Research and development for tropical legumes: Towards a knowledge-based strategy

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Summary

An estimated 140 million households in Sub-Saharan Africa and South Asia cultivate one or more of the six tropical legumes, benefiting more than 700 million people. The productivity of tropical legumes remains low because of limited use of improved technology. Based on existing knowledge from research and development, this article argues that a successful strategy to raise productivity and incomes from grain legumes must contain several components. These include the recognition that: regional diversity requires a country-specific approach; institutional challenges are as important as technical challenges; and that success will require institutional innovations not only in access to input and output markets, but also in research collaboration, and a systems approach. Current initiatives by three international agricultural research centers through the Tropical Legumes II Project seek to apply these lessons.

Introduction

Tropical grain legumes are important components of the farming systems in Sub-Saharan Africa (SSA) and South Asia (SA). More than 101 million smallholder households in SSA and 39 million households in SA, or more than 700 million people, grow one or more tropical legumes (Abate 2012). Tropical grain legumes can improve soil fertility, household food security, nutrition, and may also reduce poverty by providing alternatives to traditional cash crops. However, although SSA and SA account for 38% of the area planted to tropical legumes worldwide, they contribute only 17% of total production (FAO 2011). This is because most tropical legumes are grown under subsistence farming systems characterized by low yields and limited access to input and output markets.

The objective of this article is to outline a strategy for tropical legumes to raise productivity and capture the opportunities for commercialization. We argue that the knowledge required for a successful strategy already exists. This knowledge base includes both the results from previous research and the experience of recent initiatives to put research into use. Reviewing this knowledge base, we derive key lessons that provide the core of a successful strategy. Specifically, we argue that a successful strategy must be based on the following lessons:

1. Regional diversity, both in agroecosystems and in research capacity, requires a country-specific approach;
2. Challenges to raising productivity are as much institutional as technical;
3. Success requires institutional innovations in linking farmers with markets, in research collaboration, and in research methods.

The article draws heavily on research findings and experience from Phase 1 of the Tropical Legumes II (TL II) Project (2007–11), jointly implemented by three international agricultural research centers (IARCs) in close collaboration with national programs in ten countries (Abate 2012). A major objective of this project was to increase productivity and production of legumes by harnessing existing knowledge, on the grounds that research had generated knowledge that had not been widely disseminated or used to develop an effective strategy for research and development. The article focuses on the six major legumes targeted by this project, namely chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), pigeonpea (*Cajanus cajan*) and soybean (*Glycine max*). However, the article is not confined to the period of this project or the target countries and includes other relevant literature.

Regional diversity

Tropical legumes in SSA and SA are produced under extremely varied conditions, both in terms of agroecosystems and research capacity. Access to land, cropping systems and research priorities vary not only between countries but within countries as well. This section highlights some of the important variations in the resource-base, cropping systems, demand, trade and research impacts.

Resources. Average landholdings range from 1.1 ha per household (Malawi) and 1.7 ha (Kenya) to 7.8 ha and 7.9 ha (Nigeria, Mali), and 11.9 ha in Niger (Chianu 2009a, Simtowe et al. 2009, Ndjeunga et al. 2010). Population pressure is expected to reduce landholding still further. Average farm size in Uganda declined from 2 ha in 1992/93 to 0.9 ha in 2004/05 (UBOS 2007). Consequently, the average area planted to tropical legumes on a farm can be small. In Ethiopia, the average area planted to common bean and chickpea is 0.11 ha and 0.23 ha per household, respectively (CSA 2009). Landholdings are also fragmented. Groundnut growers in Niger have on average only two parcels per household (Ndjeunga et al. 2010) while chickpea growers in East Shewa, Ethiopia have seven (Asfaw et al. 2010). Fragmentation based on differences in land quality not only increases the cost of production but also spreads the risk of harvest failure.

Cropping systems. Legumes are grown in diverse ways even within the same region. For example, a survey of cowpea growers in Natal revealed that 67% and 59% of growers in KwaZulu Natal province and Limpopo province, respectively, planted mixed cowpea/bambara nut and cowpea/sorghum (*Sorghum bicolor*). About 80% of growers in KwaZulu Natal used row planting compared to just 7% in Limpopo. Some 81% of the farmers in KwaZulu Natal regarded aphids as the most important insect pest, compared to just 19% in Limpopo (Asiwe 2007). In India, cropping systems and crop rotations also vary by region depending on the soil type, climate suitability and availability of irrigation (Materne and Reddy 2007, Reddy and Reddy 2010).

