling & Muyaneza, 1995). Climbing bean has since spread from Rwanda to neighboring countries of Burundi, eastern Congo and the highlands of Kenya (Rameakers *et al.*, 2012).

Bush bean is more widely cultivated across Africa than climbing bean. As a result, there has been widespread adoption of improved varieties in several bush bean-growing countries: reaching 58 percent of area in Uganda and 55 percent in Malawi; although some of these areas are in varieties released before CGIAR activity in the region (Muthoni & Andrade, 2012). Likewise, there is considerable adoption of improved varieties in Tanzania (46 percent) and Ethiopia (44 percent) (Muthoni & Andrade, 2012).

The expert elicitation estimates from the DIIVA study appear to be higher than some estimates based on household survey results from other studies. For example, a survey of 180 farmers in Oromia – in the drought-prone northwest rift valley of Ethiopia, where bean is a commercial crop grown for export – found that 29 percent of farmers had adopted improved bean varieties and were growing them on over 60 percent of their area (Katungi *et al.*, 2011a). This doesn't necessarily contradict estimates from the DIIVA study as the latter is based purely on the percentage of area (versus the percentage of farmers adopting in household surveys) and was representative at the national level. Likewise, a 2011–2012 survey of 1,908 farmers in Uganda found 27 percent of them had adopted improved varieties of bean on 13 percent of their area, which again would seem to suggest some degree of overestimation in the DIIVA study (58 percent area adoption). In Uganda and Rwanda farmers who grew improved varieties on part of their bean land had more bean plots than non-adopters or full adopters, suggesting that partial adoption could be part of a diversification strategy by farmers to reduce risk (Larochelle *et al.*, 2013).

4.4 Cowpea

Cowpea covers the largest area of any grain legume in Africa and is especially important in West Africa. Although cowpea is grown in 18 countries, over three-quarters of African cowpea is produced in just two countries: Niger and Nigeria (Walker *et al.*, 2014). Most cowpea is grown intercropped with sorghum or maize.

Research on cowpea took off in the 1980s when more varieties of the crop were produced than any other grain legume in Africa. Output of cowpea varieties continued to increase through the 1990s. In the last decade, however, there has been a noticeable decline in the release of cowpea varieties, which fell to a level 50 percent below that of the 1990s. Informal variety releases – where improved materials from another country are taken up by farmers in countries that do not maintain a systematic release registry – is far more important for cowpea than other pulses, accounting for over 20 percent of recorded cowpea releases (Walker *et al.*, 2014).

Overall, fewer cowpea varieties have been released per area planted than any other legume, with cowpea ranking among the lowest of all crops in this indicator of output intensity.

Notwithstanding these difficulties, adoption of improved cowpea is estimated by expert opinion to exceed 3 million ha – a far greater area of adoption than for any other grain legume in Africa. Two-thirds of this adoption can be attributed to varieties developed in collaboration with CGIAR. And there is still potential for much greater adoption and impact as modern cowpea varieties are reported to cover just 27 percent of total area (Walker *et al.*, 2014).

4.5 Pigeonpea

Traditionally, pigeonpea has been a long season crop (150–280 days) that is inter-sown with other crops in semi-arid environments. Practically all pigeonpea is grown in developing countries, with about 75 percent of production coming from India and 10 percent from Africa (Rao *et al.*, 2010). Nevertheless, Africa has attracted all the recent attention with respect to adoption studies, so evidence from Africa is explored here before that from India.

Compared to most other food grain legumes, relatively few pigeonpea varieties have been released in Sub-Saharan Africa, and two-thirds of these releases have occurred within the last decade, perhaps making it still relatively early to be able to observe widespread adoption. Nevertheless across Kenya, Malawi and Tanzania, adoption of improved pigeonpea varieties is estimated by expert opinion to have reached a total 180,000 ha – roughly half the regional area planted to pigeonpea (Walker *et al.*, 2014). Here again, this appears to be slightly higher than some household survey-based estimates – although many of these were conducted much earlier.

A recent study in Tanzania – focused rather narrowly on the key issue of developing a protocol to identify pigeonpea varieties – interviewed 704 farmers in northern Tanzania and found that only 28 percent of sample fields were sown with improved varieties (Mine, 2012). A much earlier study that surveyed 240 farmers, principally in districts where pigeonpea research and development had been most active, similarly found 25–34 percent of farmers growing improved pigeonpea on 32 percent of area (Shiferaw *et al.*, 2005).

Pigeonpea production has been growing rapidly in Kenya, nearly tripling in the decade from the mid-1990s. This rapid growth was propelled, in part, by the export market to India and facilitated by technological intensification. A random sample conducted in 2005 of 240 farmers in two districts of Kenya found 55 percent were growing improved varieties on just over half of the pigeonpea area (Shiferaw *et al.*, 2007).

According to a random sample of 594 farmers surveyed in the major pigeonpea and groundnut growing districts of Malawi, only 24 percent reported having ever tried improved pigeonpea varieties. What is more, only 17 percent were still growing them even though improved varieties have been available for more than a decade (Simetowe *et al.*, 2010).

In India, evidence from over a decade ago indicated that significant changes had occurred in pigeonpea systems and varieties. In 1994, an estimated 57 percent of the area in western Maharashtra and 16 percent of the area of northern Karnataka – two of the largest pigeonpea growing states – were planted to improved varieties (Bantilan & Parthasarathy, 1999). Like the case of chickpea (see section 4.1), pigeonpea production has declined substantially in formerly important producing areas of semi-arid temperate northern India. Here, rotations of improved rice and wheat or rice and oilseed rape have displaced pulses, including pigeonpea. However, with the advent of improved shorter-season varieties, pigeonpea production has expanded in peninsular India as a cash crop in double-cropping systems (Rao *et al.*, 2010).

Based on data derived from recent expert opinion elicitations, improved cultivars of pigeonpea are estimated to be grown on 60 percent of the area across India. State-wide figures for adoption in 2010 are: Maharashtra, Andhra Pradesh and Tamil Nadu about 70 percent; Madhya Pradesh and Karnataka approximately 60 percent; and Uttar Pradesh 35 percent (Charyulu *et al.*, 2013: Table 14.7).

Cultivating shorter-duration varieties in a monoculture did not replace traditional pigeonpea varieties *per se*. Instead, it was a completely new crop that substituted more input-demanding rainy season crops, such as sugarcane or cotton, or less remunerative crops like sorghum or pearl millet. Besides requiring less inputs on marginal lands, short-duration pigeonpea permits post-rainy season crops like wheat to be grown (Bantilan & Parthasarathy, 1999).

4.6 Lentil

Lentil is an important food and cash crop in North Africa as well as in South and west Asia, where it thrives in arid environments, especially during the cool season. There is some evidence of adoption of improved lentil varieties in Ethiopia. In Bangladesh, where lentil is the most important legume in household diets and in production (Sartar *et al.* 2004), farm survey data indicate that improved lentil varieties have been adopted on 44 percent of lentil area (Aw-Hassan *et al.*, 2009).

