CGIAR Research Program on Grain Legumes

Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation

15 August 2012

Submitted by ICRISAT, CIAT, ICARDA and IITA

In collaboration with
Generation Challenge Program (GCP)
Brazilian Agricultural Research Corporation (EMBRAPA)
Ethiopian Institute of Agricultural Research (EIAR)
Indian Council of Agricultural Research (ICAR)
Turkish General Directorate of Agricultural Research (GDAR)
Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP)
National agricultural research and extension systems in Africa, Asia and Latin America and the Carribean
National and international public and private sector research and development partners

IITA
Research to Nourish Africa

ICRISAT
Science with a human face

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

ICARDA

CGIAR Research Program
on

Grain Legumes

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Foreword

We are pleased to present our revised proposal for CGIAR Research Program (CRP) on Grain Legumes (Grain Legumes). The revision has considered the valuable suggestions from the Consortium Board and other reviewers, and reflects the substantive inputs from all partners to address the 'must haves' indicated by the Independent Science and Partnership Council (ISPC) and the Fund Council.

The CRP on Grain Legumes will contribute to the four CGIAR System Level Outcomes and is highly complementary to other CRP targets. Consumption of grain legumes complement the nutritional value of cereals and supports a process of sustainable intensification of farming systems through nitrogen fixation, extending land cover and nutrient utilization by fitting into a wide range of intercropping configurations. Grain legume cultivation directly benefits women because they are often the primary cultivators of these crops (especially in sub-Saharan Africa) as well as being employed in small-scale processing, preparation and marketing of grain legume foods.

The partners in this global alliance for grain legumes include four CGIAR Centers (ICRISAT as Lead Center, CIAT, ICARDA and IITA), and six others who have complementary grain legume research-for-development (R4D) efforts (EIAR, Embrapa, GDAR, Generation Challenge Program, ICAR and the USAID-supported legume CRSPs).

Bringing these world-leading grain legume programs together enables us to learn more effectively from each other, thereby increasing our impacts. We will continue to share expertise, facilities and services that improve all partners' capacities, efficiency and effectiveness. We will challenge preconceptions and communicate more effectively with traditional and new stakeholders in order to achieve change.

This proposal describes how we will deliver on these promises.

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Acknowledgments

The eleven core partner institutions of Grain Legumes wish to offer their sincere appreciation to the more than one hundred scientists and external partners who have put large amounts of time and energy into this proposal, crossing institutional boundaries to work as a team. They gathered data and information, and advanced ideas in several global meetings and in many focused sub-meetings and workshops from 2010 to 2012 in order to draft, revise and refine this proposal. The effort has been worthwhile, clarifying our ideas and stimulating new ones that will improve our focus and direction in the coming years.

Apart from the scientists, many other staff in all the institutes (administration, finance, human resources and others) worked overtime to provide additional information and data, and to meet deadlines. Helpful suggestions have come from the members of ICRISAT's Governing Board, the CGIAR Consortium Board, ISPC, Fund Council, as well as several external experts. We thank all for making this a better research proposal.

Table of Contents

Appendices

Acronyms and Abbreviations

A4NH	CGIAR Research Program on Agriculture for Nutrition and Health
ACIAR	Australian Centre for International Agricultural Research
AGRA	Alliance for a Green Revolution in Africa
AIDS	Acquired Immune Deficiency Syndrome
AIP	Agribusiness and Innovation Platform
ARI	Advanced Research Institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
AVRDC	AVRDC - The World Vegetable Center
BGI	Beijing Genomics Institute
BMGF	Bill & Melinda Gates Foundation
BNF	Biological Nitrogen Fixation
CBO	Community-based Organizations
CCARDESA	Centre for Coordination of Agricultural Research and Development for Southern Africa
CCRN	Cooperative Cereals Research Network
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CLIMA	Center for Legumes in Mediterranean Agriculture
CMS	Cytoplasmic-Nuclear Male Sterility System
COP	Communities of Practice
CORAF	Counseil Ouest et Centre Africain Pour la Recherche et le Developpement Agricoles
CRP	CGIAR Research Program
CRSP	USAID Collaborative Research Support Program
CSSL	Chromosome Segment Substitution Lines
CWANA	Central and West Asia and North Africa
DFID	Department for International Development
DIVA	Diffusion of Improved Varieties in Africa
EIAR	Ethiopian Institute of Agricultural Research
ELISA	Enzyme-Linked Immunosorbent Assay
Embrapa	The Brazilian Agricultural Research Corporation
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization of the United Nations
FIGS	Focused Identification of Germplasm Strategy
FPVS	Farmer-participatory varietal selection
GCDT	Global Crop Diversity Trust
GCP	Generation Challenge Program
GDAR	General Directorate of Agricultural Research (Turkey)
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GPG	Global Public Goods
GRD	Groundnut Rosette Disease
GRiSP	CGIAR Research Program on Rice
GWS	Genome-wide Selection
HPRC	Hybrid Parents Research Consortium
IARC	International Agricultural Research Centers
IBP	Integrated Breeding Platform
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas
ICIPE	International Centre for Insect Physiology and Ecology
ICM	Integrated Crop Management
ICRAF	International Center for Research in Agroforestry
ICT	Information and Communication Technology
IDM	Integrated Disease Management
IER	Institut d' Economie Rurale (Mali)
IFAD	International Fund for Agricultural Research
IFPRI	International Food Policy Research Institute
IGP	Indo-Gangetic Plain
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INERA	Institut de l'Environnement et de Recherches Agricoles (Burkina Faso)
INRAN	Institut National de Recherches Agronomique du Niger (Niger)
IP	Intellectual Property
IPG	International Public Goods
IPR	Intellectual Property Rights
ISPC	Independent Science and Partnership Council

ISRA	Institut Senegalais de Recherches Agricole (Senegal)
IT	Information Technology
ITAS	Institute for Technology Assessment and Systems Analysis
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KARI	Kenya Agricultural Research Institute
KM	Knowledge Management
KS	Knowledge Sharing
LAC	Latin America and the Caribbean
LIFDC	Low Income Food Deficit Countries
MAIZE	CGIAR Research Program on Maize
MARA	Ministry of Agriculture and Rural Affairs
MAS	Marker Assisted Selection
MTA	Material Transfer Agreement
NARC	National Agricultural Research Council
NARES	National Agricultural Research and Extension Systems
NARS	National Agricultural Research Systems
NASFAM	National Smallholder Farmers Association of Malawi
NFSM	National Food Security Mission (India)
NGO	Non-government Organization
NSSO	National Sample Survey Organization (India)
PABRA	Pan-African Bean Research Alliance
PIA	Program Implementation Agreement
PICS	Purdue Improved Cowpea Storage
PL	Product Line
PMU	Program Management Unit
PPB	Participatory Plant Breeding
PRGA	Participatory Research and Gender Analysis
PS	Private Sector
PVS	Participatory Varietal Selection
rDNA	Recombinant Deoxyribonucleic Acid
RIL	Recombinant inbred lines
RMC	Research Management Committee
RTB	CGIAR Research Program on Roots, Tubers and Bananas
SC	Strategic Component
SCMR	SPAD chlorophyll meter readings
SSEA	South and Southeast Asia
TE	Transpiration Efficiency
TL I	Tropical Legumes I
TL II	Tropical Legumes II
TRIVSA	Tracking Improved Varieties in South Asia
TSBF	Tropical Soil Biology and Fertility Program
UB	University of Brasilia
USAID	United States Agency for International Development
US$A	United States Department of Agriculture
WANA	West Asia & North Africa
WCA	West and Central Africa
WHEAT	CGIAR Research Program on Wheat
WHO	World Health Organization
WLE	CGIAR Research Program on Water, Land and Ecosystems
WUE	Water Use Efficiency

Executive Summary

The CGIAR Research Program (CRP) on Grain Legumes unites research-for-development (R4D) efforts of eleven principal partners**:** four CGIAR centers (ICRISAT-*lead center*, CIAT, ICARDA and IITA), a CGIAR Challenge Program (Generation), four major national agricultural research systems (EIAR-Ethiopia, Embrapa-Brazil, GDAR-Turkey and ICAR-India) and the USAID-supported legume Cooperative Research Support Programs. All are leaders in grain legume research.

The research for development and conservation objectives addressed by the CRP on Grain Legumes are to increase production, sales, consumption and beneficial contribution of farming systems of grain legumes that reduce poverty, hunger, malnutrition of smallholder farmers and their households, while improving the health of mankind and sustainability of farming systems.

Vision of success

Research partners will work with numerous partners along the grain legume value chains to develop, adopt, disseminate and promote R4D innovations that will improve:

- **production performance** of grain legumes in distinct farming systems;
- **sales performance** of grain legumes in diverse local, national and international markets;
- **dietary performance** of grain legumes in all households; and
- **ecological performance** of agriculture-food systems.

By working together, the CRP partners will:

- develop an integrated approach to legumes R4D in each region rather than isolated efforts;
- improve knowledge generation and sharing through comparison/contrast learning across target legume crops and systems in their distinctive regional settings; and
- share R4D facilities and expertise to increase operational efficiency and effectiveness.

Justification

Grain legumes contribute significantly towards all four of the CGIAR System Level Outcomes (SLOs): reducing poverty, improving food security, improving nutrition and health, and sustaining the natural resource base.

Grain legumes are a cost-effective option for improving the diets of low-income consumers who cannot easily afford meat, dairy products and fish. Grain legumes also generate substantial benefits to the well-being of smallholder farm families. Often a crop cultivated by women, harvests are consumed at home and sold to generate family income.

In addition, grain legumes provide on-farm agronomic benefits. By complementing cereals, roots and tubers in farming systems of smallholder farmers, legumes can help intensify *and* diversify systems. Legumes *intensify* cropping systems by utilizing under-exploited production niches, serving as rotation-, double- and inter-crops. Increasing cropping intensity, the ability of legumes to fix nitrogen, and improve soil health can enhance overall farm productivity and smallholder incomes. Grain legumes also *diversify* farming systems, making them more nutrient-efficient, resilient and sustainable. Their fast growth not only improves soil-protective land cover, but also helps break pest, disease and weed cycles in cereal cropping systems. Furthermore, diversifying farm activities with legumes reduces risks of catastrophic farm-wide harvest losses, thereby increasing farm resilience to climate change. In summary, Grain Legumes focuses on the poorest sectors of society in order to generate a range of economic, social and environmental benefits.

Despite previous investments in R4D having improved the productivity and quality performance of grain legumes, four serious production and consumption challenges remain.

One, farmers in some regions have shifted legume cultivation to less-productive environments, as a consequence of other staple crops receiving favorable policy support, while inputs and associated yields of legumes have not increased at a similar rate. Nevertheless, concerned about production shortfalls, major grain legume producing countries such as Ethiopia, India, Brazil, and Turkey are now taking significant steps to encourage grain legume production. These improvements in the enabling policy environment will likely magnify the impacts of the CRP's work.

Two, inadequate seed production systems and the lack of access to seed by distant smallholder producers are particular bottlenecks to the adoption of improved varieties. Despite needs, the private-sector seed industry has been reluctant to invest heavily in grain legumes due to the lower seed sale volumes, a larger number of site-specific varieties, slow government procedures in releasing new cultivars, and other constraints. Institutional and technical innovations to overcome these obstacles are showing promise and will be advanced further.

Three, in some regions the per capita demand for legumes is decreasing. As countries develop and become wealthier, legumes confront competition from other foods. Food preferences change towards not only ready-to-eat snacks and meals but also increased consumption of animal products. Nevertheless, despite per capita decreases of grain legume consumption in some areas, population growth generates increasing overall demand for more legume production. Moreover, consumer food preferences can be swayed back to legumes with public, NGO and private sector activities. As governments share information on the beneficial health effects of legume consumption, legumes can become a more popular component of diets. In addition, private sector processing can make grain legumes easier to cook and eat, while marketing activities entice consumers to return to traditional cooking or try new exotic legume-based foods.

Four, grain legumes are also susceptible to climate change. Both drought and heat can severely limit their productivity. In many regions, especially Africa, farmers will face shorter and less reliable growing seasons. Consequently, in addition to developing new resilient varieties, research and development is needed to help predict which regions are urgent priorities for developing new varieties, or whether different legumes should be cultivated (Figure 1).

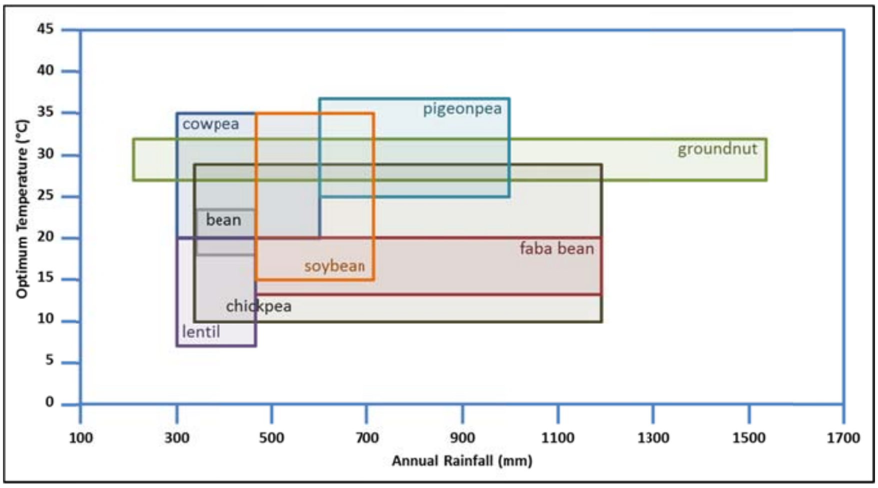


Figure 1. Where the eight priority legumes grow.

Despite such challenges, partners of Grain Legumes have achieved remarkable impacts in all target regions. They have helped countries increase grain legume yields, brought destructive diseases under control, made headway against the complex problems of drought, and connected grain legumes to export markets for higher incomes. Much more needs to be done to meet the demands of a growing population while maintaining and improving the integrity of natural resources. By unifying efforts, Grain Legumes foresees further progress in their efficiency and effectiveness to generate a wide range of economic, social and environmental benefits.

The Research Framework

The following five **Strategic Components** (SCs) contribute to advancing Grain Legumes objectives of improving the production, sales, and consumption of grain legumes.

SC 1 – Analyzing demand and setting research priorities

Identify priority research and development needs ranging from farmers, seed sellers, processors, and marketers to consumers and policymakers.

SC 2 – Developing productive varieties and management practices

Accelerate the development of more productive and nutritious legumes varieties and crop and pest management practices for resilient cropping systems of smallholder farmers.

SC 3 – Facilitating legume seed and technology delivery systems

Develop and facilitate efficient legume seed production and technology delivery systems for smallholder farmers.

SC 4 – Enhancing post-harvest processing and market opportunities

Enhance grain legumes value additions, and social and environmental benefits captured by the poor worldwide, especially women.

SC 5 – Fostering innovation and managing knowledge

Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts.

The R4D activities of the SCs support the overall **development, delivery, performance and impact** of eight Grain Legume **Product Lines** (PLs). The PLs, grouped into four key areas of priorities, advance research on high-priority challenges and new opportunities, and are built on the past breeding successes, germplasm collections and recent progress in sciences.

Addressing abiotic stresses and climate change effects

PL 1. Drought and low-phosphorous tolerant common bean, cowpea, and soybean
PL 2. Heat-tolerant chickpea, common bean, faba bean and lentil
PL 3. Short-duration, drought-tolerant and aflatoxin-free groundnut

Capturing unique legume ability to fix nitrogen

PL 4. High nitrogen-fixing chickpea, common bean, faba bean and soybean

Managing key biotic stresses

PL 5. Insect-smart chickpea, cowpea, and pigeonpea production systems

Generating new opportunities to intensify cropping systems

PL 6. Extra-early chickpea and lentil varieties
PL 7. Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties
PL 8. Pigeonpea hybrid and management practices

Regional and crop foci

Grain Legumes will improve the harvests of major grain legume crops that are most important to the smallholder farmers in four regions (listed in order of area of production by region and by crop):

- **South and Southeast Asia (SSEA)**
  Chickpea, groundnut, pigeonpea, lentil
- **Sub-Saharan Africa (SSA)**
  Groundnut, cowpea, common bean, soybean, faba bean, pigeonpea

- **Central and Western Asia and North Africa (CWANA)**
  Chickpea, lentil
- **Latin America and the Caribbean (LAC)**
  Common bean

Monitoring and assessment

Grain Legumes will advance the five Strategic Components through a unified, monitorable, impact-oriented framework. A comprehensive understanding of factors that limit consumption and production of legumes enable the CRP to prioritize initiatives according to efficiency and equity criteria. The framework also allows research and development partners to clarify their roles and responsibilities in promoting the health benefits of eating legumes and agronomic benefits of cultivating legumes in diverse farm environments. Grain Legumes will distinguish between the needs of intermediate partners (e.g., NARS, seed companies and NGOs) and ultimate beneficiaries (poor smallholder families and consumers). While both are crucial for achieving impact, the contexts and initiatives that motivate change are distinct.