Markets. Projections show increasing demand for tropical legumes (Abate et al. 2012). By 2020, regional demand for the six legumes under review is expected to reach 22 million t in SSA and 40 million t in SA. Demand in SSA by 2020 will be highest for groundnut (12 million t), followed by cowpea (8 million t), and soybean (2.1 million t), while demand for chickpea and pigeonpea will be below 0.5 million t. However, the highest rate of growth in demand during 2010–20 will be for cowpea (5.0%), followed by chickpea (2.8%), pigeonpea (3.3%), soybean (2.1%) and groundnut (1.9%). In SA, demand is projected to be highest for soybean (16 million t), followed by chickpea (13 million t), groundnut (11 million t) and pigeonpea (5 million t). The highest rate of growth in demand during 2010–20 will also be for chickpea (4.2%), followed by pigeonpea (3.5%), soybean (2.9%) and groundnut (3.5%). In SSA, supply is projected to keep pace with demand, whereas the reverse is true in SA. Figures for both regions are available for chickpea, groundnut, pigeonpea and soybean. By 2020, production of these major legume crops in SSA is projected to reach 17 million t, exceeding demand of 15 million t. For SA, projections suggest production levels of 40 million t, which is below expected demand of 45 million t. The deficit in SA will be greatest for chickpea (2.2 million t), followed by groundnut (1.1 million t), soybean (0.7 million t) and pigeonpea (0.4 million t) (Abate 2012).

Although trade in legumes has grown faster than production, markets for tropical legumes remain thin. Worldwide, about 15% of legume production enters world trade (Akibode and Maredia 2011). Data on world trade is available for four of the six legume crops under review – chickpea, common bean, groundnut grain and soybean. [The FAO classification for common bean in SA includes several other species, viz, mungbean (*Vigna radiata*), black gram (*Vigna mungo*) and others.] SSA is a net importer of beans, soybean and groundnut, but a net exporter of chickpea. By contrast, SA is a net importer of beans, chickpea and soybean, but a net exporter of groundnut. In SSA, the largest import is common bean (243,000 t), followed by soybean (110,000 t), groundnut (53,000 t) and chickpea (16,000 t) (Abate et al. 2012). In SA, the largest import is beans (574,000 t), followed by chickpea (375,000 t), soybean (147,000 t) and groundnut (12,000 t). Imports of legumes in SSA come primarily from SA. The most valuable export from SSA is groundnut (US$ 42 million) followed by chickpea (US$ 39 million), common bean (US$ 37 million) and soybean (US$ 11 million), with a similar order for SA.

Projections suggest a significant change in trade. By 2020, SSA will become a net exporter for nearly all these four legume crops, whereas in SA net trade for all four crops will be negative (Abate et al. 2012). Exports of legumes from SSA are projected to reach more than 2 million t, including groundnut (957,000 t), chickpea (582,000 t), pigeonpea (427,000 t) and soybean (32,000 t). By contrast, in SA net imports of legumes will reach 5.1 million t, including chickpea (2,224,000 t), soybean (1,436,000 t), groundnut (952,000 t) and pigeonpea (476,000 t).

Research impacts. In both SSA and SA, results from research and development in tropical legumes have been mixed. Between 1985 and 2007, overall production of the six tropical legumes increased at the rate of 6.5% and 2.8% per annum in SSA and SA, respectively (Abate et al. 2012). However, most of this growth is due to expansion of the area planted rather than increase in productivity. Area expansion in SSA was highly significant for cowpea, groundnut and soybean, and significant for pigeonpea; it was not significant for chickpea and common bean. Trends in yield were not statistically significant except for groundnut and pigeonpea (Abate et al. 2012). The contribution of yield increases to production was appreciable only for pigeonpea (68%) whereas its contribution ranged from the minimum of 2% for common bean to the maximum of 15% for chickpea. Area expansion accounted for 98% of the change in production in soybean and 57% in chickpea. In SA, the trends in area were highly significant for beans and soybean, and significant for chickpea and groundnut; but the trend was not significant for pigeonpea. The trends for yield were significant for beans and chickpea but most of the growth in production across crops was due to area expansion. For example, the contribution of area expansion to production ranged from 99% in soybean to 40% in pigeonpea (Abate et al. 2012). In sum, of the six tropical legumes only groundnut and pigeonpea in SSA and beans and chickpea in SA showed significant trends in yield, which suggests that the impact of research has been limited.

Challenges

A key lesson from research and development for tropical legumes is that the challenge of raising productivity is as much institutional as technical. While the technical challenges should not be underestimated, the primary reason for limited research impact is the failure to overcome these institutional barriers. This section outlines the scale and severity of some major challenges for tropical grain legumes.