In Ethiopia, as in Bangladesh, lentil is grown principally on residual moisture after the main season cereal crop. Here, lentil is also a significant export crop, with 28 percent of production going to market. Driven in part by increasing productivity, lentil output has increased by 15 percent annually over the period 1994–2008 (Rashid *et al.*, 2010).

A survey of 289 smallholder farmers conducted in four districts of Ethiopia found that 19 percent of them had adopted improved varieties, but on 24 percent of the lentil area in the surveyed districts (Aw-Hassan *et al.*, 2009). However, the national level adoption figure was estimated at only 3 percent (Aw-Hassan *et al.*, 2009; Rashid *et al.*, 2010). A more recent estimate by experts suggests that nationally 10 percent of the lentil area in Ethiopia is now sown to improved varieties.

While survey data and expert estimates are lacking, anecdotal evidence suggests there is significant adoption of improved lentil varieties in Nepal – currently the world's sixth leading producer (FAOSTAT, 2013). Here, lentil production is growing rapidly, displacing other crops to take advantage of an attractive export market to India (Dalton, 2011).

Overall, it appears that there are as yet unexploited opportunities for the adoption of improved lentil varieties in China, India, Iran, Syria and Turkey, all of which are more important lentil producers than Ethiopia or Bangladesh. In some of these countries modern varieties may already be used but, to date, no reliable evidence exists to substantiate this.

5. Constraints to adoption

Considerable expert opinion and household survey-based evidence exists that indicates the widespread adoption of improved grain legume varieties. However, the evidence almost always indicates that adoption is far from universal among legume farmers, even for varieties that have had a decade or more to diffuse.

Understanding the factors that constrain adoption is an important research issue. While surveys are certainly useful in measuring the extent of adoption, few studies provide compelling explanations of what limits adoption in a particular situation. This paper briefly reviews a few of the most widely considered constraints to adoption: characteristics of farmers that impede adoption, varietal traits that constrain adoption, and the availability of seed.

5.1 Farmers' characteristics and varietal suitability

Several econometric studies make thorough efforts to understand the determinants of varietal adoption (Mazid *et al*., 2009; Shiferaw *et al*., 2005; Shiferaw *et al*., 2010; Simetowe *et al*., 2010). These analyses almost always focus on the characteristics of the farmer: age, gender, wealth, education, capital, etc. As discussed in more detail below, whether improved varieties reach less wealthy or female farmers is an important issue in terms of meeting CGIAR poverty reduction objectives. However, analyses of some influences, such as age or education, may be more relevant in identifying early adopters than those factors that ultimately limit adoption. Furthermore, analyses of factors such as contact with extension agencies may only confirm the obvious. It is not clear whether the time, funding and effort invested in these analyses, with the exception of wealth or gender, are yielding useful insights for CGIAR.

Adoption can be partial where the characteristics of an improved variety make it of limited suitability in the farming system, or because some farmers lack a critical resource. For example, an improved variety may be of a class of maturity that does not fit within a particular rotation in the farm system, or it may require soil fertility or moisture levels that make it adaptable only to some fields on the farm. The availability of other resources, like stakes for climbing bean, may also constrain farmers to partial adoption. Since legumes typically fill particular and diverse niches in complex farm systems, even a well-adapted variety may only attain partial adoption.

Likewise, price differences among the various legume grain types, for example, between *desi* and *kabuli* varieties of chickpea (Asfaw *et al*., 2010), can lead to farmers growing a diversity of varieties – some to meet particular market requirements, others more for food security. This could be a strategy to manage risks both in production and at market. For example, varieties differ in terms of their tolerance to disease, pests and climatic stress. Therefore, partial adoption of improved varieties may be a reflection of a sensible risk management strategy rather than an indication of defects in the technology.

Conceptually, the expected returns from adoption should be an important factor in explaining the extent of adoption, with superior performance leading to greater adoption. However, expected returns depend not only on the degree of superiority of the new varieties, but also the role of the crop in the farm system. Where a crop plays a modest role – as is frequently the case with legumes – the incentive to adopt even a highly superior variety may be decreased. This means that even when the aggregate benefits of the new varieties across thousands of farms may be substantial, the benefits per farm are not always large.

A few of the adoption surveys reviewed in this paper attempt to assess the advantages and disadvantages of improved varieties, and this is certainly an important issue to enhance research efficiency (e.g. Bantilan *et al*., 2014; Asfaw *et al*., 2010). Nonetheless, these efforts often do not seem to generate especially insightful results. It probably makes more sense to address this issue through more in-depth methods than an adoption survey and at an earlier stage in the technology development process.

Groundnut is an important exception, where a deeper understanding of the factors impeding adoption of improved varieties is a critical issue. As discussed earlier, available evidence indicates that there has been widespread adoption of improved varieties that were released 25–35 years ago, but adoption of more recently released varieties remains quite limited (e.g. Charyulu *et al.*, 2013). It is vital to understand better the degree to which this limited success is due to varietal characteristics or weaknesses in the diffusion process.

5.2 Seed as a constraint to adoption

A lack of availability of seed is by far the most commonly cited reason for low adoption or dis-adoption of modern legume varieties in studies of their diffusion. It is indisputable that access to seed is essential to initial adoption; and that more widespread availability of improved seed will accelerate adoption, while scarce or unavailable seed will halt or even reverse the adoption process. Although farmers prefer to save their own seed, when they are forced by circumstance to sell or consume their seed stocks, availability of the seed of the improved varieties becomes an issue. Consequently, there have been many efforts to enhance seed systems to promote adoption, resulting in a rich literature on the topic (Assefa *et al.*, 2006; Biemond *et al.*, 2012; Kankwamba *et al.*, 2012; Katungi *et al.*, 2011b; Ntare *et al.*, 2008; Rubyogo *et al.*, 2007; Saxena, 2006; Singh *et al.*, 2013a; Sperling & McGuire, 2010).

Across all of these studies, the general consensus is that centralized public-sector seed systems are inadequate, while commercial seed companies have little interest in legume seed because potential sales are usually small. This is often because of varietal diversity; farmers' ability to save the seed of any self-fertilizing crop; and the small amounts of seed that individual farmers sow. This is supported by widespread evidence from Africa that few farmers seek to buy commercial legume seed.

Despite the differences in their approaches, efforts to enhance legume seed systems tend to share a few principles. Among the studies cited earlier, there is general agreement that good-quality seed can be produced locally, outside cumbersome systems of seed certification. A second widespread approach is to rely on decentralized seed distribution; be it through small-scale farmer seed enterprises, local traders or community organizations. While some seed is available at a subsidized rate or even free of charge, it appears both more sustainable and acceptable to farmers that seed is sold at real cost. The distribution of small packets of branded seed is an effective way of reaching poor farmers (Sperling & McGuire, 2010).