Innovation

By bringing together major R4D partners across crops, regions and institutions, Grain Legumes will provide opportunities for cross-learning that generate new and innovative ways of approaching the challenges outlined above. The CRP's unified interface with partners is itself a major strategic innovation that will increase mutual learning and improve communications.

Research across the eight grain legume crops will generate innovative and important insights. These crops provide an unparalleled learning opportunity at the genetic, genomic, phenotypic, agro-ecosystem, value chain, and regional and global levels. Cross-crop learning will improve the understanding of genetic and physiological mechanisms and control points for disease and pest resistance, drought and other stress adaptation, nutritional quality, biological nitrogen fixation, and other key traits. The sharing of facilities and testing environments will enable the partners to learn more about each crop and expand the range and impact of all these crops.

The value chain perspective will provide an innovation framework for integrating social and economic analysis with traditional strengths in crop improvement. It brings additional attention to constraints that have hobbled impact in the past, such as insufficiencies in input supplies (e.g., seed and soil fertility inputs). It will also innovate gains in value capture by the poor through enlarged, higher-value and novel markets, creating particular opportunities for women who bring special strengths to post-harvest processing and marketing issues.

Time frame

Grain Legumes is proposed as a ten-year program with major output targets indicated for years five and ten. Milestones are presented in this proposal for the first three years.

Management

ICRISAT will be the Lead Center for the CRP. ICRISAT's Director General and its Governing Board, in consultation with a Steering Committee and an Independent Advisory Committee, will provide oversight. A CRP Director will lead a Research Management Committee including the Product Line Coordinators and Research Directors of the other key research partners. The Research Management Committee will be responsible for the overall monitoring of research progress and outputs.

Budget

Current commitments of the Grain Legumes partners amount to US$ 38.8 million in year one. To capitalize on additional opportunities, Grain Legumes will require US$ 48.0 million in year two and US$ 52.3 million in year three. The total Grain Legumes budget for the initial three years is US$ 139.1 million.

Vision of Success

Our vision is that in 10 years, increased production, sales and consumption of grain legumes will reduce poverty, hunger, and malnutrition of smallholder farmers, while improving the health of mankind and the sustainability of farming systems. The CRP partners will leverage their knowledge and research capacities by coordinating strategies with diverse public and private organizations. Through collaborative work, the CRP will improve the performance of eight priority grain legumes in households, on farms, and in markets.

Products and services from cultivating grain legumes will address old and new demands. Grain legumes will range from being a nutritious staple crop and a nitrogen-fixing plant, to an imported exotic food and ecologically-efficient protein source, which are resilient and mitigate climate change.

The CRP will improve the **production performance** of grain legumes in distinct farming systems. Comprehensive review of (i) productivity constraints, (ii) barriers to technology adoption and use, and (iii) threats to production will enable the CRP to address the most important needs of different types of farmers. For example, multiple new varieties with better and reliable yields will reach more farmers who cultivate marginal lands. Larger harvests will benefit households by improving food supply and market sales. Other varieties will improve the competitiveness of grain legumes within farming systems by enabling labor-saving technologies to reduce weeding and harvesting costs.

The CRP will improve the **sales performance** of grain legumes in diverse local, national and international markets. Better at home-storage capacity and market information will enable smallholder farmers to obtain fair prices. Women will not only maintain their prominent role in managing grain legumes on farm, but will also increase their role in other links of the value chain. Gender-sensitive training and investments in post-harvest processing will generate jobs and answer new market demands. Farmer associations, cooperatives and private businesses will increase the value of grain legumes by sorting, grading, processing, packaging, and promotion. Such organizations will also facilitate access to inputs such as new technologies, financial credit and crop insurance. Coordination with the private and NGO sectors will enable grain legumes to expand existing niche opportunities such as: local and national consumer demands for ready-to-eat and snack foods, international markets for traditional products, urban food eaters willing to pay more for healthy socially- and ecologically-conscious foods, and environmental service markets ready to compensate farmers for reducing greenhouse gas emissions.

The CRP will improve the **dietary performance** of grain legumes in all households. Consumption of grain legumes will enable smallholder farm families to better meet their nutritional requirements of proteins, macro- and micronutrients, vitamins, fiber and health promoting carbohydrates. In addition, coordination with public health sector and private food companies will increase promotional efforts and motivate more frequent consumption of grain legume, thereby reducing obesity and cardiovascular diseases. Legumes are superior sources of lysine and therefore complement low lysine cereal diets to further increase the value of the combined proteins. Increased consumption of grain legumes will reverse trends towards eating animal-based protein, and thus help reduce negative impacts of agriculture on land and the atmosphere.

The combined advances in grain legume production, sales and dietary performance will improve the **environmental performance** of agriculture-food systems. Crop rotations and inter- and mixed-crops with grain legumes will help sustainably intensify farming systems and support global efforts to reduce deforestation and climate change. It is expected that the symbiotic ability of legumes to capture certain nutrients such as phosphorus and potassium, will improve soil fertility of cereal-legumes systems. Their fodder residues being rich in protein are expected to take an increasingly important role in cattle feed.

Over a ten-year period, the CRP and partner activities will help increase grain legume harvests by 7.1 million tons in Low-Income, Food-Deficit Countries (LIFDCs) in five regions. The estimated economic value of this impact is US$ 4.5 billion. The health of consumers will improve from the extra 2.1 million tons of protein in their diets.

Local and global benefits from environmental services will increase. Over 9% of the estimated economic value from CRP research is from benefits generated by environmental services. The additional 415,000 tons of nitrogen from biological fixation generates (i) an equivalent fertilizer cost savings of US$ 392 million, and (ii) 5.5 million tons of avoided greenhouse gas (GHG) emissions with an estimated value of US$ 55 million (US$ 10/ton CO_2e). Other measureable impact indicators will guide program management to improve program effectiveness and spur additional R4D investments from public and private organizations.

By cross-fertilizing and adapting experiences across eight priority grain legumes, the CRP will leverage previous advances in technology generation and dissemination, organizational skills and experience, information management, and policy analysis and development. Shared CRP coordination will clarify partner roles and responsibilities along grain legume value chains and improve advocacy. As part of the CRP targeting, leveraging and exit strategy, investments in training and collaborative research will build local and national stakeholder capacities.

Justification of a CRP on Grain Legumes

Why grain legumes are important

Grain legumes play important roles on farms, in human diets and for the sustainability of agriculture. Grain legumes contribute to all of the System Level Outcomes (SLOs), which guide the objectives and activities of the CGIAR Research Programs (CRPs) as enunciated in the CGIAR's Strategy and Results Framework (SRF).

Reduce rural poverty (SLO 1)

Smallholder farm households both consume and sell grain legume crop products. This flexibility enables farmers to manage their crops according to needs, and thereby their livelihood strategies (Shiferaw 2007; Lowenberg-DeBoer and Ibro 2008). The dual role of grain legumes helps meet household needs and generate income by yielding valuable and diverse products, such as grains, oil, pods, peas, leaves, haulm, and press-cake. As a human food and livestock fodder and feed, grain legumes are in demand locally, and in urban and export markets. A wide range of processed products from these raw materials can add value and generate income-earning opportunities for poor people, especially women.

Secure food supplies (SLO 2)

Within farming systems, grain legumes are often fitted into underutilized niches, and thus increase total food production per unit land area. This attribute of grain legumes is especially important for smallholder farmers constrained by land resources. Also, increased on-farm crop diversity helps to reduce food supply risks from environmental shocks and hazards. Grain legumes are usually grown as mixed- and inter-crops with cereals and tuber crops to reduce the risk of crop failure. For example, legumes sown later in the season often escape drought and disease that devastate other crops, thereby providing a harvest and family food supply. The use of legume haulms to improve fodder quality contributes to the productivity of the animals that provide the poor with draft power, milk, meat and income.

Improve diets as a nutritious, healthy food (SLO 3)

Akibode and Maredia (2011) indicate that many of the poorest countries in the world derive 10-20% or more of their total dietary protein from grain legumes. Low lysine content is the limiting constraint in cereal-dominated diets relative to human amino acid balance, such as a maize-based diet in eastern and southern Africa. Legumes are superior sources of lysine, and increase the biological value of the combined protein. The current WHO-endorsed index for protein quality is the protein digestibility-corrected amino acid score (PDCAAS) that estimates the true value of dietary protein for the human body. Experts recommend that foodstuffs of at least 70% PDCAAS should be consumed (Michaelsen et al. 2009). The PDCAAS values of cereals are around 35%, indicating their low protein quality when consumed in isolation, while a cereal-legume combination in the proportions of 70/30 (weight/weight) can usually reach or exceed this PDCAAS threshold (Ejigui et al. 2007; Michaelsen et al. 2009). Thus, even in countries where a cereal is the dominant source of protein, every gram of legume protein potentiates another gram of cereal protein. Legumes also have other important positive effects. Enhanced iron concentration in beans was shown to improve iron status in Mexican school children (Haas et al. 2010). Grain legumes exhibit low glycemic index thus reducing the risk of obesity and diabetes (Foster-Powell K. et al. 2002). Grain legume consumption also has positive effects on colon and breast cancer (Correa 1981; Hangen and Bennink 2003; Thompson et al. 2008) and cardiovascular disease (Kabagambe et al. 2005). Preliminary tests with HIV/AIDS victims fed grain legumes shows an increase in cell counts of CD4 cells, a primary element of the immune system (M. Bennink, personal communication).

Sustainably intensify farm production (SLO 4)

The ability of grain legumes to fix nitrogen in soils provides benefits not only to legumes themselves – but also to subsequent crops, the finances of smallholder farmers and the agricultural system. Through gradual release of nitrogen from decaying root biomass, grain legumes can improve overall nitrogen balance in farming systems as compared to chemical nitrogen-only strategies (Crews and Peoples 2005; Nyiraneza and Snapp 2007). Consequently, legumes help reduce fertilizer costs for cash-limited smallholders. Legumes also serve as a break to damaging weed and disease cycles, and extend the duration of vegetative cover thereby reducing soil erosion. Grain legumes further improve the capture, productive use and recycling of water and nutrients, such as end-of-season residual and fallow moisture. Use of their vegetative matter as fodder also enriches nitrogen-limited livestock diets, enhancing the sustainability potential of crop-livestock mixed farming systems. Moreover, as a synergistic complement to chemical nitrogen fertilizer, grain legumes reduce fossil fuel use and associated emissions of greenhouse gases that contribute to climate change.

Why focus on eight grain legumes

Achieving impacts from research on grain legumes requires focus. An initial task advanced in developing the CRP on Grain Legumes was to identify a priority group of grain legumes from among the over 25 that are grown by smallholder farmers. Upon examining the planted area of each grain legume and their potential to confront climate change, fourteen candidates were identified (Table 1).

Table 1. Important legumes for smallholder farmers.

Common name	Scientific name	Common name	Scientific name
Bambara nut	*Vigna subterranea* (L.) Verdc.	Lentil	*Lens culinaris* Medic.
Chickpea	*Cicer arietinum* L.	Lima bean	*Phaseolus lunatus* L.
Common bean	*Phaseolus vulgaris* L.	Mung bean	*Vigna radiata* var. *radiata* (L.) R. Wilczek
Cowpea	*Vigna unguiculata* (L.) Walp.	Pea	*Pisum sativum* L.
Faba bean	*Vicia faba* L.	Pigeonpea	*Cajanus cajan* (L.) Millsp.
Grass pea	*Lathyrus sativus* L.	Soybean	*Glycine max* (L.) Merr.
Groundnut	*Arachis hypogaea* L.	Tepary bean	*Phaseolus acutifolius* (A. Gray)

Many of these grain legumes are grown globally (e.g., common bean, groundnut, pea, chickpea and lentil), while others are more focused to only a few regions of the world (e.g., cowpea in sub-Saharan Africa; faba bean in East and North Africa, and West Asia; pigeonpea in South Asia and East Africa; and mung bean in South and South East Asia).

Further focusing of the CRP target was accomplished initially by assessing additional factors such as poverty, hunger and malnutrition (i.e., number of poor living on less than US$2 per day) in a region. By using two core factors, a matrix was constructed indicating a high/medium/low level of poverty versus high/low areas of production (Table 2). Data on poverty were obtained from the latest World Bank figures; and data on area of production are a three-year average (2007-09) from FAOSTAT. Only LIFDC in the 2012 list of FAO were included. Classes of poverty and area were chosen based on the overall assessment of the poverty and area data, to determine where 'logical' breaks in the numbers occurred.

Table 2. Grain legumes production area and regional poverty matrix (priority grain legumes in bold).

Area	**Number of Poor (<US$2 per day)**				**Total Area** (M hectares)
	HIGH (>750million)	**MEDIUM** (250-750 million)	**LOW** (<250 million)		
	SSEA (1.3 billion)	**SSA** (539million)	**CWANA** (64 million)	**LAC** (55 million)	
HIGH (>0.5M hectares)	Soybean, oil (11.4) **Chickpea (9.0)** **Groundnut (7.9)** Mung bean (5.0) **Pigeonpea (4.2)** **Lentil (1.7)** Pea (0.78)	**Groundnut (10.8)** **Cowpea (10.4)** **Bean, common (5.8)** **Soybean (1.4)** **Faba bean (0.50)** **Pigeonpea (0.50)**	**Chickpea (1.2)** **Lentil (0.6)**	Soybean, oil (4.4) **Bean, common (2.7)**	**Groundnut (19.02)** **Chickpea (10.71)** **Cowpea (10.62)** **Bean, common (8.75)** Mung bean (5.00) **Pigeonpea (4.74)** **Lentil (2.43)** **Soybean (1.58)** Pea (1.47) **Faba bean (1.04)**
LOW (<0.5M hectares)	Cowpea (0.17)	Pea (0.45) Chickpea (0.42) Bambara nut (0.12) Lentil (0.11) Pea (0.04)	Faba bean (0.4) Bean, common (0.25) Soybean (0.18) Groundnut (0.13) Pea (0.13) Cowpea (<0.01)	Groundnut (0.19) Faba bean (0.14) Chickpea (0.09) Pea (0.07) Cowpea (0.04) Pigeonpea (0.04) Lentil (0.02)	

Notes: SSEA: South and Southeast Asia; SSA: Sub-Saharan Africa; CWANA: Central and West Asia and North Africa; LAC: Latin America and the Caribbean; Figures in parentheses for each crop are area of production (in million ha)

Sources: Area of Production is a three-year average 2007-2009, FAOSTAT (2011); Number of Poor (<US$ 2 per day) – World Bank, http://iresearch.worldbank.org/PovcalNet/index.htm

Highest levels of poverty/hunger and malnutrition are in South and Southeast Asia, especially in India, Bangladesh, Nepal and Pakistan. The next highest levels are across sub-Saharan Africa. Significant, but lower, levels of poverty are also located in North Africa, across West and Central Asia and in Latin America and the Caribbean.

The eight major food legumes for focus in the CRP are **chickpea, common bean, cowpea, faba bean, groundnut, lentil, pigeonpea and soybean**. The identified priority grain legumes largely abide by the poverty and area criteria. Two additional criteria, however, restricted soybean and the inclusion of mung bean. While soybean has a large production area in South Asia (mostly in India), vegetable oil production is neither an emphasis nor a comparative advantage of the CRP; thus the area of oil-soybean was not included. Mung bean, an important grain legume in South and Southeast Asia (SSEA), is not a focus crop of the CGIAR. The World Vegetable Center (AVRDC) has significant efforts on improving mung bean production, and the CRP will consider options to partner and coordinate research efforts with AVRDC during the initial phase. For instance, including mung bean in the cross-species research efforts will have spillover effects from research on the main constraints of the CRP.