Technical challenges

Drought. Drought reflects both the quantity and distribution of rainfall. In eastern Kenya, common bean farmers estimated yield losses of 60% when rains ended too early and 42% when rains came too late. Similarly, farmers in Ethiopia estimated yield losses of 47% from a mid-season gap in rains and 32% when rains came late (Katungi et al. 2010). The impact of drought on common bean is exacerbated by low soil fertility and soil pathogens. Some crops like pigeonpea are particularly sensitive to moisture stress, especially during maturity stage.

Pests and diseases. Fungal pathogens are responsible for most diseases of tropical legumes. Many of these cause plant mortality and reduce yield. Others (such as *Aspergillus* spp in groundnut) not only affect the growth of the crop but contaminate the seed with mycotoxins, making it unsafe for consumption and unacceptable in international markets. Viral diseases are particularly important for cowpea in western and central Africa. Anthropod pests, including the African bollworm *Helicoverpa armigera* and other pod borers, are particularly important for chickpea and pigeonpea. Damage to pigeonpea in India and eastern Africa is valued at US$ 310 million (Shanower et al. 1999). In India, chickpea farmers in Karnataka reported *H. armigera* as the most important pest, with yield loss estimated at 42% (Kiresur et al. 2010b). Similarly, over half of pigeonpea growers in Andhra Pradesh, India reported that *H. armigera* was the most important insect pest (Suhasini et al. 2010). Aphids, including the cowpea aphid *Aphis craccivora* are important vectors of virus diseases in common bean (bean common mosaic virus), cowpea (cowpea mosaic virus and others) and groundnut (groundnut rosette virus). Infestation by the bean stem maggot complex (*Ophiomyia phaseoli*, *O. spencerella* and *O. centrosematis*) can result in total crop loss of common bean in many parts of eastern and southern Africa (Abate and Ampofo 1996, Abate et al. 2000). The bruchids in the genera *Acanthoscelides*, *Callosobruchus* and *Zabrotes* are cosmopolitan pests that inflict heavy losses on stored common bean and cowpea. Witch weeds *Striga gesnerioides* and *Alectra vogelii* pose great challenges to the production of cowpea in western Africa.

Crop management. Fertilizer use for grain legumes is low compared to staple cereals such as maize (*Zea mays*). Farmers in Malawi applied 45 kg ha^{-1} diammonium phosphate (DAP) to maize during the 2006/07 crop season, but only 10 kg ha^{-1} to pigeonpea and 6 kg ha^{-1} to groundnut (Simtowe et al. 2009). In Ethiopia, 51% of the area planted to cereals in the 2005/06 crop season received mineral fertilizer, compared to just 20% for grain legumes (Thijssen et al. 2008). The share of farmers applying mineral fertilizers to groundnut averaged 16% in Niger and 2% in Mali (Ndjeunga et al. 2010). On average, groundnut farmers in Niger, Mali, and Nigeria used inputs worth less than US$ 20, US$ 21 and US$ 123 ha^{-1}, respectively (Ndjeunga et al. 2010).

Institutional challenges

Seed supply. Private seed companies have less incentive to supply seed for tropical legumes because profit margins are low for self-pollinated crops. The costs of supplying seed to numerous, thinly distributed smallholders are also high. Traditionally, smallholder farmers recycle grain legume seeds for four to five years. A high proportion of farmers use recycled legume seed: 75% in Malawi, 86% in Niger, 80% in Mali and 71% in Nigeria (Ndjeunga et al. 2010). Public sector enterprises usually cannot meet the demand for improved grain legume seed, partly because priority is given to cereals. In Ethiopia, for example, only 0.4% land planted to grain legumes in the 2005/06 crop season was covered by improved seed, compared with 4% for cereals (Thijssen et al. 2008). Lack of access to quality seed is the main reason why smallholders have not adopted improved varieties of grain legumes. In Malawi, 60% of farmers reported that they did not grow improved varieties of groundnut and pigeonpea because of lack of seed and 10% said because of lack of cash to buy seed (Simtowe et al. 2009). Household surveys show that 83% of farmers in Mali, 60% in Niger and 56% in Nigeria attributed non-adoption of improved varieties to the non-availability of seed (Ndjeunga et al. 2010). The non-availability of improved seed is also a major problem in pulses and oilseeds in India (Reddy 2004, 2009), where varieties released thirty to forty years ago still dominate (Reddy and Bantilan 2012). In Tanzania, assured access to improved pigeonpea seed would increase the benefits from research by 30% (Shiferaw et al. 2008a). Similarly, harmonization of seed policies in eastern and southern Africa has increased the benefits to research by reducing the time required for improved varieties developed in one country to be officially released in other countries within the same region (Rohrbach et al. 2003).