Increasing the availability of seed is especially important to prevent dis-adoption among the most resource-poor farmers, who are often under pressure to use the seed for food security or to sell it to meet urgent cash needs. The most resource-poor farmers can find it difficult to maintain their seed stocks even of highly desired varieties, so the local availability of improved seed at planting time can be crucial to sustaining the use of modern varieties among the most vulnerable, poor farmers.

5.3 Summary

The characteristics of farmers, like education, age or resources, have especially important effects on the earliness of adoption during the process of diffusion. However, these attributes are often less important in differentiating between adopters and non-adopters once peak levels of adoption are reached. As this is already a much-studied topic, it is not clear whether further research would add to these findings.

Varietal characteristics that impede adoption are an extremely important constraint, depending on the particular crop and its growing conditions. Research systems need to have an effective feedback mechanism on early varietal performance, otherwise it is highly inefficient to learn of such issues at the adoption study stage. Approaches such as participatory research which takes place as a new variety is being developed can be much more effective at an earlier stage (see Ashby, 2009, for a review of the evidence).

Ample evidence exists on the importance of seed systems in adoption, suggesting that further research on this topic within adoption studies is unlikely to add much. The emphasis now should be on implementing best practices for grain legume seed systems. When it comes to the interface between development and research, this is an important challenge. Since this is more an issue of operational effectiveness than impact assessment, the role of SPIA in sponsoring such work is unclear – it is perhaps a matter that should be taken up by the CGIAR Research Program (CRP) on Grain Legumes.

6. Productivity gains

Unsurprisingly, many adoption studies report yield gains from the use of new varieties compared to traditional varieties. Naturally, productivity gains vary among crops and farming systems, making estimates of 'average' yield gain only useful in very general terms. Nonetheless, reported yield gains from adopting improved varieties typically fall within the 25–60 percent range. For example, a survey of 529 farmers in six districts of Uganda showed that the typical yield of local bush bean varieties is about 600 kg/ha compared to 960 kg/ha for the improved varieties (Kalyebara, 2005). And a more recent study of bean farmers finds that improved varieties led to a 53 percent increase in yields in Rwanda and a 60 percent increase in Uganda (Larochelle *et al.*, 2013).

While chickpea yields in Andhra Pradesh are highly variable both across districts and between years due to differences in rainfall, under normal conditions improved short-season chickpea varieties typically have yields around 640 kg/ha compared to 350 kg/ha for some of the traditional varieties (Bantilan *et al.*, 2014). Although the yields of improved chickpea varieties in Ethiopia appear to be more variable than yields of local varieties, the unweighted average of yields across improved varieties in three districts is 2,634 kg/ha – some 490 kg/ha or 23 percent higher than the average yield of local varieties (calculated from Asfaw *et al.*, 2010: Table 9.8).

In Uganda average yields of improved groundnut varieties were 888 kg/ha, compared to 663 kg/ha for local varieties (Shiferaw *et al.*, 2010). In Bangladesh yield gains of the improved lentil varieties averaged 61 percent – from 651 kg/ha with local varieties to 1052 kg/ha with improved varieties (Aw-Hassan *et al.*, 2009).

In Tanzania, yields of the improved and local pigeonpea varieties are reported to be similar in the absence of disease, indicating that yield differences depend on the incidence and intensity of disease. On average, productivity gains from the new varieties are calculated to vary by 15–38 percent, although survey results found an average of 425 kg/ha for local varieties and 709 kg/ha for improved varieties (Shiferaw *et al.*, 2005).

Some studies use multivariate analysis to estimate yield differences, which holds other factors constant. A stochastic frontier model analysis of data from 280 bean farmers in Uganda found a statistically significant effect of the use of improved certified seed on bean yields (Sibiko *et al.*, 2013). Using different econometric techniques to estimate the impact of improved varieties on yields of groundnut in Nigeria, Ndjeunja *et al.* (2013) discovered that the new varieties increase yields by 155–202 kg/ha. A stochastic dominance analysis was used to investigate the effects of adoption on the entire distribution of outcomes, finding that the risks of low yields declined with adoption of improved varieties (Ndjeuna *et al.*, 2013). Statistically controlling for factors other than variety, it was found that groundnut adoption in Uganda results in growth in income per hectare of US$169–198, depending on the estimation algorithm. This was calculated to lead to total benefits of US$19 million (Kassie *et al.*, 2010).

Methodologically, it is difficult but feasible to use farm survey panel data to gauge whether there are statistically significant yield differences that would provide more compelling evidence on the yield impacts of modern varieties than is generally available. More recently, newer approaches to estimating yield gains from adoption have been proposed (de Janvry *et al.*, 2010), and there has been criticism that the adoption literature in general – not just studies of legumes – has failed to satisfactorily measure productivity changes (Loevinsohn *et al.*, 2013). Nevertheless, there are still major opportunities to use at least relatively simple approaches, provided appropriate assumptions and relevant qualifiers are laid out in a transparent fashion.

7. System changes

In some cases, the adoption of an improved variety involves more than the mere substitution of a modern variety for a traditional or local one. Instead, it leads to more complex changes to the entire farm system. Examples of such fundamental system changes include: the introduction of short-season chickpea varieties that replaced other crops and led to new crop rotations in southern India; the introduction of climbing bean in the eastern African highlands that requires completely different management to traditional bush bean; and winter-sown chickpea in the Levant region of the eastern Mediterranean. These three changes in system are discussed briefly below.

The Great Lakes region of Rwanda, Burundi and eastern Democratic Republic of Congo has the highest per-capita consumption of beans in the world (FAOSTAT, 2013). Here, population pressure is high and farms are small. In these conditions, climbing bean is an especially attractive technology because it out-yields bush bean, which was traditionally the only type of bean grown in this region except at high altitudes. Aware of the need to maximize bean yields to meet the food consumption requirements of small-sized farms, at the same time as realizing the potential of climbing bean, CGIAR researchers introduced the climbing bean to Rwanda from Latin America for testing by the NARS. It was quickly found that some climbing bean from Mexican landraces were especially well adapted to the mid-altitude growing zones of Rwanda.

The introduction of climbing bean is not merely the substitution of one bean variety for another, but the adoption of an entirely new production system. Climbing bean is more labor intensive than bush bean due to the need for physical support for the plants, more intensive weeding and land preparation, and a prolonged period of harvest. Climbing bean grown with stakes require over 50 percent more labor than bush bean, and have total costs about 40 percent higher (Reckling, 2011). Where maize is a common crop, for example, in western Kenya, climbing bean can use the maize stalks for support in inter-cropping or relay cropping systems (Gichangi *et al.*, 2012). In Rwanda and Burundi, where maize is not a common crop, climbing bean is typically staked. Other system changes needed for climbing bean include a longer growing season, higher soil fertility, and enhanced potential for biological nitrogen fixation.