Initial emphasis on some of these crops and/or regions may change over the initial three years of the CRP as funding priorities could shift to other legumes and regions. A major task of the CRP management team, with input from the Independent Advisory Committee of the CRP, will be the continual assessment of crop and region priorities. This will be aided by initial research activity of Grain Legumes in gathering additional data for all targeted countries (in partnership with the CRP on Policies, Institutions and Markets). Additional targeting per country is indicated within the description of each Product Line, as described below.

Multiple benefits of grain legume cultivation, sales and consumption

In Low-Income, Food-Deficit Countries (LIFDCs), the total production area of the eight grain legumes is nearly 63 million hectares, exceeding that of maize or wheat. Although the average yields of grain legumes are about one-third to one-half those of the cereals (except for faba bean) and production by gravimetric weight (tons) is less than cereal crops, the nutritional yield and economic value of grain legumes is larger, thereby providing substantial health and income opportunities. For example, the protein content of pulses (i.e., grain legumes eaten mainly as human food) is two to three times higher than of these cereals, while the oilseed legumes (i.e., soybean and groundnut) are three to four times higher (Kimaro et al. 2009; Messina 1999). Increased consumption of proteins from grain legumes instead of from animals reduces pressures on natural resources and benefits the environment (Pimentel and Pimentel 2003; Stehfest at al. 2009). Despite the CRP working on multiple grain legumes, a common research agenda strives to achieve efficiency gains and generate significant spillover benefits among the eight priority legume grains (and perhaps others). **In LIFDCs, the eight prioritized grain legumes of CRP have an estimated US$ 24 billion market value at the farm gate**, which is on par with maize or wheat (Table 3).

Consumption trends and forecasts

Analyses across grain legumes reveal increasing and decreasing trends in demand, depending on timeframe and geographic scope. Based on FAO data, Akibode and Maredia (2011) provided the most recent comprehensive overview of production, consumption and trade trends of seven of the eight focus grain legumes (groundnut was not included). Although serving as a proxy for grain legume consumption, per capita availability (production + imports - exports) is often used as an approximate measure. In developing countries between 1995 and 2007, per capita availability increased from 7.3 to 7.9 kg, a 9% increase. Yet in LIFDCs, per capita availability of pulses has declined since the early 1960s, from 13.0 kg/capita/year in 1961-63 to 8.5 kg/capita/year in 2005-07, although the trend appears to have leveled off since the early 1990s (see Appendix 3 for the historical trends in area, yield, production and consumption trends of grain legumes).

Table 3. Area, production, yield and value of grain legumes in Low-Income, Food-Deficit Countries.

Crop	**Area** (million ha)	**Production** (million tons)	**Yield** (t/ha)	**Producer price** (US$/ton)	**Value of production** (US$ billion)
Groundnut	17.0	18.3	1.01	450	8.2
Cowpea	11.7	5.5	0.47	403	2.2
Soybean	11.6	12.3	1.06	305	3.7
Chickpea	9.2	6.7	0.73	585	3.9
Common bean	6.5	4.5	0.69	624	2.8
Pigeonpea	4.3	3.5	0.81	592	2.1
Lentil	1.9	1.2	0.64	548	0.7
Faba bean	0.7	1.2	1.63	500	0.6
Total	***62.8***	***53.2***			***24.2***
Maize	45.1	99.4	2.20	210	20.9
Wheat	50.0	131.9	1.32	213	28.1
Rice	90.4	328.9	3.29	236	77.6

Source: FAOSTAT. For production data, 2008 values are shown; for price data the 2000-2008 average is shown. FAO definition and listing of Low Income Food Deficit Countries (LIFDCs) is at www.fao.org/countryprofiles/lifdc.asp

Analysis of per capita availability also reveals differences in regional importance. In 2007, legume availability was 12.7 kg/capita/year in Latin America and the Caribbean, 8.8 kg in Eastern and Southern Africa, 8.2 kg in West and Central Africa, 7.1 kg/capita-year in South and Southeast Asia, and 4.8 kg in Central and West Asia/North Africa.

Kilocalories consumed per capita per day is another measure to estimate consumption of pulses. Since the mid-1990s, total calories consumed per capita in the developing world have risen by about 6%. While the contribution of cereals to this caloric intake has declined, the pulse share has remained level (in sub-Saharan Africa and South/Southeast Asia) or increased (Latin America and the Caribbean, Central and West Asia/North Africa) (Akibode and Maredia 2011).

FAOSTAT data are unfortunately not stratified by income class, which would aid in observing consumption trends of the poor. An approximation can, nevertheless, be achieved by comparing poor *versus* less-poor countries. Akibode and Maredia (2011) indicate that many of the poorest countries in the world obtain the highest proportion of their total dietary protein from grain legumes, e.g., (in descending order): Burundi (45%); Rwanda (38%); Uganda and Kenya (20%); Comoros, Haiti and Eritrea (18%); Nicaragua and Cuba (16%); Niger, Ethiopia, Malawi, Angola, Tanzania (14-15%); Mauritania, Sierra Leone, India, Brazil, Trinidad and Tobago, Mozambique, Cameroon (12-13%); and North Korea, Guatemala, Mexico, Togo, Belize, Paraguay and Botswana (10-11%). The authors also state that grain legumes provide 7.5% of total protein intake in the developing world, three times higher than the 2.5% proportion found in the developed world.

Income-stratified consumption data are available in India, the world's largest pulse consumer and producer, from the National Sample Survey Organization (NSSO). Consumption of pulses and products by the very poor in the rural areas in India has risen from the level of 150 g/month to 410 g/month and from 250 g/month to 510 g/month between 1973-74 and 2009-10. The consumption level for the lower middle-income group has also risen. However, for the higher middle rich and very rich income group categories, consumption of pulses has declined, particularly for the very rich. Similar trends are observed for urban consumers (compiled from various NSSO rounds on 'Level and pattern consumer expenditure', for details see Appendix 4). The data also reveal that caloric contribution of pulses to the diet of the very poor increased by 6% during 1993-2004 (Akibode and Maredia 2011). Moreover, the poorest strata in India spend more on grain legumes than on meat and animal products, while the reverse is true for the less-poor strata. Across all strata, from 1990 to 2007, per capita consumption of pulses increased from 11.4 to 12.9 kg/capita/year (FAOSTAT).

> *That the consumption of milk, eggs, meat and fish for the lowest income distribution group is still very low in India implies that next to cereals, pulses still remain the main source of protein for the poorest segment of both rural and urban India. This observation is applicable to many other countries in the world.* - Akibode and Maredia (2011)

Due to high population growth rates, Africa and the Middle East are projected to have the strongest growth in food demand and trade over the coming decade (Alene 2012). For oilseeds such as soybean and groundnut, population growth will boost demand for vegetable oils for food consumption and rising incomes will increase demand for protein meals from oilseed presscake for use as livestock feed.

Supply and import trends

Akibode and Maredia (2011) document a rebound in grain legume production and consumption since the mid-1990s, with production gains outpacing population growth (1.8% *versus* 1.3%). In the developing world, area sown increased by 10%, yields by 12% and production by 24% since that time. More than half of the increase in production in the developing world occurred in sub-Saharan Africa.

Nevertheless, this progress has still not been sufficient to meet growing demand over the past fifteen years. Developing countries are compelled to import an increasing proportion of their grain legumes (Akibode and Maredia 2011). If current trends continue in West and Central Africa, cowpea supply will grow slower than demand (2.55% vs. 2.70% per year) between 2010 and 2030. Nigeria, already a large net importer, exhibits the largest demand-supply gap and consequent importation requirement (Alene et al. 2012). Africa is also projected to face a soybean production deficit of 1.7 million tons by 2020 (Alene et al. 2012). Pulse imports worldwide have been increasing since the mid-1990s, particularly by India, exceeding the growth rate of global production. A total of 6.7 million tons of pulses worth US$ 4.5 billion were imported in 2006-08, a substantial outlay of scarce foreign exchange (Akibode and Maredia 2011). India imported 3.5 million tons in 2010-11 that included a number of different pulses. However, growth in total supply of pulses (domestic production plus imports) could not keep pace with demand.

As a result of these production shortfalls, Clansey (2009) foresees continuing increases in imports to fill the grain legumes supply-demand gap globally, particularly in sub-Saharan Africa due to that region's rapid population growth. Akibode and Maredia (2011) estimate that even if area sown to grain legumes continues to increase at the same rate as in the past decade (0.37%/year), yields will still need to grow at a rate 50% faster in order to meet projected demand growth to 2020.

India, the world's largest producer and consumer of pulses, generates about one-third of the developing world's total pulse production, and one-quarter of the world total. Nevertheless, India increased imports of pulses from 350,000 t in 2001 to 2.7 million t in 2008 (FAOSTAT). Reddy (2004; 2009) and Reddy et al. (2010) forecast that India's domestic supply will be insufficient to meet demand by 9% to 26%, depending on scenario outcome. Concerns about demand continuing to outstrip supply has prompted India to take aggressive steps to foster increased grain legume production, such as raising minimum support prices and launching the Accelerated Pulses Production Program (A3P), described below in more detail.

Major emerging economies such as China and India as well as some countries in North Africa, the Middle East, and South Asia are not able to meet their vegetable oil needs from domestic production and will need to import (Alene et al. 2012). If past trends continue, Africa is projected to face a soybean production deficit of 1.7 million tons by 2020 and Asia will have a deficit of 60 million tons.

Aggregate supply and demand projections in LIFDCs of four grain legumes (groundnuts, chickpea, pigeonpea and soybeans) also estimate that demand is expected to be greater than supplies. In addition, the IFPRI IMPACT model (Rosegrant et al. 2008) forecasts that supply-demand gaps for these countries are projected to widen in the long term, if the same productivity trend continues (see Appendix 6 for details).

As a consequence of pulse production shortfalls in recent years, the poor has been affected by increasing food prices (Akibode and Maredia 2011; Chandrashekhar 2011; Prensa Libre.com 2012). High prices limit the ability of the poor to purchase sufficient quantities (as indicated by income elasticity data). High prices can also force the poor to change their diets towards less nutritious foods - a caution issued from a recent international conference on "Leveraging Agriculture for Improving Nutrition and Health" (IFPRI 2011).

Akibode and Maredia (2011), Joshi (1998) and Rao et al. (2010) indicate four reasons for slower yield growth in grain legumes: (i) low input use, (ii) shifts into marginal growing areas, (iii) less policy support than other commodities, and (iv) limited R4D and dissemination of improved technology. Only 25% of the grain legume crop area in the developing world is high input/irrigated, compared to 60% of the cereal area. Similarly, only 6% of fertilizer in sub-Saharan Africa is used on grain legumes, compared to 26% for maize and 11% for wheat/barley (Bumb et al. 2011).

Since the Green Revolution, research priorities on grain legumes have largely emphasized stress resistance breeding (e.g., drought, heat, insects, diseases, nutrient-depleted soils, short-season niches). Consequently, breeding for maximum yield potential has been less relevant. The slow pace of growth in production and yield of grain legumes over recent decades can largely be attributed to less policy and institutional support compared to other commodities, causing a shift of cultivation to less productive environments and lower use of inputs such as fertilizer, irrigation and improved seed. Breeding programs have therefore placed priority on selecting for adaptation to the stresses of marginal environments rather than on yield potential under non-limited conditions. As a consequence of unfavorable government and research policy contexts, global average yields of grain legumes are one-third to one-half as large as those of cereals, and are increasing at a slower rate (0.4% per year, compared to 1.5% for cereals since the mid-1990s).

In summary, Akibode and Maredia (2011) suggest that long-term (multi-decade) *global* per capita consumption of grain legumes (and also for cereals) will probably decline as wealth and urbanization enable people to consume costlier livestock-based protein and convenience foods. However, as indicated in the SRF and SLOs, the target beneficiary group of the CGIAR is the poor of the developing world, rather than the global population as a whole. Those developing-world poor who are unable to afford livestock products will remain dependent on grain legumes for a significant portion of their dietary protein and other nutrients. Akibode and Maredia (2011) conclude that grain legumes will remain crucially important as “poor person’s meat”. Thus the benefits of grain legume R4D will naturally accrue to the poorest peoples who are the prime target of the CGIAR SLOs.

Combined research priorities and activities

Since legumes are cultivated and consumed across a range of biophysical and socio-economic contexts, identifying priority research and development activities for the CRP is a formidable challenge. A perspective of three “worlds of agriculture” – with economies being agriculture-based, transformed or urbanized, as described in the *World Development Report 2008* helps clarify the potential role of legumes within larger processes of rural and national development.

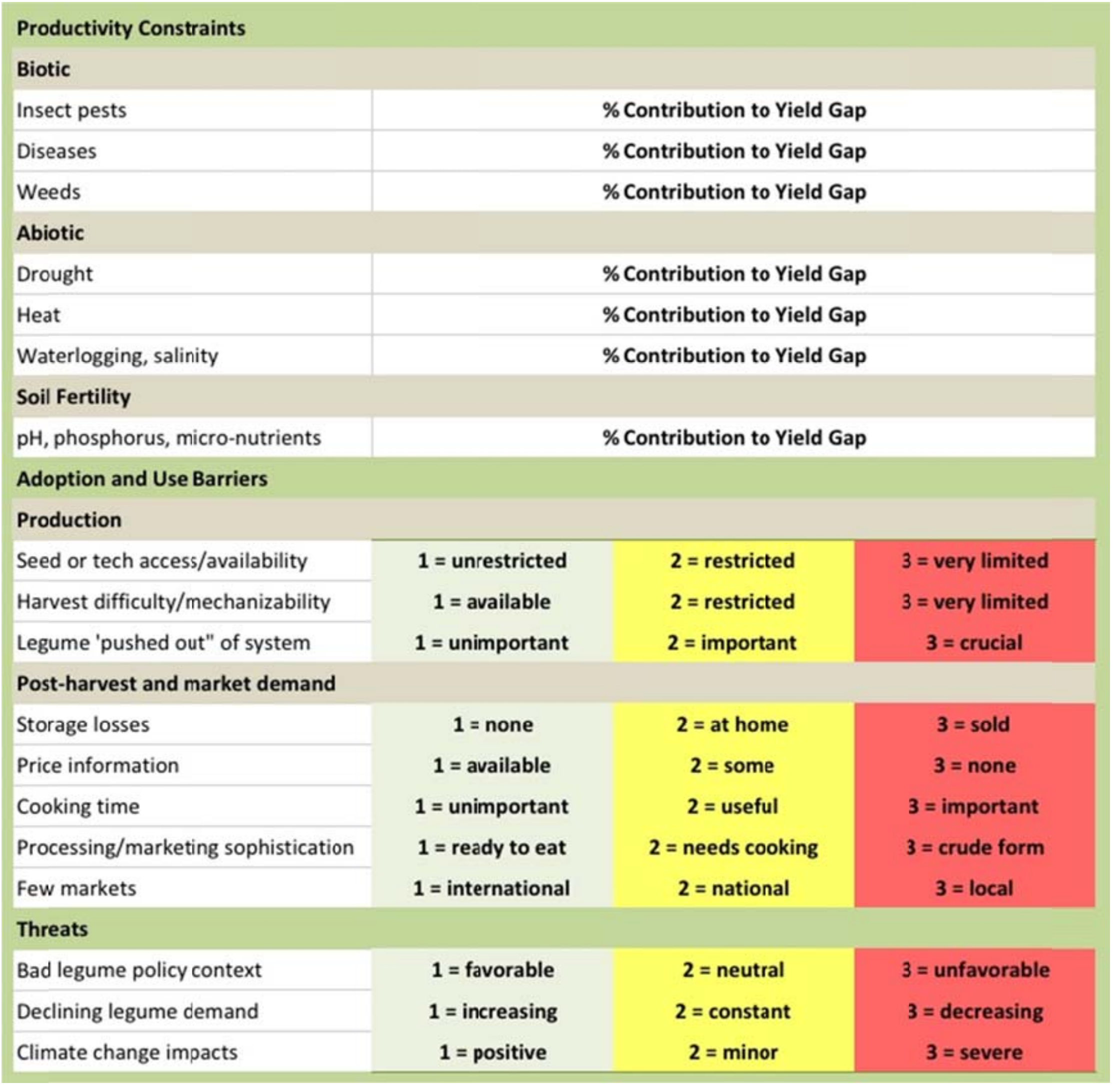
These agricultural worlds, found throughout the tropical regions of Africa, Asia, and Latin America, require different types of research products and interventions. For example, in agriculture-based and transforming economies, basic constraints of pests and diseases restrict on-farm yields. Limited availability of improved varieties and management practices also cause production to be low. Often, many varieties are cultivated to perform according to distinct production environments, with unpredictable rains and to meet household food and fodder preferences. Access only to local markets restricts demand and incentives to increase production.