Markets. Opportunities to increase access to markets face several challenges. Prices of tropical legumes fluctuate sharply. In SSA, average producer prices peaked in the mid 1990s but slumped later that decade (Abate et al. 2012). For example, the price of chickpea declined from US$ 302 per t in 1991 to about US$ 183 per t in 1994, only to rise to US$ 610 per t in 1997 before falling to US$ 183 per t just two years later. Walker et al. (2006) reported that in Mozambique between 2002 and 2003, prices for groundnut, cowpea and pigeonpea declined by 8%, 13% and 46%, respectively. Similarly, in India price fluctuations were higher for grain legumes than for cereals (Reddy and Reddy 2010).

International trade is constrained by non-tariff barriers. Maximum tolerance levels for aflatoxins range between 5 and 30 nano grams per kg of seed; some European countries have zero tolerance level (Oliveira et al. 2009). Such restrictions, coupled with other production constraints, have led to a decline in the export of groundnuts from SSA. In 1965–67, exports averaged 1.25 million t, compared to 70 thousand t in 2005/07. Over the same period the average value of exports declined from US$ 218 million to US$ 38 million. SSA is currently a net importer of groundnut.

Domestic prices often show big differences between the prices that farmers receive and the prices paid by consumers. In Kenya, the value-chain for dry pigeonpea shows that farmers received 40% of the price received by urban retailers, and 30% of the price received by supermarkets (Shiferaw et al. 2008b). Similarly, chickpea growers in Ethiopia received 70% of the price received by urban retailers and 46% of the price in urban supermarkets (Shiferaw and Teklewold 2007). These price differences reflect high marketing costs and profit margins by traders in the value-chain. Marketing costs are high because the value-chain includes numerous actors, including rural assemblers, wholesalers, processors and retailers. The large number of small, scattered producers also increases transaction costs for buyers. The structure of the market and the absence of direct links between growers and buyers inflate prices, limiting domestic demand in urban markets and also competitiveness in export markets.

Access to markets is affected by poor infrastructure. Chickpea farmers in Karnataka, India have to walk 3 km to the nearest village market while the main market is 9 km away, and roads to village markets are impassable for more than half the year (Kiresur et al. 2010a). Likewise, chickpea farmers in Ethiopia have to walk 3 km to the village market and 10 km to the main market, while roads to the village market are accessible by vehicle for only five months of the year (Asfaw et al. 2010).

Underinvestment in research. Despite positive growth in the 1980s, public investment in agricultural research and development (AR&D) in SSA declined by 0.2% per annum in the 1990s (Beintema and Stads 2010). By contrast, in China and India research investment grew consistently between 1981 and 2000. By 2000, expenditure on agricultural research and development for the whole of SSA (US$ 1.2 billion) was equivalent to that of Brazil (US$ 1.2 billion) or India (US$ 1.3 billion) and half that of China (US$ 2.3 billion). AR&D in SSA depends largely on aid donors. In 2000, 13 of 23 countries in SSA received more than 40% of their research funding from donors; only Sudan, Botswana and Malawi received more than 95% from national governments (Beintema and Stads 2010). A recent Global Conference on Agricultural Research for Development (GCARD) called for SSA countries to spend 1.0% to 1.5% of the value of their agricultural output on AR&D. The current average is just 0.7% (Beintema and Stads 2008). During 1981–2000, expenditures per researcher declined in Ethiopia, Kenya, Malawi, Mali, Niger and Nigeria (Beintema and Stads 2011), despite high rates of return on investments made on AR&D in Africa (Alston et al. 2000, Thirtle et al. 2003). A 10% increase in AR&D expenditure raises agricultural productivity by 2% per year (Alene 2010). Agriculture generally is underinvested. The Maputo Declaration (2003) called for all members of the African Union to increase investment in the agricultural sector to at least 10% of the national budget by 2008. Of the 36 countries for which data was available, only eight (22%) had complied with the Declaration by 2007 (NEPAD 2009).

Within SSA, the capacity to invest in AR&D is highly variable. In early 2000s, the intensity ratio (total public AR&D as a percentage of agricultural gross domestic product) varied from 0.2% for Niger to 2.6% for Kenya. Despite increasing investment since 2000, capacity leaves much to be desired. In Kenya and Niger, the number of professionals has actually declined while the share of women professionals remains low, even though women account for the majority of the agricultural workforce. Consequently, many countries have limited capacity to carry out effective research and development on tropical legumes, which have traditionally received less attention than cereals and cash crops.