As discussed in section 4, chickpea in southern India is another example of major systems change (Bantilan *et al.*, 2014). The introduction of short-duration chickpea varieties has led to a five-fold increase in the area sown to this crop; consequently reducing the areas of alternative crops including sorghum, millet, sunflower, groundnut, cotton and tobacco. Chickpea now accounts for 67 percent of cropped land. As the area continues to expand, tractors are replacing bullocks. Chickpea is grown in the post-rainy season (*rabi*) on residual moisture and often faces terminal drought-stress at the pod formation stage. Typically, chickpea is sown in vertisols, usually after a fallow period (Bantilan *et al.*, 2014).

Short duration is the outstanding trait of the new varieties that farmers cited in focus group interviews. Compared to the alternative crops that chickpea is replacing, the improved varieties require less investment, less labor, fewer mechanical operations and are in a high demand at market. Overall, they are a less risky option for farmers. As a result, chickpea has become a major commercial crop instead of a traditional subsistence crop. As the area planted has expanded, there has been an increase in land rentals, wage rates and mechanization.

In parts of Madhya Pradesh, growing long-duration cotton as the main crop in the rainy season formerly did not allow chickpea cultivation in the dry season (Chand *et al.*, 2013). However, the introduction of soybean – today by far the most important rainy season (*kharif*) crop – has permitted double cropping. Consequently, chickpea is now the most important post-monsoon season (*rabi*) crop, with an area four times greater than wheat and virtually all of it planted to improved varieties.

In some agroclimatic zones, around 85 percent of chickpea is grown with irrigation, mostly tube wells, while in other zones most of the chickpea area is rainfed. In contrast to Andhra Pradesh, the prevalence of irrigation in Madhya Pradesh may reduce the attractiveness of the short-duration varieties, which are not widely grown.

A good example of a major system change comes from chickpea in Syria, where improved cold-tolerant and ascochyta-disease-resistant varieties are designed to shift the planting of chickpea to the time of the main winter rains. This is in contrast to the previous method of planting on residual moisture in the spring (Mazid *et al.*, 2009). As a completely new cropping system, it involves a major change in crop rotations, not just a change in chickpea variety. With regard to the winter crop, the study finds improved productivity and profitability as well as the more efficient use of water, in addition to an increased demand for female labor. However, it neglects to compare the profitability or productivity of both farm systems, including other crops in the rotation; for example, wheat, which is economically more important. Given the civil war that has been ongoing since 2011, the immediate prospects of promoting or assessing the adoption of this new system are low in Syria, but could perhaps be taken up elsewhere in future.

These three examples illustrate that, from a methodological perspective, measuring the productivity gains of improved varieties is more complicated than simply calculating yield differences between varieties. Specifying the counterfactual requires more of a systems approach than a single crop enterprise analysis. In future, quantifying system changes as part of a whole systems approach could lead to more meaningful and effective studies of the impact of new legume varieties.

This is an exciting opportunity that may offer exceptional benefits, and it is certainly more complex in its implications for outcomes. Legumes are often opportunistic in the varied niches they occupy in farming system rotations or intercrops. These examples demonstrate that new germplasm can create completely novel outcomes beyond improving the productivity of a crop in its traditional system or ecoregion.

8. Reducing rural poverty

Reducing rural poverty is a key SLO for CGIAR. Improved legume varieties that increase productivity, incomes and employment can presumably have impacts on reducing poverty, but the effects of crop varieties on poverty are mediated by complex socioeconomic processes that are not always easy to trace. Considerable effort is needed to sort through the transmission mechanisms to measure the impact of new varieties on poverty.

These impacts can be examined through a series of questions: Do resource-poor farmers adopt the new varieties? Do improved varieties perform well in the working conditions of resource-poor farmers? How much are the incomes of resource-poor farmers increased by new varieties? These questions are also addressed in this report.

Although low-income consumers may benefit from new technologies that increase food supplies and thereby lower prices, adoption studies do not address this issue. Instead, they can provide information on poverty reduction benefits that accrue to producers. While not all studies look explicitly at the relationship between adoption and poverty (e.g. Asfaw, 2010; Bantilan *et al.*, 2014), a common and straightforward approach to probing these issues within adoption surveys is to appraise whether adoption is biased in favor of better-off farmers. Benefits accruing to small producers contribute to CGIAR poverty reduction efforts, so there is good reason to be concerned about whether smallholder farmers are included among the beneficiaries of new varieties. In Ethiopia, submarginal bean farmers (with landholdings of less than 1 ha) were found to be less likely to adopt improved varieties than smallholder farmers (with landholdings of more than 1 ha) (Katungi *et al.*, 2011a). In Uganda, non-adopters are reported to be significantly less well off than adopters of climbing bean (Larochelle *et al.*, 2013).

However, the findings in this regard are inconsistent. Some studies observe that poor farmers have as high or higher adoption rates as wealthier farmers, while in other cases adoption is skewed towards wealthier farmers (Ndjeunga *et al.*, 2008; Kayungi *et al.*, 2011a; Larochelle *et al.*, 2013; Simetowe *et al.*, 2010). But in many low-income communities, even the better-off farmers – who often cultivate no more than half a hectare per capita – are themselves poor by almost any standard. In these instances, findings of technology bias in favor of the wealthy may not actually be very meaningful.

A few studies go further to distinguish between the yield performance of improved varieties on small versus larger farms. Regressions run by different income quartiles suggested that, out of a group of surveyed groundnut growers in Nigeria, the wealthier 50 percent reaped a higher yield gain from adoption than the poorer 50 percent (Ndjeunga *et al.*, 2013).

In an earlier study of groundnut in Nigeria, adopters tended to have large landholdings, more capital and greater access to modern technology (Ndjeunga *et al.*, 2008). Moreover, across the country wealthier households received substantially more benefits per ha from improved groundnut varieties – perhaps because they used more fertilizer. Meanwhile in Niger there were no differences in benefits per ha between wealthier and poorer households. And among groundnut farmers in Malawi, larger farms were significantly more likely to adopt improved varieties (Simetowe *et al.*, 2010).

Again, these findings are not consistent. The relationship between varieties and poverty is not simple or direct, but is mediated by a number of context-specific factors including socioeconomic structures. Furthermore, legumes may have different roles, occupying differing proportions of cultivated land on poor versus better-off farms. Consequently, they not only have different absolute effects on farm income (assuming adoption and performance are constant) but also varying effects on farm income.

In Rwanda, for example, it is estimated that net annual increases in income from growing improved bean varieties is US$73 per household – an increase of about 2 percent per average family income. This rather modest figure is largely due to the very small areas planted to bean – 0.2 ha per household. The incidence of poverty is calculated to fall 0.4 percent due to the improved bean varieties, while poverty depth and severity are estimated to decrease by 0.3 percent and 0.2 percent, respectively. These figures would all roughly double if the impact of improved varieties released before 1998 was also included.