In contrast, legume production for competitive urban markets, in India and Mexico for example, often face different production and demand challenges. Research priorities typically emphasize specialized commercially preferred market traits, such as easing difficulties of mechanizing harvests. Priorities also include fostering value-added processing that simplifies preparation and boosts consumption, such as ready-to-eat or snack foods.

Few studies in the CGIAR examine production, sales, and consumption of grain legumes in diverse farming systems and LIFDC countries (Tripp 2011; Akibode & Maredia 2011). To help prioritize research efforts within diverse production, sales and consumption contexts, a comprehensive analysis identified and estimated the relative importance of constraints, barriers and threats along the value chain. National and international partners of the CRP conducted the performance review of the eight grain legumes per major farming systems of each relevant LIFDC. Grain legume experts assessed the biophysical constraints at the farming system level; while for policy-economic constraints, the unit of analysis was at a higher, country level. Some responses differed depending on state of knowledge and type of constraint.

The review of production performance estimated actual yields, the relative importance of biotic and abiotic constraints, and the adoption levels of modern varieties. Next, reviews of sales and consumption examined aspects of technology use, sophistication of post-harvest activities and scope of market offerings (Table 4). Yield productivity constraints included biotic (insect pests, disease, weeds), abiotic (drought, heat) and other factors (waterlogging, soil fertility). Technology and use barriers comprised three contextual factors affecting: production availability/access to seed or technology (unrestricted, restricted, very limited), difficulty in harvesting and mechanizability (available/unimportant, restricted important, very limited/crucial), and legumes being "pushed out" of farming systems because of policy support or productivity gains of other crops, typically cereals (not applicable/unimportant, restricting important, very limited/crucial).

Table 4. Topics of pan-legume analysis: constraints, barriers and threats.



Productivity Constraints			
Biotic			
Insect pests	**% Contribution to Yield Gap**		
Diseases	**% Contribution to Yield Gap**		
Weeds	**% Contribution to Yield Gap**		
Abiotic			
Drought	**% Contribution to Yield Gap**		
Heat	**% Contribution to Yield Gap**		
Waterlogging, salinity	**% Contribution to Yield Gap**		
Soil Fertility			
pH, phosphorus, micro-nutrients	**% Contribution to Yield Gap**		
Adoption and Use Barriers			
Production			
Seed or tech access/availability	**1 = unrestricted**	**2 = restricted**	**3 = very limited**
Harvest difficulty/mechanizability	**1 = available**	**2 = restricted**	**3 = very limited**
Legume 'pushed out" of system	**1 = unimportant**	**2 = important**	**3 = crucial**
Post-harvest and market demand			
Storage losses	**1 = none**	**2 = at home**	**3 = sold**
Price information	**1 = available**	**2 = some**	**3 = none**
Cooking time	**1 = unimportant**	**2 = useful**	**3 = important**
Processing/marketing sophistication	**1 = ready to eat**	**2 = needs cooking**	**3 = crude form**
Few markets	**1 = international**	**2 = national**	**3 = local**
Threats			
Bad legume policy context	**1 = favorable**	**2 = neutral**	**3 = unfavorable**
Declining legume demand	**1 = increasing**	**2 = constant**	**3 = decreasing**
Climate change impacts	**1 = positive**	**2 = minor**	**3 = severe**

Barriers affecting post-harvest activities and market demands included: storage losses (stored without losses, stored with losses, sold immediately), price information (available, some but insufficient, none), cooking time (unimportant, useful/helpful, important), level of processing/marketing sophistication (ready-to-eat, transformed and needs cooking, crude form), and available market (international, national, local). Threats to legume cultivation addressed: bad legume policy context (positive/favorable, none/neutral, negative/neutral), declining legume demand (increasing, constant, decreasing per capita), climate change (positive temp/rain, minor negative impacts, severe yield impacts). Refinement of the analytical methods and results will continue as a research activity within SC1.

Overall, the dataset represents 368 legume x country x farming systems. From both national and international programs, 43 experts evaluated particular legumes according to their field and other professional experience. A minimum farming system area within a country of 1500ha was selected to reduce the size of dataset while also enabling the identification of common bio-physical conditions and potential spillover benefits. This framework is used to illustrate how the research priorities of both the Product Lines (PL) and Strategic Components (SCs) address challenges along the value chain from production to consumption.

Data was both quantitative and qualitative. For example, yield losses were estimated according to percentage contribution to the yield gap (not % yield loss of yield potential). In contrast, the barriers were assessed according to a qualitative green-yellow-red scale representing no/low importance - medium importance - high importance/critical.

Summary results per legume and per region are in Table 5. Analysis of constraints, barriers and threats reveals important similarities and differences across the grain legumes and regions. Productivity constraints of insect pests and disease are perceived as being very important for six of the eight legumes: chickpea, cowpea, faba bean, groundnut, lentil and pigeonpea. Low soil fertility is especially important to beans, and to a lesser extent, soybeans. Crop diseases are the most important constraint in nearly all regions.

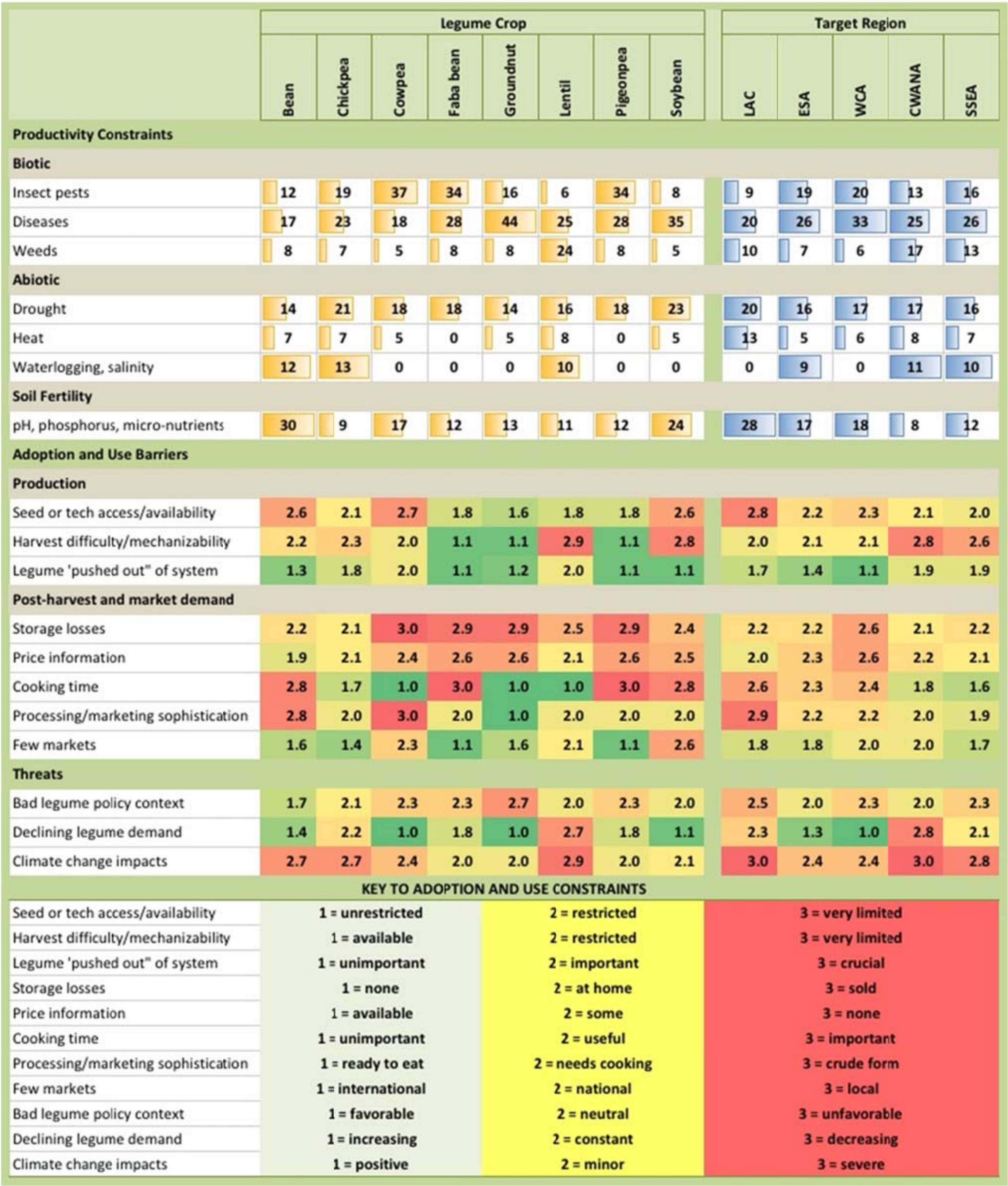
Barriers to adoption and use also differed per legume and region. Access to seed is very limited with beans, cowpeas and soybeans. Difficulty of harvest restricts lentil and soybean production. Policies are perceived to have pushed lentils, cowpeas and chickpeas out of some farming systems.

Post-harvest constraints also have differing levels of perceived importance. Lack of ability to store harvests and losses during storage greatly affects cowpea, faba bean, groundnut, and pigeonpea. Western and Central Africa face the greatest storage challenges. A lack of price information affects all legumes to differing degrees – with information most scarce for faba bean, groundnut, pigeonpea and soybean.

Ease of cooking was considered a challenge in preparing to pigeonpea, faba beans, beans and soybeans, but not so for cowpea, groundnut and lentil. Levels of processing/marketing also have a wide range of sophistication. While cowpeas and beans are mostly available only in crude forms, the other legumes had higher levels of processing, with groundnut the most processed legume. Market scope ranges from the internationally traded pigeonpea and faba bean, to locally-marketed soybean and cowpea.

Perceived importance of threats also differed according to legume and region. Groundnut production faces the most negative policy environment; while declining demand for lentils is an important threat. Growing demand is perceived for cowpea, groundnut and soybean and to a lesser extent beans. These results are used to inform CRP management for setting priorities within the PLs and SCs.

Table 5. Summaries of pan-legume constraints/threats analysis.



	Legume Crop								Target Region				
	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	LAC	ESA	WCA	CWANA	SSEA
Productivity Constraints													
Biotic													
Insect pests	12	19	37	34	16	6	34	8	9	19	20	13	16
Diseases	17	23	18	28	44	25	28	35	20	26	33	25	26
Weeds	8	7	5	8	8	24	8	5	10	7	6	17	13
Abiotic													
Drought	14	21	18	18	14	16	18	23	20	16	17	17	16
Heat	7	7	5	0	5	8	0	5	13	5	6	8	7
Waterlogging, salinity	12	13	0	0	0	10	0	0	0	9	0	11	10
Soil Fertility													
pH, phosphorus, micro-nutrients	30	9	17	12	13	11	12	24	28	17	18	8	12
Adoption and Use Barriers													
Production													
Seed or tech access/availability	2.6	2.1	2.7	1.8	1.6	1.8	1.8	2.6	2.8	2.2	2.3	2.1	2.0
Harvest difficulty/mechanizability	2.2	2.3	2.0	1.1	1.1	2.9	1.1	2.8	2.0	2.1	2.1	2.8	2.6
Legume 'pushed out" of system	1.3	1.8	2.0	1.1	1.2	2.0	1.1	1.1	1.7	1.4	1.1	1.9	1.9
Post-harvest and market demand													
Storage losses	2.2	2.1	3.0	2.9	2.9	2.5	2.9	2.4	2.2	2.2	2.6	2.1	2.2
Price information	1.9	2.1	2.4	2.6	2.6	2.1	2.6	2.5	2.0	2.3	2.6	2.2	2.1
Cooking time	2.8	1.7	1.0	3.0	1.0	1.0	3.0	2.8	2.6	2.3	2.4	1.8	1.6
Processing/marketing sophistication	2.8	2.0	3.0	2.0	1.0	2.0	2.0	2.0	2.9	2.2	2.2	2.0	1.9
Few markets	1.6	1.4	2.3	1.1	1.6	2.1	1.1	2.6	1.8	1.8	2.0	2.0	1.7
Threats													
Bad legume policy context	1.7	2.1	2.3	2.3	2.7	2.0	2.3	2.0	2.5	2.0	2.3	2.0	2.3
Declining legume demand	1.4	2.2	1.0	1.8	1.0	2.7	1.8	1.1	2.3	1.3	1.0	2.8	2.1
Climate change impacts	2.7	2.7	2.4	2.0	2.0	2.9	2.0	2.1	3.0	2.4	2.4	3.0	2.8

KEY TO ADOPTION AND USE CONSTRAINTS

Seed or tech access/availability	1 = unrestricted	2 = restricted	3 = very limited
Harvest difficulty/mechanizability	1 = available	2 = restricted	3 = very limited
Legume 'pushed out" of system	1 = unimportant	2 = important	3 = crucial
Storage losses	1 = none	2 = at home	3 = sold
Price information	1 = available	2 = some	3 = none
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Few markets	1 = international	2 = national	3 = local
Bad legume policy context	1 = favorable	2 = neutral	3 = unfavorable
Declining legume demand	1 = increasing	2 = constant	3 = decreasing
Climate change impacts	1 = positive	2 = minor	3 = severe

NOTE: Integers in Productivity Constraints represent % of yield gap. Decimal figures in Adoption and Use Barriers are qualitative classifications of constraints on a 1 to 3 scale.

Matching the allocation of CRP resources with expected benefits is a challenging exercise. The PLs represent different approaches to increasing productivity. PLs 1 to 5 emphasize the reduction of yield constraints. In contrast, PLs 6 and 7 strive to increase area planted to grain legumes by fitting the crop into a short-season niche, or by reducing pressures on scarce labor resources for weeding and harvesting. PL 8 is primarily an effort to increase yields by applying hybrid technologies to pigeonpea (which could also benefit other grain legumes). Consequently, no simple formula exists to measure the cost-benefit ratio of the PLs.

As part of the pan-legume analysis, experts also estimated likely adoption rates and the potential to increase yields within a given production context. Adoption studies and parameters within the value proposition analysis (Appendix 7) were also used. Although not referring to the PLs *per se*, such yield increases reflect not only the results of the PLs, but also other interventions such as applying known crop cultivation practices and socio-econo-political contexts. This part of the analysis identified regions, crops, countries and farming systems with greater and lesser likelihood of significant yield and adoption rate increases. Calculations combining adoption and increased yields generated an estimate of increased production. Summary and detailed estimates within an Excel spreadsheet can be accessed at www.GrainLegumes.cgiar.org.

In ten years, the expected average of net yield gains is 232 kg/ha. With respective grain legumes, expected yields gain on average are largest with faba beans (356 kg/ha). Largest percent increase in expected yields is with cowpea. In terms of regional gains, the largest expected gains are in CWANA and SSEA. Per crop and farming system, expected yield increases range from a low of 100 kg/ha of beans in marginal production zones of in many African countries and 122 kg/ha (a 9% increase) in Myanmar where yields are already considered high. The largest expected yield increases are over 600 kg/ha of faba bean in Ethiopia, where substantial yield increases of other grain legumes (e.g., beans) have occurred before. Other countries and farming systems with likelihood of significant yield increases include the highlands of Tanzania, Uganda and Zimbabwe for beans, or groundnut in Ghana. Of course, many biophysical and socio-econo-political factors affect these expected yield increases.

In ten years, efforts to improve adoption of new technologies are expected to produce an average net increase of 13% with an average adoption rate of 30%. Largest increases are expected with lentils and faba beans, and in the CWANA region. Expected increases in technology adoption differ per legume and country. The most substantial gains (net increase >30%) are expected in areas where use of modern varieties is rare such as Haiti, and where legumes are important within farming systems such as beans in Central America and chickpeas in Western Asia. In contrast, modest increases (net increase <5%) are foreseen in areas where modern varieties are already widely cultivated, such as beans in parts of Kenya and Mexico.

Table 6 is a summary of expected production outcomes per PL. Total increases in production were calculated by multiplying the expected adoption rate by the expected yield gain derived from expert opinion. Calculations of production increases were made for each farming system in each target country. The attribution of the yield gains was divided equally among the product lines in which the crop participates. In some cases, five product lines contribute to a yield gain; while in other cases, a sole product line contributes to the expected increase in yield. In all instances, production gains are assumed to be due to productivity gains rather than increases in the area harvested. Production increases are stated in metric tons.