Although investment in R&D increased between 2000 and 2008, the lion's share was received by a few countries – namely the so-called 'big eight' (Beintema and Stads 2011). In descending order, these are Nigeria, South Africa, Kenya, Ghana, Uganda, Tanzania, Ethiopia and Sudan. Together, they account for 70% of AR&D investment in SSA. Of the 10 countries targeted by the TL II Project, only four (Nigeria, Kenya, Tanzania and Ethiopia) invested more than US$ 50 million annually in AR&D. Only Kenya had an intensity ratio of more than 1%, and only Nigeria, Kenya and Tanzania spent more than US$ 100,000 per researcher per year. Except for Nigeria, Kenya and Tanzania, none of the TL II Project target countries had more than 500 full time research staff.

Strategy

For each of the challenges listed above, there is a large body of existing knowledge and, in some cases, technological solutions. Indeed, the problem is not the paucity of knowledge, but the ability to put it into use. Based on existing knowledge, this section identifies four essential components for a successful strategy for tropical grain legumes. We present examples showing how the institutional challenges described in the previous section have been overcome.

Seed supply. Several institutional innovations have been developed to increase access to improved seed. These include Quality Declared Seed (QDS), revolving seed schemes, and special seed distribution programs by governments and NGOs.

Revolving seed schemes are a mechanism by which seed growers are supplied with breeder/foundation seed on condition that they return back seed with interest (usually double the original amount), after which the recovered seed is sold to other growers or NGOs. The Malawi Seed Industry Development Project is one such example. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) contracts growers and provides seed on credit, then buys the seed with cash from the revolving fund. The seed is certified by the government Seed Services Unit. ICRISAT then sells the certified seed to seed traders and NGOs and the cash is used to replenish the revolving fund. Traders and NGOs sell or distribute the certified seed to farmers. In 2010, the project supplied more than 790 t of certified groundnut and pigeonpea under the MASA (Malawi Seed Alliance) brand. The project has benefited some 395,000 farmers by providing access to certified seed.

Subsidy programs can increase access to improved seeds, particularly those with higher costs like groundnut. Malawi has recently included legumes in its Input Subsidy Program (ISP). The use of small seed packets (100 g to 5 kg) is extremely popular with farmers, particularly where landholdings are very small, which is usually the case with households headed by women. Access to quality seed can also be improved by strengthening private traders. A study of pigeonpea traders in Makueni district, Kenya showed that most traders made no distinction between grain and seed, and pooled seed of different varieties. Improving information about seed purity and quality sold through traders would create incentives for sale and purchase of quality seed in local markets (Nagarajan et al. 2008). In Malawi, ISP provides farmers with vouchers to buy 2 kg of legume seeds from participating sales outlets. By using private traders, ISP has not only been able to improve access to quality seed but encouraged market development. NGOs have operated seed distribution programs, either to replace seed stocks lost through drought or to promote cultivation of legume crops as part of wider food security and nutrition programs. Most of these schemes were subsidized and competed with private traders (Kambewa 1999).

Experience with the TL II Project and elsewhere (Neate and Guei 2011) indicates that seed production for legumes will remain in the realm of smallholders. Quality Declared Seed is produced by growers and may be sold directly to buyers as seed without the need for formal seed certification. In Tanzania, legume seeds are produced by trained farmers, inspected by the regulation agency and marketed within the community. Depending on the quality of seed, it may be sold as quality declared or truthfully labeled. At present, QDS may be sold only in India, Tanzania and Zambia. Many countries in eastern and southern Africa have regulations that only permit the sale of certified seed. By relaxing these regulations to legalize the sale of QDS, however, Tanzania has successfully increased the supply of legume seed. Amending Kenya's Seed and Plant Varieties Act to allow local production and sales of either truthfully-labeled seed or QDS in local markets would improve the supply of quality seed (Audi et al. 2009).

Access to markets. Grain legumes are an important source of cash income, particularly in semi-arid areas. In eastern and southern Africa, Kenya and Malawi are the two biggest producers of pigeonpea. In Kenya, 45% of the crop is sold, while in Malawi the share is 35% (Shiferaw et al. 2008b, Simtowe et al. 2009). In Ethiopia, which is Africa's biggest producer of chickpea, 80% of the crop is sold (Kassie et al. 2009). In Malawi, the region's biggest producer of groundnut, 29% of the crop is marketed (Simtowe et al. 2009). The share of farm households selling legumes is high. In Kenya, 60% of growers sell pigeonpea (Shiferaw et al. 2008b), while in Malawi the share is 91% (Simtowe et al. 2009). In Malawi, 73% of growers sell groundnut (Simtowe et al. 2009). In India the marketed surplus ranges from 40% to 80% of production for different grain legumes and the share has increased over time (Reddy and Reddy 2010).