There is a more noticeable immediate change in food insecurity in Rwanda, which declines from 15 percent of households among non-adopters to 8 percent among adopters (Larochelle *et al.*, 2013).

In Uganda – where the average area in bean is 0.32 ha per household – net annual family income rises by US$63 through the adoption of improved bean varieties. Food security increases from 38 percent among non-adopting households to 45 percent among adopters of improved bean varieties (Larochelle *et al.*, 2013).

In neighboring Rwanda, resource-poor farmers – who make up about two-thirds of the rural population and typically own 0.5 ha or less of land per household – obtain average climbing bean yields of 1.18 tons/ha. The better-off third of farmers who have roughly 0.75 ha per household and more livestock, achieve higher yields at 2.27 tons/ha. These yield differences are largely due to the constraints of poorer farmers in obtaining enough stakes with which to support the bean, which leads to lower plant population densities (Reckling, 2011). The yield difference might also be due, in part, to the tendency of poorer, more food insecure farmers to consume large amounts of immature pods. Poorer farmers have a higher share of their land in bean, while better-off farmers cultivate, on average, a greater area of bean (Reckling, 2011).

It was found that groundnut technology in Uganda had a significant and measurable effect on reducing the depth of poverty. Despite not lifting a large number of households over the poverty line, it did manage to narrow the gap above and below the line (Kassie *et al.*, 2010). This finding probably reflects the fact that, as is often the case with legumes, groundnut does not provide a large share of total household income in Uganda. Therefore, even though benefits to the poor may be substantial when aggregated across households, the benefits to individual households may not represent large increases in income.

Grain legumes can have a catalytic role in increasing the income of poor famers. Production of pigeonpea in northern Tanzania (Shiferaw, 2005), along with bean in parts of Ethiopia (Assefa *et al.*, 2006), have increased the dynamism of rural economies by providing new opportunities to earn a greater income. Nonetheless, commercialization alone does not eradicate poverty, which remains high even in, for example, parts of West Africa where groundnut has long been a cash crop (Ndjeunga *et al.*, 2008).

The poorest of the rural poor in many regions typically depend as much if not more on selling their labor than on the productivity of their tiny landholdings, if they have any at all. Consequently, the impact of new varieties on the demand for labor is a critical issue for the poorest of the poor. Although some studies of the impact of new varieties note in passing that there is a greater demand for labor in harvest or sometimes weeding (Bantilan & Parthasarathy, 1999; Mazid *et al.*, 2009), overall this issue has been neglected in adoption analyses to date.

As mentioned previously, climbing bean is more labor intensive; and, in fact, in central Kenya a minority of farmers cite this as a disadvantage (Ramaekers *et al.*, 2013). In contrast, the ease of mechanization is reported to be an advantage for the new chickpea varieties in southern India, but the effects on labor requirements or wages are not explored in any detail (Bantilan *et al.*, 2014). The impacts of improved varieties on poverty cannot be adequately understood by looking at yields only; more attention needs to be given to labor market effects if CGIAR seriously intends to address the plight of the poorest of the poor.

In summary, the adoption and performance of new varieties among resource-poor farmers is variable, depending on the particular circumstances involved. Sometimes the levels of adoption and results are just as good among poor farmers as wealthier farmers, and with as good results, in other cases not. Where grain legumes are a secondary crop in the farm system, contributing a modest share of total household income, the effects of adoption on poverty are also likely to be modest. Employment is a critical issue for the poorest of the poor, but this issue is almost completely overlooked in previous adoption studies.

9. Food security and nutrition

Improving food security as well as nutrition and health are two more CGIAR SLOs. Evidence of the effects of new legume varieties on these outcomes is nonetheless particularly scarce. One rare result comes from a recent study which found that improved bean varieties in Uganda had a much greater impact on food security than they did on poverty (Larochelle *et al.*, 2013).

Although it seems logical that improved crop production should lead to improved food security and nutrition, there is clearly a knowledge gap with respect to the impacts of new varieties on these objectives. To some extent, remedying this gap involves new and potentially expensive data collection as well as requiring a new skillset within CGIAR. Taking these SLOs seriously means paying greater attention to their all-important outcomes. While it is unlikely that this would become a routine dimension of every future adoption study, a couple of well-targeted case studies would seem to be called for.

10. Natural resources

More sustainable management of natural resources is the fourth CGIAR SLO. Legumes have a unique role in sustaining soil fertility through symbiotic biological nitrogen fixation. There is extensive experimental evidence showing that the presence of grain legumes in the farm system significantly increases the yields of the subsequent crop in the rotation (Chauhan *et al.*, 2012; Kamanga *et al.*, 2010; Jeranyama *et al.*, 2007; Lunze *et al.*, 2011; Lunze & Ngongo, 2012; Odhiambo *et al.*, 2011; Thierfelder *et al.*, 2012).

While there is no doubt that grain legumes can improve overall system productivity, whether the introduction of new varieties enhances that effect is less clear. Improved varieties might have a soil fertility effect through the production of increased biomass, if the residue is incorporated in the soil. However, where an improved grain legume variety replaces a traditional variety, it is less clear that nitrogen fixation would be enhanced, especially when the new varieties have not been selected for their nitrogen fixation capacity, which has generally been the case to date.

In contrast, where the introduction of improved varieties leads to more fundamental changes in the farm system, there could be greater nitrogen fixation and a resulting increase in the productivity of subsequent crops. This is likely to be the case in southern India where short-season chickpea has replaced crops like sorghum; or in eastern and Central Africa where climbing bean, with a higher natural nitrogen fixation capacity, has been introduced as a monocrop. These could potentially be attractive cases to assess whether improved legume varieties have had an impact on sustaining soil fertility.

To illustrate the complexity of these interrelationships, in Rwanda climbing bean fixes nitrogen at an average rate of 93 kg/ha. Despite this, resource-poor farmers in the country, who fed all crop residues to livestock, had an average negative N-budget of −43kg/ha, while better-off farmers who retained some crop residues on their fields ended up with an N-budget of −3 kg/ha (Reckling, 2011).

While the sustainability of soil fertility is especially relevant with legumes, other resource management issues may also deserve attention. Water resources, for example, could be an important issue in south India where some chickpea production is at least partially dependent on tube well irrigation. At the same time, climate-smart agriculture is a solution that is beginning to receive more attention (see, e.g. Singh *et al.*, 2013b).

11. Gender-related impacts

Improving gender equity is a priority theme for CGIAR and cuts across the four SLOs. Evidence of the impact of improved legume varieties from a gender perspective is fragmentary. However, it suggests that the relationship between gender and adoption decisions or employment is highly variable, depending on the roles of women in agriculture, which are essentially a matter of social structure and culture.