The input-output analysis reveals consistencies and inconsistencies of matching resources with expected impacts. (By identifying magnitudes of production increase, this exercise also reveals where more post-harvest work is needed.) In Table 6, PL 1 appears to be overfunded with respect to the benefits generated. PL2 is the most underfunded initiative.

Table 6. Estimated gross value of production increase per Product Line (LIFDCs, including India)

Grain Legume	PL1	PL2	PL3	PL4	PL5	PL6	PL7	PL8	
Bean	136,548,155	136,548,155	-	136,548,155	-	-	-	-	409,645,088
Chickpea	-	122,852,522	-	122,852,522	122,852,522	122,852,522	122,852,522	-	614,263,193
Cowpea	83,218,963	-	-	-	83,218,963	-	-	-	166,438,328
Faba bean	-	17,204,220	-	17,204,220	-	-	17,204,220	-	51,613,160
Groundnut	-	-	284,031,840	-	-	-	-	-	284,032,290
Lentil	-	52,687,124	-	-	-	52,687,124	52,687,124	-	158,061,919
Pigeonpea	-	-	-	-	127,244,893	-	-	127,244,893	254,490,377
Soybean	37,216,666	-	-	37,216,666	-	-	-	-	74,433,637
Sum per PL	256,983,783	329,292,020	284,031,840	313,821,562	333,316,377	175,539,645	192,743,865	127,244,893	2,012,977,992
Input distribution	25%	10%	12%	12%	16%	5%	7%	6%	93%
Output distribution	12%	15%	13%	14%	15%	8%	9%	6%	93%
Difference	13%	-5%	-1%	-2%	1%	-3%	-2%	0%	0%

Nevertheless, CRP inputs and outputs can be interpreted differently. Besides emphasizing different research objectives and benefits as revealed in the value proposition analysis, the CRP on Grain Legumes generates impacts in countries with different partners. Thus the match between inputs and outputs depends types of benefits considered (e.g., economic, nutrition, environmental) and on if countries are considered as benefitting or contributing to research outcomes. For example, Table 7 reveals a different input-output assessment where a major partner to the CRP, India, is not considered as a benefitting country. In this case, the match between inputs and outputs amongst the PLs is closer in some cases and more distant in others.

Table 7. Estimated gross value of production increase per Product Line (LIFDCs, excluding India)

Grain Legume	PL1	PL2	PL3	PL4	PL5	PL6	PL7	PL8	Sum
Bean	136,548,155	136,548,155	-	136,548,155	-	-	-	-	409,645,088
Chickpea	-	24,290,848	-	24,290,848	24,290,848	24,290,848	24,290,848	-	121,454,827
Cowpea	83,218,963	-	-	-	83,218,963	-	-	-	166,438,328
Faba bean	-	17,204,220	-	17,204,220	-	-	17,204,220	-	51,613,160
Groundnut	-	-	182,306,111	-	-	-	-	-	182,306,561
Lentil	-	26,895,983	-	-	-	26,895,983	26,895,983	-	80,688,496
Pigeonpea	-	-	-	-	17,650,522	-	-	17,650,522	35,301,636
Soybean	37,216,666	-	-	37,216,666	-	-	-	-	74,433,637
Sum per PL	256,983,783	204,939,206	182,306,111	215,259,889	125,160,333	51,186,831	68,391,051	17,650,522	1,121,881,733
Input distribution	25%	10%	12%	12%	16%	5%	7%	6%	93%
Output distribution	21%	17%	15%	18%	10%	4%	6%	1%	93%
Difference	4%	-7%	-3%	-6%	6%	1%	1%	5%	0%

In summmary, the pan-legume and value proposition analyses are frameworks that enable researchers to examine key factors that affect production of the priority grain legumes and their diverse benefits. Nevertheless, efforts to justify investments in the PLs also require consideration of many factors, many of them changing (e.g., consumer demands, technology, etc.). As the CRP refines its priority-setting methods and analyses, adjustments to the program will be made in order to improve efficiencies and impacts.

Alignment with the priorities of regions, nations, farmers and development investors

Grain Legumes has considered the priorities within the agricultural development agendas of its partner regions and countries in establishing the CRP priorities. Although priority-setting information is not available for all countries and crops, the examples below indicate common perspectives, issues, constraints and opportunities.

West and Central Africa

- The CORAF/WECARD Strategic Plan (2007-16) ranks groundnut as third in priority among all crops in terms of research benefits (US$ 3.4 billion) via exports. Legumes collectively contribute 8.7% of agriculture GDP in the region.
- Numerous development investors support grain legumes R4D in WCA region because of their role in enhancing nutrition and livelihoods: the EC, DFID, SDC, CIDA, USAID and the World Bank.
- More recently, the Bill & Melinda Gates Foundation (BMGF) is investing in cowpea, common bean, groundnut and soybean research through the Tropical Legumes (TLI and TL II) projects with the

objective of increasing productivity and productivity of grain legumes and the income of smallholder farmers in Burkina Faso, Ghana, Mali, Niger, Nigeria and Senegal.

- The N2Africa project (supported by BMGF) aims to leverage biological nitrogen fixation for doubling the yields of common bean, cowpea, groundnut and soybean in the WCA region.
- Major investments are also coming from the USAID-sponsored Feed the Future Program (Feed the Future 2010) targeting soybean (along with rice and maize) to transform commodity value chains for high impact on nutrition, gender equity and poverty in WCA.

Eastern and Southern Africa

- ASARECA's strategic plan 2006-15 ranks groundnut as first priority among legumes, and states "pulses have relatively high current and expected future demand in the region".
- Ethiopia has been increasing the production of legumes for export during the last decade (IFPRI 2012), earning over US$ 90 million (in addition to local consumption) in 2007-08. The Government of Ethiopia is strongly supportive of the pulses value chains for export. Major legume crops are chickpea, common bean, faba bean, pea and lentil. IFPRI reported that pulses account for 13% of cultivated land and 15% of protein intake, and concluded "diversification by rotating staple cereals with pulses is an important income opportunity."
- SADC's new agricultural research subsidiary body, CCARDESA, has not yet produced a crop prioritization for Southern Africa, but national policies in Malawi, Mozambique and Zambia are informative. Malawi's 2011-15 prioritized strategy (Malawi Ministry of Agriculture 2011) targets "promoting diversified and enriched foods in complementary feeding programs for maternal nutrition and HIV/AIDS affected people through the use of soybean, common bean, pigeonpea and groundnut as key ingredients". These same legume crops were also part of the government's supported agricultural inputs subsidy program aimed at food and nutrition security and reducing poverty. Likewise, Zambia and Zimbabwe have put legumes on the priority list, and included in the agricultural inputs programs that support smallholder farmers.
- The National Small Farmers Association of Malawi (NASFAM) places priority on sustainable farming methods and risk management against droughts and climate change. As part of Strategic Development Plan process, groundnut and soybean were considered as next best options to tobacco (NASFAM 2011).
- Beans are a priority crop for enhancing both food security and income of smallholder farmers in both Tanzania through Kilimo Kwanza (a national agricultural development framework) and in Rwanda through the Plan for Agricultural in Rwanda.
- ASARECA ranks common beans a "high value crop" and considers beans to be a "major staple food crop in the region, in terms of contribution of both calories and protein."
- The USAID's "Feed the Future" program prioritizes legumes in Malawi; soybean, common bean, groundnut and sesame in Mozambique; and commodity value chains for maize, legumes and oilseeds in Zambia.
- In Uganda, common bean (for nutrition) is one of the three "Feed the Future" priorities, along with maize (for food security) and coffee (for growth).
- The BMGF supported Tropical Legumes projects are working in Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe with the aim of increasing production and productivity of legumes.
- The N2Africa project targets Malawi, Mozambique, Kenya, Rwanda and Zimbabwe to raise BNF of legumes and consequently yield of grain legumes, as well as the subsequent crop (in rotation) that benefits from residual nitrogen left in the soil by the legume.

South and Southeast Asia

- India is the world's largest producer and consumer of grain legumes. To address the gap between production and consumption (as described earlier) the Government of India has launched the Accelerated Pulses Production Programme (A3P) under the National Food Security Mission (NFSM).

Crops addressed are chickpea, pigeonpea, mung bean, urd bean and lentil among the pulses. A3P targets increased pulse production of 2 million tons (over the base line of 15 million tons/year). The target was achieved in 2010-11 with 17.3 t produced, due to increased area, favorable weather and high prices (Chandrasekhar 2011). The program has been extended under the 12th Five-year Plan (2012-16).

- The BMGF funded TL II project also operates in India and Bangladesh to increase production and productivity of chickpea, groundnut and pigeonpea.
- In Nepal, USAID's "Feed the Future" program prioritizes pulse value chains, along with rice, maize and vegetables. Prioritization was based on Nepal's own priority for investment, unmet demand, and a significant role in nutrition.

Latin America and the Caribbean

- SICTA (Central American System of Integration for Agricultural Technology) is the regional body coordinating agricultural research among seven countries in Central America. SICTA prioritizes the maize-bean system as an important value chain to be strengthened through technological innovation (http://redsicta.org/redesNacionales.html).
- The Generation Challenge Program highlights the maize-bean system as a priority to be targeted in efforts to address drought, malnutrition and poverty.
- In Honduras, one of the USAID's "Feed the Future" priorities is to increase the productivity of the two main grain crops, beans and maize. Besides improving food security in this impoverished country, this will free up agricultural land for cultivating higher-value export crops such as vegetables, fruits and coffee.
- "Feed the Future" in Nicaragua prioritizes beans along with coffee and horticulture, based on the following criteria: a priority of the country's government, largely smallholder-based, nutritionally important in diets, high export potential, high potential for production gains, and potential to employ women in processing.
- Guatemala, Haiti, Nicaragua and Honduras participate in the Bean Technology Dissemination Project aiming to reduce these countries' dependence on bean imports (Prensa Libre.com 2012). This project is convened by the USAID-supported Dry Grain Pulses CRSP and is aligned with "Feed the Future".

Central and West Asia and North Africa

- The International Assessment of Agricultural Knowledge, Science and Technology for Development report (IAASTD 2009) states that grain legume consumption in the region has increased as animal products have become more expensive due to high costs of feeds in the region. It urges that legumes also be included in CWANA cereal-based farming systems in order to improve the sustainability and productivity of the farming system.
- In Syria, wheat and cotton are by far the most important crops, but the government also sets producer prices for lentil and chickpea as well as for barley, sugar and tobacco (Westlake 2001).
- Morocco's Ministry of Agriculture and Fisheries has declared food legumes, particularly faba bean, to be a priority for research and development (MAPM 2007, 2010).

Review of past research

Conclusions drawn from research over the past three and a half decades on the eight grain legumes are summarized below, according to key constraints to production: diseases, insect pests, drought, high and low temperatures, edaphic problems, salinity and aluminum toxicity, nitrogen fixation, phenology and weeds. More details are provided in Appendix 8 and full reviews for each crop are available on the Grain Legumes website (www.GrainLegumes.cgiar.org).

Diseases

- Of the several foliar and viral diseases in soybean rust is the most important yield reducer and endemic in soybean growing areas of west, east and southern Africa with only a few new cultivars bred in Nigeria and Uganda being resistant.

- In common bean, resistant germplasm sources have been identified for most major diseases. Cultivars resistant to bean common mosaic virus, bean golden yellow mosaic virus (BGYMV) have been developed and deployed in farmers' fields. Molecular markers have been identified and used in selection for resistance to bean common mosaic necrotic virus.
- Both chickpea and lentil suffer from the same pathogens. Fusarium wilt is an important disease for both crops. Ascochyta blight and botrytis gray mold are other important diseases. Using resistant germplasm sources, Fusarium wilt resistant varieties have been developed and released for cultivation in several countries. Molecular markers linked to two major QTL are being used in marker-assisted breeding for resistance to Ascochyta blight in chickpea and Fusarium wilt in lentil.
- Faba bean is affected by several foliar diseases, different root rot complexes and viruses. Using resistant sources, breeding lines with resistance to Ascochyta blight, botrytis, chocolate spot, and rust have been developed, shared with NARS partners and released as cultivars.
- In groundnut, leaf spots (early and late leaf spot) and rust are widespread and important diseases. Aflatoxin contamination affects groundnut trade and profitability worldwide. Groundnut rosette disease (GRD) is the most devastating disease of groundnut in sub-Saharan Africa. Using resistant sources, breeding lines with resistance to early and late leaf spots and rust and GRD and with low levels of aflatoxin contamination have been developed and shared with NARS partners. Molecular markers have been identified for use in marker assisted breeding for rust and late leaf spots.
- Fusarium wilt and sterility mosaic disease (SMD) are the major pigeonpea diseases. Sources with individual and combined resistance to Fusarium wilt and SMD have been identified, and used in developing and deploying resistant cultivars. Phytophthora blight is emerging as a major threat to pigeonpea production.

Insects

- All legumes suffer significant losses to insect pests, especially chickpea, cowpea and pigeonpea. *Helicoverpa armigera* is a serious pest on chickpea and pigeonpea, and *Maruca vitrata* on pigeonpea and cowpea. Integrated Pest Management (IPM) systems, including host-plant resistance where available, have been the focus of research on control methods. Moderate levels of resistance to *Helicoverpa* have been identified in chickpea and pigeonpea, leading to the release of tolerant cultivars. Wild relatives have high levels of resistance and have been used in developing breeding lines with higher levels of resistance. IPM is necessary due to ineffectiveness of individual control methods and the lack of high levels of resistance for *Helicoverpa* in chickpea and pigeonpea and for *Maruca* in pigeonpea and cowpea. Development of transgenic plants (e.g., using one or more Bt genes) appears to have high potential for enhancing resistance to *H. armigera and Maruca.* Flower thrips in cowpea, and leaf miner and bruchids in chickpea are also important in some areas and resistant breeding lines have been developed.
- Bt cowpea has shown promising results in controlling *Maruca* in several confined field trials in Nigeria. Efforts are underway to transfer the trait to farmer-preferred varieties.

Drought

- Drought is one of the most important constraints to crop production in all crops, especially as drought can occur at any stage of crop development. Short-duration cultivars have been developed in legumes to overcome end-of-season drought. In groundnut, end-of-season droughts not only reduce yield, but predispose the crop to infection by *Aspergillus flavus* and aflatoxin contamination.
- Drought tolerance has been dissected into its component traits such as root morphologies, specific leaf area, improved mobilization of photosynthate to grain, chlorophyll content, transpiration efficiency, carbon isotope discrimination and canopy temperature and sources of such traits used in developing drought tolerant cultivars that have been shared with NARS. Many of these have been deployed and adopted by farmers in the rainfed dryland areas.
- Molecular markers that lead to increased water use efficiency have been identified for key root traits such as lateral root number, maximum root length, root fresh weight, root dry weight and slow wilting related to increased drought tolerance in soybean, groundnut, chickpea and cowpea and are being used in marker-assisted selection to develop drought tolerant cultivars. Several legume species

appear to share common mechanisms of adaptation to drought, opening promising opportunities for cross-learning on tolerance traits. Transgenic approaches (e.g., DREB) may offer alternative methods to enhance drought tolerance, but further development and testing is required before knowing the full potential.

High and low temperatures

- Research by CCAFS has shown that high temperature stress (above 30^0C) will occur with increasing frequencies in the near future in East and Southern Africa, India, South East Asia and Northern Latin America, which are important legumes growing areas. Heat stress even for a few days during flowering and pod filling stages drastically reduces seed yield. Chilling temperatures during the early reproductive growth cause yield losses in chickpea in many parts of Asia, particularly in high latitudes and hilly areas and low temperature at germination in post-rainy season groundnut.
- Low temperatures result in poor germination, poor plant stand and reduced yield. Sources in germplasm have been identified both for heat stress and low temperature for use in developing tolerant cultivars in chickpea, groundnut, lentil and faba bean.

Edaphic problems

- Soil constraints, especially low soil fertility, limit legume yields across the tropics in smallholder agriculture. Root traits for efficient acquisition of nutrients (e.g., phosphorous) could contribute to improved efficiency in fertilizer use in legumes. Pigeonpea has the capacity to cope with low soil phosphorus as its roots secrete pissidic acid to solubilize phosphorus from the soil. Several common bean lines having tolerance to low soil fertility have been developed.
- The use of phosphate solubilizing bacteria, especially from *Pseudomonas*, *Bacillus* and *Rhizobium,* has been used as inoculants to increases phosphorus uptake by the plant and increase crop yields. Phosphate solubilizing bacteria and plant growth promoting rhizobacteria together could reduce phosphorus fertilizer application by up to 50% without any significant reduction of crop yield.