Clearly, smallholders have access to markets for tropical legumes; the problem is the nature of that access. There are several ways in which access can be made more favorable. One is to reduce unit costs of production by providing access to new technology. As we have seen, this requires institutional innovations to increase access to improved seed and inputs such as inoculum and fertilizers. In Kenya in 2005, only 55% of growers used improved pigeonpea varieties (Shiferaw et al. 2008b), while in Malawi in 2007 the proportion was only 17% (Simtowe et al. 2009). Similarly, in Ethiopia it was estimated that in 2001, improved varieties covered less than 1% of the area planted to chickpea (Kassie et al. 2009). (Since then, the share planted to improved varieties has increased but recent figures are not available at the national level.) In Malawi in 2007, improved varieties covered only 40% of the area planted to groundnuts (Simtowe et al. 2010). A second way is to reduce marketing costs. Producer Marketing Groups (PMGs) can bulk their products, cutting out middlemen and selling directly with processors and exporters. They can also negotiate higher prices for bulk delivery and quality, and store legumes to sell when prices are highest. In Ethiopia, farmer cooperatives that sell chickpea to local processors received 52% of the final price, whereas those that sold directly to exporters received 83% (Shiferaw and Teklewold 2007). In Kenya, growers who belonged to PMGs got significantly higher prices for pigeonpea than those who sold to rural assemblers. However, farmers still preferred to sell to assemblers because PMGs were unable to pay farmers immediately in cash; it took PMGs five weeks to pay farmers after they had delivered their grain (Shiferaw et al. 2006). To compete with other buyers, PMGs required access to credit.

Improving seed quality can directly affect farmers' access to markets. Breeding programs have developed varieties of chickpea and pigeonpea that meet market requirements for seed color, size and early maturity. For example, the improved pigeonpea variety ICEAP 00040 widely grown in Babati district, Tanzania, has cream seed coat and large seed size attractive to consumers in SA. The groundnut variety CMGV4 has high oil content, making it favorable for oil extraction but not for peanut butter because the oil separates after bottling. Currently, farmers lack incentives for quality since they receive no price premium in primary markets (Shiferaw et al. 2006). India, the world's largest market for dry grain pigeonpea, recognizes only Fair Average Quality. Where grades and standards exist, they may not include traits valued by consumers. The government of Ethiopia has recently introduced grades and standards for common bean and a similar effort is under way to include other legumes. The lack of quality control and standards is one major reason for large fluctuations in producer prices. Introducing standards can reduce price risks and encourage adoption of improved varieties. Access to markets can also be improved by controlling aflatoxins. The maximum allowable level of aflatoxin contamination for imports to the European Union (EU) is 4 parts per million (ie, 0.004 g t^{-1}). A nationwide survey in 2007 showed that 49% of groundnut and 73% of powdered groundnut sampled in local markets had aflatoxin levels above the EU safe limit (Monyo et al. 2011). Meeting the EU standards requires an integrated approach that combines improved crop, aflatoxin testing and traceability. The National Smallholder Farmers Association of Malawi (NASFAM) is implementing this approach through its farmer groups (Siambi et al. 2008). The development of simple test kits for aflatoxin (*Aspergillus flavus* and *Aspergillus parasiticus*) in groundnut has enabled Malawi to start the recovery of lost export markets in UK and other countries in Europe.

Research collaboration. Five IARCs are involved in research and development for one or more tropical legumes. There is a need to harmonize their research agenda and forge partnerships. The CGIAR Research Program (CRP) on Grain Legumes brings together 10 institutions with research programs on grain legumes, including four IARCs (ICRISAT 2011). The CRP prioritizes eight legume crops across five regions, pools research resources and adopts a shared value-chain perspective. The CRP has set an ambitious target of increasing yields and area planted to legumes in these five targeted regions. Although the impact of the CRP remains to be seen, it represents a step forward for collaborative research on tropical legumes.