In particular, women may be more likely to benefit from new varieties when they are the head of household and, as a result, tend to manage both farm decisions and income. The frequency of female-headed households, though, ranges widely from practically zero to the majority of households. For example, less than 1 percent of groundnut-growing households are female-headed in Nigeria, but in Mali the figure is 45.5 percent and Niger 7.6 percent (Ndjeunga *et al.*, 2008). In Kenya, 65 percent of climbing bean growers are reported to be female, as are 80 percent of bush bean growers (Ramaekers *et al.*, 2013).

Among pigeonpea growers in Kenya, female-headed households comprised 24 percent of the surveyed population, apparently due more to separation of the couple and male mortality than to male migration for work (Simtowe *et al.*, 2010). These female-headed households have a higher dependency ratio than male-headed households (1.7 versus 1.2) and the incidence of poverty is 77 percent among female-headed households compared to 70 percent among male-headed households.

In Ethiopia, women head 7 percent of surveyed chickpea-growing households, and female-headed households have an average total income equal to that of male-headed households (Afsaw *et al.*, 2010). Most farmers managing climbing bean (65 percent) in the central highlands of Kenya are female (Ramaekers *et al.*, 2013). In Rwanda, 24 percent of bean-growing households are female-headed, while in Uganda the figure is 20 percent (Larochelle *et al.*, 2013).

Even where females head households and make decisions for the farm, they may face gender-related constraints that impede their adoption of improved varieties. This makes the measurement of gender-based differences in adoption an important issue. However, as in the case of the proportion of female-headed households, whether there are gender differences in adoption is itself variable.

Some studies report no differences in adoption by gender, for example, among bean growers in Rwanda and Uganda (Larochelle *et al.*, 2013). Among groundnut farmers in Malawi, female-headed households comprise 24.5 percent of non-adopters and 22.4 percent of adopters. Probit analysis shows no significant difference by gender in adoption among groundnut growers in Malawi (Simetowe *et al.*, 2010). In Mali there are more females among adopters (48.9 percent) than among non-adopters (39.3 percent) (Ndjeunga *et al.*, 2008).

On the other hand, the opposite occurs in Niger where 9.5 percent of non-adopters are female and 3.4 percent of adopters are female (Ndjeunga *et al.*, 2008). Likewise, in Tanzania males are significantly more likely to adopt pigeonpea varieties (Shiferaw *et al.*, 2005).

As these examples show, there is no constant relationship between gender and adoption, which depends on the prevailing social situation and presumably on specific varietal characteristics too. Still, gender differences in varietal preferences may be crucial in some contexts and well worth study; although it is more effective to do such appraisals early in the technology development process rather than during or after the diffusion phase.

Income streams from improved varieties for women may also be generated or depressed through the labor market, as well as for farm operators. Women may have significant agricultural roles even where few are heads of household or farm decision-makers.

For example, among chickpea growers in India almost no women are heads of households, but their labor force participation is about the same as males: 59 percent of females work in agriculture compared to 61 percent of males, while 26 percent of females are employed in non-agricultural occupations, essentially the same as males at 28 percent (Bantilan *et al.*, 2014). Traditionally, females have played an important role in sowing, weeding and harvesting chickpea in Andhra Pradesh, but this role is declining with mechanization. However, the study did not explore in any depth how the spread of new chickpea varieties affects women's welfare or opportunities. Since there seems to be a relationship between the new chickpea varieties and mechanization, there could be gender consequences of the new varieties worthy of exploration in this case.

In Ethiopia, women generally provide labor for chickpea production, especially in weeding, harvesting and post-harvest handling. However, they typically have less control than men over decision-making or ownership of the means of production. Women may have a role in marketing decisions, but little is known about such intra-household decisions. Women do not always evaluate varieties by the same criteria as men, but there is not a consistently discernable difference in preferences for particular traits like earliness in crop maturity or grain types (Afsaw *et al.*, 2010).

It has been suggested that winter-sown chickpea in Syria might increase the demand for female labor (Mazid *et al.*, 2009), while it has been reported that improved pigeonpea varieties in south India also increase the demand for female labor (Bantilan & Joshi, 1996), but in neither case is there solid evidence of this.

There may be varietal differences in post-harvest processing that have particular consequences for women who typically are principally responsible for these tasks, but no studies appear to have examined this either. Nor do any studies directly assess the welfare impact on women of improved varieties. Likewise, family income increases due to improved varieties may be subject to intra-household decision-making that affects gender relations, but again no studies examine this issue. However, intra-household gender relations are likely to be a more important factor in the gender-differentiated distribution of benefits from improved varieties than the characteristics of the varieties themselves.

The adoption studies noted in this section are taking some steps to address gender-differentiated outcomes, but the opportunity to go into greater depth on these issues remains to be fully exploited. Rather than expect a major effort to explore these issues in all adoption studies, it probably makes more sense to have a minimum set of gender-related data for adoption studies and select a few cases for in-depth study, where initial appraisals suggest that this could be a particularly important consideration.

12. Conclusions and directions for future research

Despite the various methodological issues discussed in this report, a large body of survey research indicates there has been substantial adoption of improved legume varieties in different countries and regions of the world. Adoption has been extensive in some crops and countries, confirming that legume research can be highly effective in generating outputs. Nonetheless, there are still opportunities to achieve greater levels of adoption. Research to improve grain legume varieties has been demonstrably effective and has scope to achieve further impact. Further studies of the development impacts of adoption also deserve greater attention.

This concluding section addresses three topics, including: a summary of the major findings of adoption studies to date; some opportunities for further adoption surveys, crop by crop; and priorities for future research in terms of methodological corrections and CGIAR strategic objectives.

12.1 Summarizing evidence of adoption

Chickpea: Recent survey evidence finds that there has been widespread adoption of improved short-duration chickpea varieties in the southern Indian state of Andhra Pradesh, extensive adoption of earlier released medium-duration chickpea varieties in the central Indian state of Madhya Pradesh, as well as small pockets of adoption of improved chickpea varieties in the Horn of Africa (Chand *et al.*, 2013; Bantilan *et al.*, 2014; Asfaw *et al.*, 2010).

Groundnut: Surveys from several African countries, including Nigeria – the leading producer in Africa – provide evidence of large-scale adoption of improved groundnut varieties (Kassie *et al.*, 2010; Ndjeunga *et al.*, 2013), while a recent study based on expert opinion finds similar results in India (Charyulu *et al.*, 2013). However, in both Africa and India there has been at best modest adoption of varieties released in the last 25–35 years.

Bean: Evidence from a number of surveys showed widespread adoption of improved bean varieties across Latin America (Johnson *et al.*, 2003; Reyes *et al.*, 2012), and a number of surveys confirm the substantial adoption of bean varieties in various other countries in eastern and Southern Africa (Larochelle *et al.*, 2013; Katungi *et al.*, 2011a; Sperling & Muyeneza 1995; Ramaekers *et al.*, 2013).

Cowpea: Although recent survey evidence is scarce, expert opinion indicates that there has been significant adoption of improved cowpea varieties in West Africa (Walker *et al.*, 2014).