Salinity and aluminum toxicity

- Saline soils limit legume production to a great extent. Variation for tolerance to salinity has been reported in several legumes and can be used in developing salinity tolerant cultivars. Knowledge of the tolerance mechanisms in crops like chickpea or groundnut can greatly hasten progress on similar constraint in other crops.
- Aluminum toxicity is the single most important factor that effects plant growth and yield under acidic soils. Genetic variation for tolerance to aluminum toxicity has been reported in groundnut, common bean, and lentil indicating feasibility of genetic improvement for this constraint.

Nitrogen fixation

- Legumes fix atmospheric nitrogen (symbiotic nitrogen fixation or SNF), and also increase access to nutrients such as phosphorus. Sufficient numbers of compatible *Rhizobia* are often not naturally occurring in most of the soils where grain legumes are cultivated and there is need for *Rhizobia* application to seeds. Production of efficient inoculants and distribution to smallholder farmers is a limitation, and needs to be addressed.

- Most legume crops have shown promise for a positive contribution of nitrogen fixation to the yields of subsequent crops and/or system productivity. Common beans with climbing growth habit consistently fix more nitrogen than bush types due to longer growth cycle and vegetative vigor. One of the major limitations for optimizing nitrogen fixation is the higher sensitivity of the symbiosis to stresses (e.g., drought, low fertility and salinity), which needs primary focus. Legume species also vary in their nitrogen fixation potential, which also offer cross-learning opportunities.

Phenology

- Early maturity is required in many crops by farmers around the world to avoid end-of-season drought, beside exploitation of short season niches, and in the multiple cropping systems. Significant genetic variation for earliness is available in the germplasm, and selection of earliness *per se* is not scientifically challenging, but rather the challenge is to combine earliness with other traits that are associated with late maturity, especially high yield and in some cases disease and pest resistance.

Breeding for short-duration is becoming more relevant in many legumes with the predicted decline in length of the growing (rainy) seasons due to the effects of climate change.

Weeds

- Weeds (parasitic and non-parasitic) remain a major production constraint to grain legumes, as they are poor competitors to the prevalent weeds. Non-parasitic weeds compete with the crop for light and nutrients, often leading to yield losses up to 40%. Manual weeding has become uneconomical and impractical for many smallholder farmers due to non-availability of labor and high labor wages. In several agricultural production systems, intensification has led to serious problems of soil fertility and parasitic weed infestation. Sources of resistance to parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii* in cowpea and *Orobanche crenata* in faba bean and lentil have been identified, and are being deployed.

Constraints to adoption of improved cultivars and production technologies in grain legumes

The available studies suggest that, in general, adoption of improved cultivars and production technologies has been low and slow in grain legumes, as compared to commercial crops.

Inadequate dissemination of information to farmers – At the most fundamental level, many farmers simply do not know about the improved cultivars and production technologies available and/or their potential advantages. Various awareness creation activities (field days, farmers' fairs, farmers' field schools, news programs through electronic and print media and training program) and farmer participatory varietal selection (FPVS) trials have been used in some projects (e.g. Tropical Legumes II) to increase the levels of awareness among farmers. The FPVS trials provide the farmers an opportunity to see advantages of improved cultivars on their own fields.

The improved cultivar lacks one or more key traits desired by the farmers – Adoption of an improved cultivar may also be restricted if it lacks one more key traits desired by farmers related to production, marketing or consumption.

Inadequate availability of seed – One of the key factors limiting adoption of improved cultivars of grain legumes is the inadequate availability of quality seed of improved cultivars to the farmers. In some cases seed may be available, but not in adequate quantity or at the place and time required by the farmers, or at the price affordable by the farmers. The commercial (both public and private) seed industry has shown limited interest in seed production of grain legumes mainly because of the following factors.

- The public seed sector generally gives higher priority to staple food crops and commercial crops and has not been able to meet the seed demand of grain legumes.
- The private seed sector is more involved in commercial crops, vegetables and hybrids where profits are higher.
- Farmers recycle legume varieties multiple times once they receive the initial seed.
- Some grain legumes have a high seeding rate (e.g. 60 to 120 kg/ha for chickpea and groundnut). This poses challenges in producing large quantities of seed and distributing it to farmers who are widely scattered in the inaccessible rural areas.
- Seed viability of common bean, faba bean, groundnut and soybean is lost rapidly.

Currently, there is a need for stronger public-sector seed production of legumes as the involvement of private seed sector is very limited. In addition, seed production by informal seed systems (individual farmers, communities and farmers' groups) also needs to be strengthened. The activities that can facilitate promotion of informal seed systems may include training of farmers in seed production and marketing, organizing farmers' groups/communities/cooperative societies, and facilitating these for seed production and marketing, promoting rural seed entrepreneurs, organizing seed fairs and distribution/sale of small seed packs.

Lack of farmers' access to inputs and output value chains – The uptake of technologies by farmers also depends on their access to markets for both inputs and outputs. The investment of farmers in adoption of new technologies is affected by the resources governments provide to farmers, their access to credit, market opportunities and available polices. Addressing the needs and priorities of smallholder farmers and other actors along the value chain is necessary for greater technology uptake and impacts.

Examples of past efforts and successes on adoption of improved cultivars of grain legumes

The limited studies available on the adoption of improved cultivars of grain legumes revealed variable results, ranging from very low adoption in some regions to very high and rapid adoption in other regions. There are considerable evidences to demonstrate that the rate and the extent of adoption increases when concerted efforts are made to enhance adoption of improved cultivars. Key reports are summarized here and the details are given in Appendix 9.

Beans in sub-Saharan Africa

- A study conducted in 2005 on adoption of bean varieties across five countries (Tanzania, Uganda, Rwanda, DR Congo and Malawi) showed that percentage of total bean area occupied by new varieties released during 1985-1994 was 31 to 68% (Kalyebara et al. 2008).
- Sperling and Munyaneza (1995) used nationwide household data and estimated the adoption rate of 40% and intensity of 10-20% for climbing beans in Rwanda, after about 7 years of intervention.
- Unlike improved varieties, the adoption of improved crop management practices, particularly those addressing soil fertility, has been modest for beans (Kalyebara et al. 2008; Katungi et al. 2011b). This has been attributed to problems on both the supply and demand sides.

Chickpea in Asia and North Africa

- A study conducted in Hamirpur district, Uttar Pradesh, India during 2002-06 showed that improved chickpea varieties replaced almost 75% of local varieties in project loactions, and the adoption of a full chickpea technology package increased from about 10% farmers in 2002-03 to 45% farmers in 2004-05 in these locations (Singh et al. 2008).
- The improved chickpea varieties cover about 80% of the chickpea area in Andhra Pradesh state of India, where there has been 3.8-fold increase in area and 9.3-fold increase in production during 1999/00 to 2008/09 (Gaur et al. 2012).
- There has been a rapid adoption of improved chickpea varieties in Myanmar. The varieties Yezin 3, Yezin 4, Yezin 5 and Yezin 6 released during 2000 to 2004 covered about 82% of total chickpea area in Myanmar during 2007 (Than et al. 2007).
- The kabuli chickpea variety “Gokce” is grown in 85% of the chickpea area in Turkey (Tripp 2011).

Cowpea in sub-Saharan Africa

- A study conducted in 1999 in Kano and Jigawa states in northern Nigeria found that about 38% of the cowpea area was planted to improved dual-purpose cowpea varieties (Kristjanson et al. 2002).
- A study conducted in 2004 on the role of farmer-to-farmer diffusion of improved cowpea varieties in Kano and Kaduna states in northern Nigeria showed that over 70% of the farmers in the project villages adopted improved varieties (Alene and Manyong 2006). Similar studies on adoption of improved cowpea varieties in other parts of northern Nigeria showed adoption estimates of 56% of the sample households in Bauchi and Gombe states (Agwu 2004) and 40% of cowpea area in Borno state in 2007 (Gadbo and Amaza 2010).
- In Ghana, the new cowpea variety, Vallenga released in 1987, was grown on more than 20,000 ha in the northern region during early 1990s (Sanders 1994). A study conducted in 2007 found adoption estimates of 16% of the cowpea area in the Northern and Upper West regions (Abatania et al. 2010).
- In northern Senegal, Schwartz et al. (1990) found that the introduction of an early maturing cowpea variety in 1985 doubled the area sown to cowpea and increased the national production from the previous 15-year average of 17,800 to 66,000 tons in that year.
- In Burkina Faso, Sanders (1994) found that by 1992 diffusion of eight new cowpea varieties was almost 100% of the cowpea area.
- In 2010, IITA carried out a survey of national cowpea improvement programs in 16 countries, which together account for over 95% of the total cowpea production in sub-Saharan Africa (Alene 2012).

The results showed that improved varieties accounted for an estimated 23% of the total cowpea area in Sub-Saharan Africa.

Lentil in South Asia and sub-Saharan Africa

- The improved varieties of lentil were adopted in an estimated area of about 60,000 ha area in Bangladesh and BARI Masoor 4 alone occupied about 39,000 ha (Sarker et al. 2004). In Nepal, the improved lentil varieties occupied about 35% area in Tarai region (Neupane et al. 2008).
- In Ethiopia, the overall adoption rate of new lentil varieties among the surveyed farmers was 19% with higher adoption rates in Ada-Liban and Gimbichu districts (Aw-Hassan et al. 2009). The adoption rate of improved lentil technology is estimated to be about 36% (ICARDA 2010).

Groundnut in sub-Saharan Africa and South Asia

- A baseline household survey of adoption of improved groundnut varieties conducted as part of the Groundnut Seed Project in West and Central Africa, indicated adoption rates of 14% in Niger, 44% in Mali, and 32% in Nigeria (Ndjeunga et al. 2008). A similar baseline household survey of adoption of improved groundnut varieties, conducted as part of the Tropical Legumes II project, indicated adoption rates of 24% in Niger, 8% in Nigeria, and 3% in Mali (Ndjeunga 2010). The discrepancies in the adoption rates are largely explained by the fact that the samples were not nationally representative and were localized in and around intervention sites.
- In a recent nationally representative survey in Nigeria, the adoption rate of improved groundnut varieties was found to be 22% of the cultivated area. Using a nationally representative survey from Uganda, Kassie et al. (2010) estimated that 53% of the groundnut area was planted with improved varieties. These estimates are more or less consistent with expert opinion surveys carried out in various countries across sub-Saharan Africa. Estimates from experts show adoption rates of 47% in Kenya, 57% in Malawi, 27% in Mali, 12% in Niger, 22% in Nigeria, 32% in Tanzania, and 56% in Uganda (Ndjeunga 2012; Simtowe 2012).
- In a study by ICRISAT, it was found that variety ICGS 44 was adopted in the Andhra Pradesh state of India to the extent of 98% during the rainy season, 58% during the post-rainy season and 32% during the summer season of 1997 in Guntur and West Godavari districts.
- The groundnut variety ICGV 91114, which was released in 2006 in Anantapur district of Andhra Pradesh, India showed a very low level of adoption (0.2%), the main reasons being the deficiencies in the informal seed systems and lack of irrigation facilities. However, the variety was found to be adopted during years of drought due to better crop and fodder yield (Birthal et al. 2011).

Pigeonpea in sub-Saharan Africa and South Asia

- A nationally representative sample survey of uptake of improved pigeonpea varieties in Tanzania showed an actual adoption rate of 19% with a potential adoption of 62% had all pigeonpea growers been exposed to the varieties (Simtowe et al. 2011).
- Data from expert opinions from the DIVA project showed adoption rates of 13% in Malawi, 40% in Tanzania, 50% in Mali and 60% in Kenya (Simtowe 2012).
- In a study conducted in project villages in Uttar Pradesh state of India, it was found that 80% of the area was planted with the improved pigeonpea variety NA 1 in the target villages and 25% in the neighboring villages (Singh et al. 2008).

Soybean in sub-Saharan Africa

- In Benue state of Nigeria, which is the major producer of soybean in the country, Sanginga et al. (1999) found that adoption of new varieties increased from mere 9% of farmers in 1989 to over 75% farmers in 1997, with the new varieties occupying an estimated 30% of the total soybean land area.
- In 2010, IITA carried out a survey of national soybean improvement programs in 14 countries, which together account for over 75% of the total soybean production in Sub-Saharan Africa (Alene 2012). Largely because soybean itself is new as a crop and its cultivation is made possible through improved varieties, the total soybean area in Cote d'Ivoire, Malawi, Zambia, and Zimbabwe is under improved varieties, whereas Uganda, Nigeria, and Ghana have adoption levels of over 90%.

Product Lines and Strategic Components

By joining efforts, the partners in Grain Legumes will (i) streamline and harmonize coordination amongst diverse partners, (ii) improve their knowledge-management capacity and (iii) increase their operational efficiency and effectiveness by sharing facilities, expertise, locational presence and services. The convening partners are four CGIAR centers (ICRISAT-*lead*, CIAT, ICARDA, IITA) together with major collaborating partners (EIAR, EMBRAPA, GDAR, Generation Challenge Program, ICAR, and the USAID-supported legume CRSPs) that are all leaders in complementary topics and regions on these crops.

Grain Legumes will improve the grain legume crops that are the most widely grown by smallholders in LIFDCs of four regions: sub-Saharan Africa (SSA that includes Eastern and Southern Africa [ESA] and Western and Central Africa [WCA]), Central and Western Asia and North Africa (CWANA), South and Southeast Asia (SSEA) and Latin America and the Caribbean (LAC). Analyses of crop harvest area and poverty guided the prioritization of eight food crops: **chickpea, common bean, cowpea, faba bean groundnut, lentil, pigeonpea and soybean**.

Grain Legumes is based on a R4D process of informed decisions to establish research priorities, developing and disseminating improved seed and crop management technologies, increasing value with product processing and promoting widespread consumption. Also accompanying this process are supporting activities that foster innovations systems and manage knowledge (Figure 2).

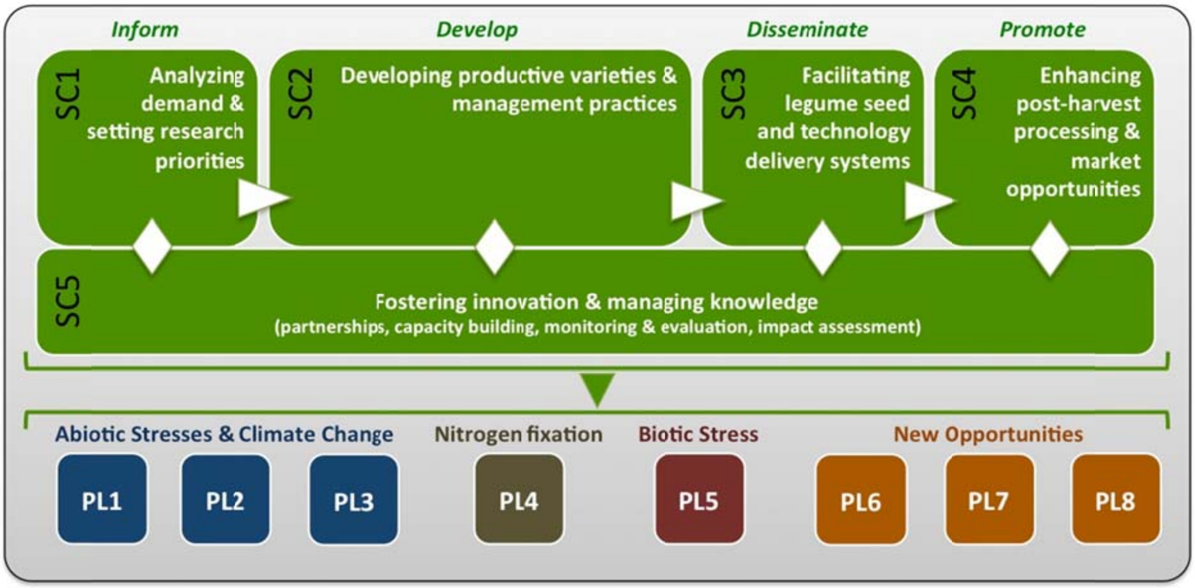


Figure 2. Operational framework of the CRP: Strategic Components (SCs) and Product Lines (PLs).