Similarly, the variation in capacity between NARS offers scope for greater collaboration. Regional research networks are one example. The Pan-African Bean Alliance (PABRA), with 18 NARS members, is recognized as an example of a commodity network that has built capacity among partners (Brunold et al. 2006). There are no equivalent networks for other legumes. Partnerships between NARS can be facilitated through Sub-regional Organizations (SROs). In SROs, the primary mechanism for producing regional public goods is a system of competitive grants. The grants come with conditions for partnerships between two or three member countries. Despite this conditionality, the competitive grant model system has favored bigger NARS. In the Association for Strengthening Research in Eastern and Southern Africa (ASARECA), 60% of competitive grants for A-stream projects went to Kenya, Tanzania and Uganda, while countries with weaker NARS (Burundi, Madagascar, Eritrea, Sudan) received less than 5% of total funds (NRI 2007). The principles of partnership and scientific excellence have proved hard to reconcile. The result has been ‘forced marriages’ where there was little evidence of genuine partnership and the lead institution does most of the work (NRI 2007). Among the ‘big eight’, the incentives for partnership are limited; if they are to become genuine mentors, other models are needed. The TL II Project brings together almost 100 institutions and 300 scientists from ten countries. This provides opportunities for mentoring of the smaller NARS. Donor pressure to demonstrate quick impacts may also discourage CG centers from partnering NARS where potential impact is limited by research capacity. Countries with big geographic areas – such as Mozambique – may receive less support from CG centers than smaller countries where impact can be achieved at lower cost. These hard realities highlight the need to ensure that smaller NARS at least participate in setting research priorities, even if their role in implementation is limited.

Systems approach. The importance of a systems approach has long been recognized and is receiving new emphasis. We use ‘systems’ in a broad sense to describe an approach that looks for the links between different research components in order to address the same problem in a holistic way.

The benefits of a systems approach are illustrated by experience with integrated pest management (IPM). The economic and environmental benefits of IPM are high where farmers used pesticides. Generally, however, farmers will not invest in crop protection for crops that have low yields or limited market value. This is often the case with tropical legumes. Generally, IPM has been most successful where it has offered farmers ways to reduce their costs but did not require additional investment of cash or labor (Orr 2003). For example, cowpea in east and northern Uganda was originally grown for its leaves, which provided food in the hungry season. But the decline of cotton and the advent of a market for cowpea grain have transformed cowpea into a valuable cash crop. Farmers growing purely for sale grow a cowpea variety with a higher market value, invest in pesticides, and spray more frequently (Isubikalu et al. 2000). This has presented IPM with an opportunity to rationalize pesticide use. Among IPM strategies, host plant resistance and classical biological control have been particularly effective, because the cost of these strategies is borne by the research system and they do not require expensive investment in farmer training. In the case of tropical legumes, therefore, adoption of IPM is likely to be market-driven as farmers respond to growing market demand.

Experience with IPM for legumes highlights the need for a systems approach, since farmers may adopt IPM strategies for reasons other than crop protection. In Malawi, for example, farmers reduce yield losses from the bean pest complex by growing early-maturing varieties. But most farmers are unaware of this pest complex and attribute yield losses to other causes. They grow early-maturing varieties to provide protein in the hungry season (Orr et al. 2001). In this case, the incentive for IPM is determined by the wider need for household food security. Similarly, farmers in Malawi, particularly women, preferred to enhance soil fertility by growing edible legumes like groundnut and pigeonpea, rather than green manures, because these legumes had added benefits for household food security and nutrition (Bezner-Kerr et al. 2007).

There is growing recognition that improved varieties alone may not deliver the expected increase in productivity, and that small landholdings also need improved crop management (Shiferaw et al. 2007, Abate et al. 2011). Legumes are often planted as intercrops, at low density, and receive few if any cash inputs. Where grown for home consumption, legumes are often managed by women, and competing demands for their labor may result in late planting, late or infrequent weeding or delays in processing, which may reduce yields and grain quality. Varieties identified through participatory variety selection (PVS) may be inappropriate if not evaluated under farmer management. Several management practices have demonstrated potential to increase yields of legumes. On-farm seed-priming can increase yields of groundnut and cowpea (Ousman and Aune 2011). Experience with a systems and partnership approach with chickpea, common bean and lentil (*Lens culinaris*) has demonstrated that the current levels of yields could be more than doubled (Abate et al. 2011). Recent studies in India and Bangladesh also show the positive effects of relay-cropping and intercropping systems for legumes (Abate 1991, Reddy et al. 2007, Hossain et al. 2008, Reena et al. 2009, Priya et al. 2009).