Pigeonpea: Recent surveys find evidence of pockets of adoption in a few countries in East and Southern Africa. Recent expert elicitation found adoption of improved pigeonpea varieties to be 70 percent in India, consistent with earlier studies (Shiferaw *et al.*, 2005; Shiferaw *et al.*, 2007; Simetow *et al.*, 2010; Bantilan & Joshi, 1996; Bantilan & Parthasarathy, 1999).

Lentil: There is survey evidence showing the adoption of improved lentil varieties in Ethiopia and Bangladesh (Aw-Hassan *et al.*, 2009), but evidence of adoption is lacking from the most important lentil-producing countries, e.g. China, India, Nepal and Turkey.

12.2 Opportunities for further adoption surveys

Where expert opinion or previous field reports suggest there may be widespread adoption of improved varieties and where no surveys have been conducted, stronger evidence of adoption could be sought. Priority for further adoption studies might sensibly be placed on situations where there is reason to believe that widespread adoption has occurred. The major opportunities center on cowpea in West Africa and pigeonpea in India. In both cases, there are reports of major adoption taking place but little recent substantive evidence to date.

Other suggested options for further adoption surveys are:

Chickpea: Recent studies do a satisfactory job of documenting large-scale adoption of improved varieties in southern India and countries in Africa where chickpea is important (Bantilan *et al.*, 2014; Yigezu *et al.*, 2012; Chand *et al.*, 2013). Most of the adoption in India dates from varieties that were released one or even two or more decades ago. Perhaps the most relevant research question – though it is not an adoption survey as such – would be to assess what can be done to re-energize the diffusion of research outputs from the last two decades of chickpea improvement work in India.

Although there may have been significant adoption in Turkey that has yet to be properly documented (Dalton, 2011), overall coverage of the adoption of chickpea varieties is relatively ample and further adoption surveys would not appear to be a high priority at the moment. Instead, in-depth studies on the effects of improved chickpea varieties on poverty in rural southern India would be a very high priority. Increases in East African chickpea production for export to South Asia could be another exciting future topic.

Groundnut: There is a reasonably adequate set of surveys covering groundnut adoption in some African countries (Ndjeunga *et al.*, 2013, Kassie *et al.*, 2010) and a recent study based on expert opinion has likewise suggested widespread adoption in India. However, some of the most widespread improved groundnut varieties in Africa have been cultivated for decades and largely predate CGIAR (Ndjeunga *et al.*, 2012: Table 22) and the situation is quite similar in India (Charyulu *et al.*, 2013). Consequently, more useful than further adoption surveys would be an action-oriented review to appraise what can be done to accelerate the flow to farmers of more recently developed groundnut varieties.

Bean: There is already an extensive set of surveys examining bean adoption levels, dating from the 1980s and 1990s in Latin America (summarized in Johnson *et al.*, 2003), and more recently in Africa (e.g. Ramaekers *et al.*, 2013; Sibiko *et al.*, 2013). Interest in Latin America among CGIAR and many of its stakeholders is perhaps modest compared to interest in other regions, and resources for a renewed effort to document the adoption of more recently released varieties appears unlikely to be forthcoming in the region.

One exception could be case studies on the adoption of biofortified varieties, which represent a new type of technology with the peculiar trait of not being directly observable by farmers or consumers. In Africa, it could be worthwhile to continue with a few follow-up adoption surveys to appraise the longer term effectiveness of the huge effort that has been made in seed distribution; and, as discussed below, an in-depth exploration of impact differentiated by gender could be especially informative in the case of bean in Africa.

Cowpea: There is little documentation of the adoption of cowpea in West Africa. Since expert opinion suggests there has been extensive varietal adoption, this could be a good contender for a survey study, even though the pace of recent varietal releases has not been high.

Pigeonpea: A recent expert elicitation study suggests widespread adoption of improved varieties in India (Charyulu *et al.*, 2013), consistent with earlier surveys. It is unclear that the cost of a representative all-India survey would be justified, but perhaps a state-level survey could usefully confirm these existing studies.

Lentil: There are indications that the adoption of improved lentil varieties may have taken place in China, India, Iran, Syria and Turkey (Dalton, 2011) – all of which are important lentil producers. It might be worthwhile to consider a study in one or more of these countries.

Summary: There are a number of possibilities for surveys of specific crops in particular countries, and the CRP on Grain Legumes and the CGIAR centers most involved in the crop research may want to undertake such studies themselves. From the system perspective, though, it is suggested that SPIA might better focus on documenting especially large impacts that might have occurred but are yet to be documented.

12.3 Future research issues

While there is scope for further adoption studies on specific crops in particular countries, future research on the impacts of legume research should consider some related issues. First, the quality of information from adoption studies has to be assured. Second, approaches to managing the costs of adoption studies and enhancing the operational use of the information have to be taken into account. Third, it is essential to go beyond measuring adoption outcomes to assessing development impacts, as explained below.

Study quality: To be useful for internal operations or credible to external stakeholders, information from adoption surveys must be reliable. This has not always been the case; due, for example, to poorly structured samples or errors in varietal identification (Mine, 2012; Tripp, 2011a). Some of these research quality issues may have led to the misinterpretation of the results from different types of studies. For example, it is perfectly legitimate to do a purposive sample of early users of a new variety to discover its performance from the point of view of farmers. This can provide important feedback to guide varietal development research. Obviously, though, it is misleading to treat such information as if it were a nationally representative measure of adoption.

The principles of sampling are well established and it is equally well known that thorough pretesting of survey instruments is standard good practice, for example, to elicit local names or identifiers of improved varieties. Many adoption surveys use statistically representative samples and properly tested surveys to yield reliable information, and there is no reason why this should not be expected of all future studies (e.g. Bantilan *et al.*, 2014; Larochelle *et al.*, 2013).

Teasing out important relationships among variables is a key part of exploiting the information from adoption surveys. Such analysis can assess, for example, whether resource-poor farmers or women or subsistence farmers are adopting with the same degree of success as others. While many studies address these questions, few use multivariate analysis to go beyond simple comparisons of mean values. Wider use of multivariate methods of analysis could enhance the value of information that is derived from adoption surveys (see, e.g. Simetow *et al.*, 2010; Ndjeunga *et al.*, 2013; Mazid *et al.*, 2009).

Methodologically, there is an emerging awareness that adopting farmers differ systematically from non-adopters, requiring new, more sophisticated approaches to avoid systematic bias in results (de Janvry *et al.*, 2010). It could be worthwhile to conduct a case study of the usefulness of these new methods.

Research efficiency: The conduct of adoption research is itself an activity that consumes resources and is therefore one where consideration of research costs is appropriate. Expert elicitation can be an economical alternative to adoption surveys. A major recent study has shown that carefully conducted expert opinion can generate estimates of adoption that, on average, are only modest overestimates of the results obtained from sample surveys (Walker *et al.*, 2014). However, the same study is carrying out further analysis of the results of farmer focus groups, which are less expensive than surveying individual farmers and might be more reliable than the opinions of outside experts.