The Strategic Component **SC2** *Variety breeding and management practices* is a central focus and comparative advantage of Grain Legumes. SC2 is linked with other Strategic Components (SCs) before technology development: **SC1** *Demand analysis and research priorities*, afterwards with **SC3** *Seed and technology delivery* and **SC4** *Processing and marketing*, while **SC5** *Innovation systems and knowledge management,* provide support in fostering coordination, communication, critique and collaboration amongst diverse research and development partners.

Product Lines (PLs) correspond to particular crop improvement objectives that some or most grain legumes have in common. These eight PLs either address either persistent challenges to grain legume production or strive to advance unrealized potentials and opportunities.

The CGIAR Research Program on Grain Legumes will advance a portfolio of eight product lines (PLs) that group grain legumes according to similar challenges or unrealized potentials. Improving the **production performance** of grain legumes is based on four general objectives, to:

- address abiotic stresses and climate change effects,
- capture the unique ability of grain legumes to fix nitrogen,
- manage key biotic stresses, and
- generate new opportunities to integrate grain legumes in intensive cropping systems.

Built on the past successes, germplasm collections, and recent progresses in science, PL research will employ both conventional breeding approaches and modern molecular tools. Prioritization, dissemination and promotion activities of the SCs support the PLs in achieving production, sales, consumption and environmental performance objectives. The PLs are as follows:

Addressing abiotic stresses and climate change effects

PL 1. Drought and low-phosphorous tolerant common bean, cowpea, and soybean
PL 2. Heat-tolerant chickpea, common bean, faba bean and lentil
PL 3. Short-duration, drought tolerant and aflatoxin-free groundnut

Capturing unique legume ability to fix nitrogen

PL 4. High nitrogen-fixing chickpea, common bean, faba bean and soybean

Managing key biotic stresses

PL 5. Insect-smart chickpea, cowpea, and pigeonpea production systems

Generating new opportunities to intensify cropping systems

PL 6. Extra-early chickpea and lentil varieties
PL 7. Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties
PL 8. Pigeonpea hybrid and management practices

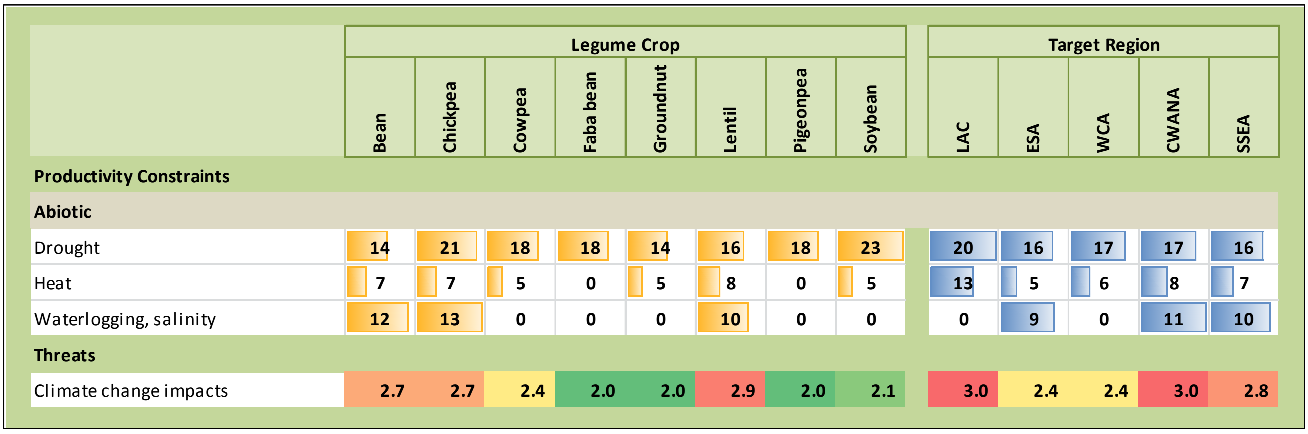
Each Product Line indicates the specific target traits, grain legume crops, regions and countries that are presented in the rationale of each Product Line. The countries have been selected based on ability and requirements to participate in each of the Strategic Components in the Product Line. Key research partner countries, where an active research program will be conducted, are indicated under SC2. Additional countries are indicated under SC3 and SC4 based on the opportunities to involve these countries more in the evaluation and dissemination components. Finally, all countries will be considered under SC1 for data gathering and priority setting, and will have options to participate in and access the knowledge sharing and capacity programs under SC5. Grain Legume resources will be highest for those countries involved in SC2, with more reliance on in-country and third-party resources for participation in the other SCs. The initial three-year workplans/logframes are presented for each PL in Appendix 10.

Product Lines (PLs)

Addressing abiotic stresses and climate change effects

The combined effect of drought and heat on grain legumes causes an estimated 18-28% of total yield losses. Climate change is expected to worsen these stresses. Critical yield impacts are foreseen to faba bean, lentil, common bean and chickpea, moderate impacts to cowpea and minor impacts to soybean, pigeonpea and groundnut (Table 8). In response, three Product Lines target particular challenges in order to improve the production performance of the seven legumes most affected by abiotic stresses and climate change. Given the complexity of these stresses and their interactions with other biotic and abiotic factors, stress tolerance must be sought in combination with other traits relevant for a given crop.

Table 8. Associated legumes and productivity constraints/threats of Product Lines 1, 2 and 3.



	Legume Crop								Target Region				
	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	LAC	ESA	WCA	CWANA	SSEA
Productivity Constraints													
Abiotic													
Drought	14	21	18	18	14	16	18	23	20	16	17	17	16
Heat	7	7	5	0	5	8	0	5	13	5	6	8	7
Waterlogging, salinity	12	13	0	0	0	10	0	0	0	9	0	11	10
Threats													
Climate change impacts	2.7	2.7	2.4	2.0	2.0	2.9	2.0	2.1	3.0	2.4	2.4	3.0	2.8

Product Line 1. Drought and low-phosphorus tolerant common bean, cowpea and soybean

Rationale

Water deficits (drought) and low soil fertility (poor plant nutrition) are considered to be major abiotic stress limitations for production (Stamp and Visser 2012), especially for legume crops that are cultivated in relatively marginal environments. Research on abiotic stresses including breeding has a long history in the CGIAR legume programs, but was given a fresh impulse by the Tropical Legumes I and II projects that focus on improving tolerance to drought. Lessons from those projects have positioned legume crops to improve genetic adaptation to drought through an innovative combination of approaches: trait based selection with some sharing of common approaches across different species; genomics combined with a thorough understanding of adaptation mechanisms and their genetic basis; crop simulation modeling to help navigate the biological complexity; and interspecific crosses with desert species *Phaseolus acutifolius* in the case of common bean. This PL builds on those lessons to extend the impact of drought tolerant cultivars, and incorporates a component of enhancing adaptation to low fertility soils, especially soils with low phosphorus (P) availability. Low soil fertility is the most widespread and chronic limitation to crop yield in the tropics, often co-occurring with drought in areas where legumes are cultivated. Improving on-farm yields demands dealing with multiple stresses. Addressing drought and low P in a combined manner is both innovative and necessary.

Combined drought and low P stress can result in negative interactions for the crop. Application of the Decision Support System for Agrotechnology Transfer (DSSAT) model to maize and bean production in Central America under scenarios of climate change indicate that drought will be disastrously limiting production in regions of low fertility (CIAT, unpublished data). Drought reduces moisture in the soil surface where most available P is found, and this may limit P supply to the plant. Low soil P may also limit root expansion for more water capture, and both stresses will severely reduce symbiotic N fixation (Sinclair and Vadez 2002) and limit N supply for grain. Such interactions necessitate understanding better the stresses on farm, and combining tolerance traits. A factorial experiment on farm for the main factors (water, P, N) will determine the most limiting factor for each targeted species and farming system.

Relevant traits will be targeted to the most limiting stresses, using existing knowledge and knowledge developed in other PLs (e.g. PL4). A comparison of stress tolerance traits across crops will shed light on the most promising strategy for both drought and low soil P. For example, Ratnakumar and Vadez (2011), Zaman-Allah et al. (2011) and Belko et al. (2012) looked at water saving traits in groundnut, chickpea, and cowpea using similar experimental protocols. Traits may contribute to either source strength or sink strength. For example, plant traits of both root (basal root development; root hair density and length; root exudates**)** and shoot (e.g., water conserving traits**)** determine the relative adaptability to edaphic constraints of different species and of genotypes within a species. Photosynthate translocation efficiency for enhanced grain filling has been investigated in common bean and addresses multiple stresses (Beebe et al. 2008). A common denominator of legumes is the abortion of a large proportion of flowers, especially under stress but even if the carbon source does not appear to be limiting (for example, with *Phaseolus coccineus* which produces a huge biomass but sets very few pods). Flower abortion may limit sink capacity. Cowpea is relatively less sensitive to low P than other legumes, and may express adaptation mechanisms that could be targeted in the other crops. Soybean is especially sensitive to low P and requires attention, especially considering that this aspect is not addressed in most other breeding programs of soybean except in southern China where significant progress has been made. This PL assumes that on-going selection for essential agronomic traits (e.g., resistance to rust in soybean) is a necessary part of this effort.

A rather simple, mechanistic model has been developed as part of Tropical Legumes I project for simulating growth, development and yield. This model has proved to be robust across a wide range of locations and weather environments, and needs to be adapted to simulate response of common bean, cowpea and soybean in a range of conditions. The comparison of the simulations with the experimental results offers a tool for greater insight about the plant traits and mechanisms causing the observed results and about the comparative sensitivity of the model to various plant traits in the experimental locations. A refined and validated legume model for each crop will serve as an excellent tool to target stress adapted cultivars to specific target environments.

Table 9. Targeted countries for Product Line 1.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Drought tolerance, Low P availability, Disease resistance	Common bean	Latin America, Africa	Ethiopia, Kenya, Malawi, Guatemala, Honduras, Mexico		
				Nicaragua, Tanzania, Uganda	
					Burundi, DR Congo, Mozambique, Zambia, Zimbabwe, Colombia, El Salvador
	Cowpea	Africa	Nigeria, Burkina Faso, Mozambique, Niger		
				Mali, Senegal, Tanzania	
	Soybean	Africa	Mozambique, Nigeria		
				Malawi, Uganda	

Targets

Five-year outputs

- Sources of tolerance to low phosphorus and drought identified
- Common bean, cowpea and soybean cultivars having combined tolerance to drought and low phosphorus developed

Ten-year outputs

- Common bean, cowpea, and soybean cultivars having combined tolerance to drought and low P

Activities

- Identify potential research sites representative of production regions for drought stress and low P availability
- Standardize and share phenotyping methods for physiological traits across legumes
- Assess genetic variability and identify sources of drought and low P tolerance in cultivated and wild species
- Identify traits and associated molecular markers for drought and low P tolerance
- Understand molecular mechanisms of flower abortion and photosynthate translocation to grain in common bean under drought stress and low P availability
- Use existing soybean simulation models to develop similar ones for common bean and cowpea, and estimate the effects of plant traits in different production environments

Output targets

- Quantitative data available on degree of stress in different environments, and on interactions among the stresses (SC1)
- Common screening methods for tolerance to drought and low P stress developed (SC2)
- Field screening sites with managed stress conditions identified for phenotyping and breeding (SC2)
- Sources of shoot traits (transpiration efficiency, water saving traits, and for sink strength) for tolerance to drought, and root traits for tolerance to low P in germplasm and breeding lines identified (SC2)
- Key alleles contributing to superior photoassimilate translocation under drought or low P stress in common bean and other species identified (SC2)
- QTL for reduced flower abortion and enhanced pod formation under drought stress in common bean mapped (SC2)
- Gene based markers for improving drought and low P tolerance identified (SC2)
- Ideotypes with key traits and related genetic makeup for stressful production environments developed (SC2)
- Cultivars with enhanced yield and resource use efficiency in drought and P-limited environments developed and disseminated (SC2/SC3)
- Post-harvest processing technologies for common bean, cowpea and soybean refined and disseminated (SC4)
- Capacity of NARS in research on drought and low P tolerance in grain legumes enhanced (SC5)

Partnerships

CIAT and IITA will cooperate to lead this effort. Drought and edaphic constraints are priorities within the Dry Grains Pulse CRSP that has historically focused on cowpea and common bean, and collaboration can be foreseen in this area. However, the range of traits that need to be addressed cannot be covered by one research program or one center, and greater progress can be attained by combining different approaches with active participation of a range of partners, e.g., by tapping existing phenotyping platforms (http://www.icrisat.org/bt-root-research.htm). The development of a network of phenotyping sites naturally implies partnership with strategically placed partners in relevant environments, mostly in developing countries. Testing of lines will be carried out in combination with crop management components together with Dryland Systems and HumidTropics.

Impact pathway

This product line is knowledge intensive, and will generate knowledge that will need to be applied either in crop improvement or in agronomic management. Thus knowledge sharing will be a critical part of the impact pathway. In addition to conventional channels of formal publication, capacity building in techniques of plant analysis including whole plant physiology will be far more important. Capacity building will take the form both of degree training and as training of field technicians, and as knowledge evolves, this latter component must be expanded and updated occasionally through field workshops. Outputs of improved cultivars will follow standard seed based technology dissemination. Experience in Tropical Legumes-II that focused on stressful environments is especially relevant here.

Product Line 2. Heat-tolerant chickpea, common bean, faba bean and lentil

Rationale

Many countries could experience unprecedented heat stress because of global climate change (Battisti and Naylor 2009). Heat sensitivity in crops such as chickpea, common bean, faba bean, and lentil is a major limiting factor that can reduce yields, product quality, and lead to restricted geographic adaptation (Summerfield et al. 1984; Rainey and Griffiths 2005a; Wang et al. 2006; Beebe et al. 2011; Upadhyaya et al. 2011). Yield losses occur under high night temperatures, which negatively affect all stages of reproductive development (Hall 2004). Pod set can be reduced to zero if night temperatures exceed 30^0C. Day temperatures >30^0C and night temperatures >20^0C can result in yield reductions in common bean (Rainey and Griffiths 2005a, b). In chickpea, the high temperature stress ($35/16^0$C) during pod development decreased seed yield by 53 to 59% as compared to the control ($20/16^0$C) (Wang et al. 2006). Heat stress during the reproductive phase in legumes adversely affects pollen viability, fertilization, pod set and seed development leading to abscission of flowers and pods and substantial losses in grain yield (Nakano et al. 1998, Hall 2004; Devasirvatham et al. 2012). Improving heat tolerance in these legumes would increase yield stability, protect against global warming, and maintain and extend the geographic range of cultivation, particularly in lower elevations in many countries. Pollen-based screening methods developed to evaluate heat tolerance in soybean (Salem et al. 2007) and mung bean (Suziki et al. 2001) could be useful for evaluating genotypes for tolerance to heat stress. Climate change has also a number of observed, anticipated, or possible consequences on crop health (Savary et al. 2011). In the changing climate scenario of rainfed lowland to mid-altitude environments, heat stress invariably leads to soil moisture deficit during reproductive growth stages of chickpea, common bean, faba bean and lentil thus predisposes them to necrotrophic pathogens such as *Rhizoctonia bataticola* causing dry root rot (DRR) (Pande et al. 2011). Heat stress is increasingly becoming a serious constraint to grain legumes production in certain regions due to a large shift in area of grain legumes from cooler, long season environments to warm, short-season environments (e.g. shift in chickpea area from northern to southern India), increase in area under late sown conditions, and reduction in winter period and higher temperatures due to climate change (Gaur et al. 2012). Even in current climates, high temperature is the climatic factor which is most widely limiting the common bean yields, and breeding for heat tolerance could benefit 7.2 million ha of common bean (some of which could benefit by drought tolerance), and could increase highly suitable areas by some 54% (Beebe et al. 2011).