Higher yields alone may not be sufficient incentive for smallholders to adopt improved management practices. In Ethiopia, farmers traditionally planted chickpea and beans on marginal land with minimum management between sowing and harvesting. Today, many farmers plow, row-plant and weed. Rising prices for both crops make it profitable for farmers to invest in crop management (Abate et al. 2011). As with IPM, the incentive to raise productivity came from growing market demand and the promise of higher cash income.

Conclusions

Over the past three decades, research has generated a wealth of knowledge on how to increase the productivity and production of tropical legumes, and the incomes of millions of resource-poor farmers. Despite this, increases in production have generally been the result of area expansion, rather than of increased productivity. This is unsustainable, given increasing population pressure, increased land fragmentation and declining average farm size. Based on existing knowledge and recent project experience, we argue that a successful strategy to put research into use requires a set of institutional innovations. These include innovations in access to new technology and access to markets, as well as innovations in how research is organized and conducted.

Variations in agroecosystems and demand preclude a universal strategy. Within SSA, variations in landholding and the area planted to legumes suggest that the benefits from increased productivity at the household level will vary between regions and countries. Similarly, variations in cropping systems (even for the same crop in the same region) mean that interventions must be designed to suit local conditions. Finally, differences in domestic supply and demand, and in international trade suggest the need for regional strategies. By 2020, the gap between supply and demand for legumes in SA will widen significantly. SSA will become a net exporter, particularly for groundnuts, chickpea and pigeonpea. Strategies to boost productivity must take account of these major shifts in the pattern of regional production and trade. Growers in SSA will need varieties with traits required to meet demand from consumers in SA, whereas in SA growers will require new technology and policy interventions that allow them to compete more effectively with imports. In sum, a successful strategy for tropical legumes must be region- and country-specific, reflecting the diversity of needs and priorities.

The challenges to boosting productivity are as much institutional as technical. True, drought, pests and diseases remain major challenges. However, the primary reason for low adoption of improved technologies has been lack of access to inputs, particularly seed. Similarly, price fluctuations and high transaction costs have limited smallholder production for the market. Declining investment in agricultural research between 1980 and 2000 has left the majority of NARS in SSA with limited capacity to address these challenges. Research capacity is unevenly distributed. Within SSA, only four of 23 countries spend more than 1% of the value of their agricultural output on research and development. Most rely on foreign aid for research investments.

A successful strategy, therefore, must overcome several institutional challenges. The knowledge and experience of how to overcome these challenges already exist, and can be leveraged to increase research impacts. Seed supply is crucial. Several models have now been developed that demonstrate the importance of smallholder seed producers in increasing supply and of private traders in seed distribution. However, they also require appropriate laws that can stimulate seed production and commercialization of improved varieties by smallholders. Similarly, there is now considerable experience of linking smallholders with markets. Again, a variety of models have been developed. These have demonstrated the potential of collective action to reduce transaction costs, increase smallholders' share of the final price, and reduce price risks from price fluctuations. However, collective action by smallholders has required significant investment in training, finance and infrastructure development. Institution-building needs external resources. To link smallholders with markets, there is no alternative to the 'long march' through institutions. The example of groundnuts in Malawi shows what can be achieved when a producer organization links smallholders with international markets.

Variations in research capacity between regions and countries can be seen as an opportunity rather than a threat. The strengths of the few better-endowed countries can be harnessed to benefit the others. In SSA, the resources of 'big eight' can be shared through regional programs, training and mentoring young scientists, and access to research facilities. The harmonization of seed regulations in eastern and southern Africa, which has reduced the time and resources required to develop improved legume varieties, has shown the benefits that can result from collaboration. Similarly, the new partnership between three CG centers involved with tropical legumes is expected to improve sharing of research resources and target research to where it will have the greatest impact.

Lastly, a successful strategy requires looking for connections between research challenges, which we have called a systems approach. This is particularly relevant for tropical legumes, which are often intercropped and receive fewer inputs than staple cereals. Interventions that boost productivity, such as IPM or improved crop management, are unlikely to be widely adopted unless they also contribute to the household's needs for food security or cash income. Demand, market access and higher prices will increase the incentive for farmers to intensify the production of tropical legumes, underlining the need for a systems approach.

How can this strategy be implemented? New research programs and projects are addressing some of the constraints enumerated in this article. The strategy for the CRP on Grain Legumes emphasizes research collaboration, and institutional innovations to supply seed and link farmers to markets. Similarly, Phase II of the TL II Project, with its emphasis on country-specific strategies, will focus research on local priorities, where it will have greatest impact. Both programs focus on getting existing knowledge into use. How far these objectives are met will largely determine the success of AR&D in increasing the productivity and profitability of tropical legumes.

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