Completing multi-crop adoption studies across a given ecology could be more economical than doing a survey for each individual crop. It would also be enlightening to capture innovation as a process across the farm system, instead of one that occurs on a crop-specific basis. This research would focus on an ecology, region or farm system of priority interest – like the Indo-Gangetic Plain that covers parts of India, Pakistan and Nepal and almost all of Bangladesh, or the Sahelian savannahs of West Africa – rather than where there is an expectation of the adoption of a new technology. This approach has the added advantage of focusing on the target human population rather than on a single crop. However, it could also represent a significant institutional challenge to change the thinking of CGIAR researchers to systems over commodities.

For reasons of local knowledge and cost-effectiveness, the implementation of adoption surveys is already widely outsourced to national or local institutions. However, there has not been widespread uptake by national programs of the initiative for undertaking adoption studies. Without the institutionalization of adoption research among NARS, the burden of such studies remains with CGIAR and, as a result, the findings are likely to be sporadic and incomplete in their coverage.

Research efficiency depends not just on costs, but also on the operational use of the information that is obtained. It was not costs alone that led to the demise of adoption research on bean in Latin America. Participatory research methods have proven to be a more effective way of generating feedback at the early stage of variety development than adoption studies, which occur at a latter stage in the diffusion process. Still, adoption surveys can generate insights on patterns of variety use among different types of farmers that may not otherwise be easily observed.

Moreover, adoption studies provide information not only to research scientists, but also to stakeholders who fund the research. Indeed, a main function of adoption surveys is to inform funders of the returns to their investment (Kelley *et al.*, 2008). Yet, the relationship between adoption performance and stakeholder investment is not a simple one. Did the findings of widespread adoption of bean varieties in Latin America indicate that this was a worthwhile investment that should be increased? Or did it indicate that the job was done and resources should go elsewhere? Does the documentation of the widespread adoption of chickpea varieties in south India suggest that further chickpea research is a better investment than cowpea, where adoption is less well studied? While individual commodity research programs have a general incentive to show investors what progress is being made, the incentives to invest in adoption research are irregular and, as a consequence, some studies are delayed.

Commodity research programs are often more inclined to concentrate their scarce research resources on strengthening their genetic work, rather than conducting adoption studies. However, the formation of the CRP on Grain Legumes could both increase the availability of resources as well as provide a platform to undertake adoption studies.

Understanding the constraints to adoption could also be an important product derived from adoption studies. Analyses of the factors determining adoption form part of a large literature on innovation; but, as discussed here, it is far from clear whether many new insights are emerging from this work. Seed availability is a consistently important factor in promoting or hindering adoption (Assefa *et al.*, 2006; Biemond *et al.*, 2012; Kankwamba *et al.*, 2012; Katungi *et al.*, 2011b; Ntare *et al.*, 2008; Rubyogo *et al.*, 2007; Saxena, 2006; Singh *et al.*, 2013a; Sperling & McGuire, 2010) and there is now enough evidence and experience to set out best practice in this area and ensure it is introduced. This is probably more an ordinary operational concern of the CGIAR centers and CRPs, rather than a topic in which SPIA should get involved.

As a rule, information from adoption studies should be more cumulative. Although there are some notable exceptions (e.g. Walker, 2014) there is a tendency for adoption studies to be one-off projects, measuring in isolation the adoption of a particular crop in a single country. It would be useful for the CGIAR management team to have a comprehensive overview of the aggregate adoption and impact across all countries for each commodity. An initial effort along these lines could be completed as a desk study using available information.

Summary: Resources with which to assess impact are going to remain limited. It is never going to be possible to undertake all the studies of potential interest, or to always use the most thorough (and, consequently, expensive) methods. SPIA has a clear role in encouraging strong and credible methods, but it also needs to keep in mind the cost and the value of the information being sought. In particular cases, only the most advanced methods will be acceptable, but there will be other instances where the cost of collecting the information has to be weighed against the operational usefulness of the more painstaking studies.

12.4 From adoption to impact studies

The first core principle of the CGIAR Strategy and Results Framework (http://www.cgiar.org/resources/strategy-and-results-framework/) is that impact will be measured against the four SLOs: reducing rural poverty; improving food security; improving nutrition and health; and managing natural resources sustainably. Measuring varietal adoption, therefore, tends to address CGIAR outputs rather than actual impacts. A few recent adoption studies have covered SLOs (e.g. Larochelle *et al.*, 2013; Kassie *et al.*, 2010), but this is the exception rather than the rule.

As discussed earlier, compared to fairly extensive evidence on the adoption of new varieties, there is, at best, relatively modest evidence of the impacts of grain legume research on poverty, food security, nutrition or natural resources. Consequently, to meet CGIAR expectations, greater attention has to be devoted to assessing impacts on SLOs, rather than just measuring areas under new varieties. Of course, estimating the extent of adoption can be a step along the way to estimating the impacts on outcomes; but; with the exception of some recent studies, there has been a tendency to assess only the level of adoption, rather than going on to measure the impacts on SLOs.

There are some excellent opportunities to assess the impacts on the SLOs, where there is already strong evidence of widespread adoption. For example, in the case of chickpea in southern India, it could be worthwhile to look in more detail at how the new varieties have affected smallholder farmers and agricultural laborers. Chickpea is an important crop in the region and could be important in reducing poverty. Likewise, the introduction of chickpea into the system is a sufficient change that may have had effects on natural resources, like soil fertility or groundwater. This latter study should only be undertaken on scientific advice that there may be phenomena worth exploring.

Similarly, when it comes to bean in Africa – where there has been significant adoption – it could be worthwhile to assess in more detail how technical evolution has affected women who, traditionally, were largely responsible for producing bean. Have the new varieties remained mostly women's crops? How have the production gains from bean been used in the family? Alternatively, there could be natural resource impacts arising from the need for staking material and increased soil fertility in order to grow climbing bean successfully.

The very highest standards of research methods should be used, particularly for these more in-depth studies on outcomes. These effects can be very subtle to measure, and any findings need to be academically credible. It is quite likely that CGIAR centers or CRPs will not have the in-house capacity to implement such specialized studies to the highest standard. Partnerships with truly world-class experts need to be established and SPIA could help CGIAR centers to identify and build such partnerships.

As much as the imprecise measurement of adoption is a serious knowledge gap, assessing how adoption has affected poverty, food security, nutrition, natural resources or gender equity is just as serious a gap in knowledge. The extensive body of research reviewed in this paper enables us to be reasonably confident that, indeed, millions of farmers have adopted improved legume varieties. But the real challenge for impact assessment now is to better ascertain how far this adoption has gone towards reaching the SLOs. This task requires carefully designed, detailed case studies targeted at specific objectives, and it is most likely to be successful and credible if led by academic specialists.

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