Genetic variation for heat tolerance has been identified in chickpea (Krishnamurthy et al. 2011, Upadhyaya et al. 2011), common bean (Rainey and Griffiths 2005; Porch 2006; Petkova et al. 2007) and lentil (Erskine et al. 2011). Diverse sources of heat tolerance will need to be exploited to develop heat tolerant cultivars. Interspecific lines derived from crosses of tepary bean (*Phaseolus acutifolius)* with common bean have better yield over common bean checks in Puerto Rico (Porch et al. unpublished data). Tepary bean is a valuable genetic resource to improve common bean for hot, dry climates, and several hundred interspecific progenies exist for gene mining. The precision and efficiency of breeding programs will be enhanced by integrating novel approaches, such as high throughput phenotyping, marker-assisted selection (MAS), genome wide selection (GWS), chromosome segment substitution lines, rapid generation turnover and gametophytic selection. Grain legume cultivars with enhanced heat tolerance and management strategies of emerging diseases will minimize yield losses in cropping systems/growing conditions where the crop is exposed to high temperatures at the reproductive stage. Heat and necrotrophic pathogen tolerant cultivars of chickpea, common bean, faba bean and lentil are expected to be more resilient to climate change and variations in sowing dates to enhance opportunities for expanding area of grain legumes to new niches and cropping systems, such as rice-fallows in south Asia for chickpea and lentil and maize-based systems in east and southern Africa for common bean and faba bean.

This PL provides an opportunity for comparative studies on heat tolerance across legumes. The levels of heat tolerance available in different species can be compared and the most heat tolerant species can be identified for a target environment. PL2 will also help in establishing common sites and protocols for heat tolerance screening. Comparative studies on physiological mechanisms of heat tolerance will help in understanding mechanisms of heat tolerance across legumes and developing a lab-based screening method (e.g. pollen selection) for heat tolerance. The candidate genes for heat tolerance identified in one species can be used to identify homologous genes across species.

Table 10. Targeted countries for Product Line 2.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Heat tolerance, Disease resistance, Grain quality	Chickpea	SSEA, Africa	India, Pakistan		
				Myanmar	
					Tanzania, Malawi, Ethiopia
	Common bean	Latin America and Africa	Malawi, Uganda, Colombia, Honduras, Brazil, Puerto Rico		
				DR Congo, Kenya, El Salvador	
					Cameroon, Tanzania, Mozambique, Guatemala, Haiti
	Faba bean	CWANA, Africa	Ethiopia		
				Morocco	
					Egypt, Syria
	Lentil	South Asia, CWANA	India		
				Bangladesh, Nepal	
					Syria, Iran, Ethiopia

Targets

Five-year outputs

- Better understanding of the physiological and molecular mechanisms of heat tolerance
- Breeding lines/varieties with heat tolerance during reproductive phase developed

Ten-year outputs

- Area cultivated under heat tolerant cultivars increased, including expansion of cultivation in new agro-ecological niches

Activities

- Identify high temperature hot spots for each crop that can serve as primary screening sites in different target areas, and develop high throughput phenotyping protocols
- Assess genetic variability for heat tolerance within and between crop species
- Understand physiological mechanisms and identify candidate genes conferring tolerance to heat stress, and develop molecular markers for heat tolerance
- Elucidate physiological mechanisms of heat tolerance and interaction of heat and moisture stresses.
- Develop chromosome segment substitution lines through introgression of tepary bean segments to the common bean genome
- Assess effects of heat stress on grain quality traits that can affect market-value of the grain
- Develop breeding lines and varieties with enhanced levels of reproductive stage heat tolerance, dry root rot resistance and improved grain quality by using integrated breeding approaches
- Refine ICM practices for target legumes grown under heat stress conditions
- Test and disseminate heat tolerant chickpea and lentil cultivars along with ICM packages to enhance their adoption by farmers
- Develop a database on existing and potential heat prone areas and new niches that can be brought under cultivation due to availability of heat tolerant cultivars
- Strengthen capacity of NARS partners in grain legume improvement for heat tolerance

Output Targets

- Target areas and cropping systems requiring heat tolerant cultivars of chickpea, common bean, faba bean and lentil identified (SC1)
- Phenotyping protocols for heat tolerance developed and sources of heat tolerance identified in each target legume species (SC2)
- Better understanding of the physiological mechanisms of heat tolerance (SC2)
- Interaction between heat and moisture stress understood (SC2)
- Candidate genes, molecular markers and novel breeding methods for heat tolerance identified/developed (SC2)
- Chickpea, common bean, faba bean and lentil germplasm and breeding lines combining enhanced heat and dry root rot tolerance and improved grain quality available (SC2)
- ICM practices for chickpea, common bean, faba bean and lentil crops grown under heat stress conditions developed (SC2)
- Area under cultivation of heat tolerant cultivars of chickpea, common bean, faba bean and lentil enhanced (SC3)
- Genotype-environment combinations that provide optimum grain quality in chickpea, common bean, faba bean and lentil identified (SC4)
- Capacity of stakeholders in research and development on heat tolerance in grain legumes enhanced (SC5)

Partnerships

CG centers (CIAT, ICARDA and ICRISAT), ARIs and NARS will be involved in development of technologies, while NARES, government and non-government extension agencies, NGOs, Farmers' groups and farmers in target countries will be involved in dissemination of technologies.

Impact pathway

The intermediate products developed under this product line include efficient screening methods for heat tolerance, sources of heat tolerance, knowledge on mechanisms and genetics of heat tolerance, molecular methods and novel breeding methods for heat tolerance and elite breeding lines with improved heat tolerance. These products will be developed in partnership with NARS partners and shared with others via publications, group meetings, training programs and supply of breeding materials. The intermediate products of this PL will enhance capacity of NARS breeding programs in developing heat tolerant cultivars. The heat tolerant cultivars developed in partnership with NARS partners will be promoted by knowledge empowerment of farmers and strengthening seed supply systems. The heat tolerant cultivars will help in expanding the area of legumes in new niches, and stabilize yield in areas prone to heat stresses and mitigate impacts of climate change. The farmers will realize higher and more stable yield of grain legumes, leading to enhanced income, enhanced food supply and nutrition.

Product Line 3. Short-duration, drought tolerant and aflatoxin-free groundnut

Rationale

Over two-thirds of the global groundnut is produced as a rainfed crop where drought is a major yield constraint. While drought can occur throughout the growing season, mid-season drought and end of season drought are estimated to cause losses of 500 million US$ annually (Sharma and Lavanya 2002). Therefore, breeding and selection for drought adaptation are important for alleviating drought effects on groundnut productivity. Pod yield-based breeding for drought tolerance is less favored due to excessive genotype × environment interactions (e.g., Hamidou et al. 2012) and therefore trait based breeding approaches can be more rewarding by pyramiding alleles of traits that confer yield stability and resilience, assuming the mechanisms of adaptation to specific types of drought are understood. Seed yield under water-limited environments is determined by components that relate to water as transpiration (T), transpiration efficiency (TE) and harvest index (HI). Increase in water use may be desirable, although it did not seem to play a critical role in the case of groundnut (Vadez and Ratnakumar, in preparation). Rather, it seems to be the timing of water extraction during the grain filling period that is important (Ratnakumar and Vadez 2009).

Increased water use efficiency (WUE) had been pursued by many in breeding for better drought tolerance (Condon et al. 2004). However, screening for WUE can be cumbersome and expensive particularly in case of breeding programs when thousands of breeding lines are to be assessed in a relatively short time. Moreover the complex interactions of the individual components of yield and difficulties faced to resolve WUE in breeding programs and the influence many physiological and environmental factors on TE have led scientists to look for alternate and more heritable traits that contribute to WUE (Blum 2005; Sinclair 2012). Surrogate traits earlier used to screen for WUE, i.e. specific leaf area (SLA), specific leaf nitrogen or SPAD chlorophyll meter readings (SCMR) or carbon isotope discrimination, have indeed a limited value (Krishnamurthy et al. 2007; Devi et al. 2011). More promising appears to be the capacity of certain groundnut genotypes to limit transpiration at high vapor pressure deficit, which allow these to save water under hot and dry conditions (Devi, Sinclair and Vadez 2010), a trait that has also been tracked in several other crops such as cowpea (Belko et al. 2012) and chickpea (Zaman-Allah et al. 2011). Similarly harvest index had been shown as the major component that suffers under drought and improvement in this was shown to improve the drought tolerance of individual genotypes (Ratnakumar and Vadez 2011; Hamidou et al. 2012; Krishnamurthy et al. 2010). Then the maintenance of a high harvest index was a consequence of developing smaller leaf canopy, which saved water (Ratnakumar and Vadez 2012). Recently, Hamidou et al. (2012) demonstrated success of field evaluation and identification of sources for intermittent (mainly mid-season) drought tolerance. Therefore, a two-pronged approach of yield based drought tolerance assessment and a parallel evaluation of traits that are known to contribute and the search for newer and simple contributory traits had to continue.

End-of-season drought not only reduces crop yield substantially but also predisposes groundnut to infection by aflatoxin producing fungi *Aspergillus flavus* and *A. parasiticus*. Aflatoxin contamination is an important quality and health concern worldwide affecting its trade and profitability (Wu et al. 2008). *A. flavus* and *A. parasiticus* can invade groundnut seed in the field before harvest, during post-harvest drying and curing, and in storage. The semi-arid tropical environment is especially conducive to pre-harvest contamination due to end-of-season drought, whereas in wet and humid areas, postharvest contamination is more prevalent. Appropriate drying, curing and storage practices can minimize postharvest aflatoxin contamination. However, these will work only if the groundnuts are free from pre-harvest aflatoxin. Therefore, resistance to pre-harvest aflatoxin contamination (seed infection and aflatoxin production) is a major objective in breeding (Nigam et al. 2009). Pod wall, seed coat and cotyledons are all potential barriers to the aflatoxin producing fungi. The fungi have to first penetrate the pod wall, then the seed coat to reach the cotyledons where they produce aflatoxin (Mehan 1989). These three components of resistance are inherited independently (Upadhyaya et al. 2002, Utomo et al. 1990). Sources of resistance to all three types of resistances have been reported in the cultivated groundnut (Mehan 1989, Rao et al. 1995, Upadhyaya et al. 2001, Waliyar 1994). However, the levels of resistance that are available are not high in cultivated groundnut and use of wild relatives as sources of resistance, or a transgenic may be needed to develop varieties with adequate levels of resistance to aflatoxin buildup.

Short-duration high-yielding groundnut cultivars are required for short-growing seasons, necessitated by end-of-season droughts, escape diseases and to fit in to short windows in multiple cropping systems. These cultivars will not only avoid the losses due to end-of-season droughts but will also be useful in reducing pre-harvest infection and aflatoxin contamination. New sources of early maturity with improved agronomic performance and seed and pod traits than the most commonly used variety 'Chico' (Bailey and Hammnos 1975) have been identified (Upadhyaya et al. 2006). An organized effort to assemble, evaluate and group these available cultivars across Africa and Asia is needed. There is also a need to diversify the genetic pool of donors of drought tolerance and the available vast germplasm resources can be utilized adopting the examples of other crops (Krishnamurthy et al. 2010). Short-duration high yielding cultivars that fit into the growing season, with tolerance to drought and high levels of resistance to seed infection and aflatoxin contamination are required, that when used with appropriate management strategy would result in groundnut with very low or nil levels of aflatoxin.

Table 11. Targeted countries for Product Line 3.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Earliness, Drought tolerance, Aflatoxin-free	Groundnut	SSEA, Africa	India, Malawi, Mali, Nigeria		
				Mozambique, Tanzania, Uganda, Niger	
					Senegal

Targets

Five-year outputs

- Short duration high yielding groundnut cultivars suitable for target regions developed
- Drought tolerant and low aflatoxin cultivars suitable for drought prone environments developed

Ten-year outputs

- Short-duration drought tolerant groundnut cultivars and integrated aflatoxin management practices promoted in different agro-ecologies

Activities

- Map areas with high risk of drought (mid- and end-season) and aflatoxin contamination
- Develop precision phenotyping tools for drought tolerance related traits
- Identify sources of traits associated with drought tolerance and aflatoxin contamination in cultivated germplasm and wild *Arachis* species
- Develop transgenic groundnut with higher levels of drought tolerance and resistance to aflatoxin contamination
- Develop introgression lines using amphidiploids with tolerance to drought and low levels of aflatoxin contamination
- Understand mechanisms and genetics of drought tolerance and resistance to aflatoxin contamination
- Develop genomic tools for use in breeding for drought tolerance
- Develop short duration breeding lines and cultivars with appropriate levels of resistance to key stresses and enhanced nutritional traits using integrated breeding platforms
- Develop drought tolerant nutrient dense breeding lines
- Support formal and informal seed systems for quality seed supply for enhanced adoption of improved varieties
- Refine and evaluate integrated aflatoxin management practices
- Strengthen capacity of NARS partners in groundnut improvement for short duration, drought tolerance, and aflatoxin management

Output Targets

- Target areas requiring short-duration, drought tolerant cultivars and aflatoxin management identified (SC1)
- High precision phenotyping tools for drought tolerance traits developed (SC2)
- Sources of traits related to drought tolerance, aflatoxin resistance and nutritional quality identified (SC2)
- Transgenic events of groundnut with high levels of drought tolerance and resistance to aflatoxin contamination developed (SC2)
- Better understanding of mechanisms and genetics of drought tolerance and aflatoxin contamination (SC2)
- Genomic tools developed and integrated in breeding for drought tolerance (SC2)

- Short-duration, drought tolerant, nutrient dense and low aflatoxin breeding lines/varieties developed and shared with partners (SC2)
- Enhanced adoption of short duration, high yielding cultivars and integrated crop management practices (SC3)
- Formal and informal seed systems strengthened to ensure adequate seed supply (SC3)
- Post-harvest processing technologies for reduced aflatoxin contamination and value added products refined and disseminated (SC4)
- Capacity of stakeholders in research and development on short-duration, drought tolerance and aflatoxin management strengthened (SC5)

Partnerships

ICRISAT, ARIs, Peanut CRSP, CIRAD (France), US$A and Louisiana State University (USA) on output target 5, Catholic University of Brasília (Brazil) and NARES, government and non-government extension agencies, NGOs, Farmers' groups and farmers in target countries. The translation of transgenic work will be done with the Indian NARS.

Impact pathway

This product line addresses the most important abiotic stress (drought) and an important factor that affects quality of the produce (aflatoxin contamination) in groundnut. Sources of drought tolerance and aflatoxin resistance will be shared with partners along with high precision phenotyping methods, genomic tools and breeding methods for traits related to drought tolerance and aflatoxin contamination. The NARS breeding programs will be able to enhance efficiency in developing drought tolerant and low-aflatoxin cultivars. The breeding material supplied to NARS partners will lead to release of short-duration cultivars with enhanced drought tolerance and reduced aflatoxin contamination. Short-duration, drought tolerant, nutrient dense and low aflatoxin resistant cultivars developed in this product line will be promoted for cultivation in target environments using different promotional activities. The biggest bottleneck in adoption of improved cultivars is the availability of quality seed. This will be addressed by strengthening both formal and informal seed systems. Enhanced adoption of improved cultivars and integrated crop management practices will lead to improved groundnut productivity and quality in drought prone environments.

Capturing a unique legume ability to fix nitrogen

Grain legumes are often cultivated on marginal, less-productive soils. Generally, such conditions cause an estimated 9-30% of total yield losses (Table 12). The ability of grain legumes to fix nitrogen in soils not only benefits legume crops but also, to varying degrees, the performance of all crops within farming systems. Increasing the ability to fix nitrogen reduces needs for chemical fertilizer, thereby lowering costs of production and associated greenhouse gas emissions.

Table 12. Associated legumes and productivity constraints/threats of Product Line 4.

	Legume Crop								Target Region				
	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	LAC	ESA	WCA	CWANA	SSEA
Productivity Constraints													
Soil Fertility													
pH, phosphorus, micro-nutrients	30	9	17	12	13	11	12	24	28	17	18	8	12

Product Line 4. High nitrogen-fixing chickpea, common bean, faba bean and soybean

Rationale

Symbiotic nitrogen fixation (SNF) is a trait that distinguishes legumes among the major world crops. In the target areas of CRP on Grain Legumes, that are often low input systems, the capacity of grain legumes to capture nitrogen (N) symbiotically is a fundamental characteristic that needs to be fully harnessed and exploited. Legumes meet a large part of their own N demand through SNF and also partially contribute to the N requirement of the following crop in the system. Past efforts to enhance SNF through inoculation with improved Rhizobium strains were partially successful, and N2Africa project is addressing this aspect. Although, many factors determining the rate of nitrogen fixation are set by the host plant, starting with the phloem flow (Walsh et al. 1989), breeders have been reticent to incorporate SNF as a breeding objective due to lack of good selection tools, and without clear evidence of the potential of success among other multiple breeding objectives. New strategies that are focused on the plant, and that address the fundamental limitations to SNF, must be developed, employing new tools that have come on board in the past two decades, and using recently developed germplasm reference collections that are a gateway to access diversity. ^{15}N natural abundance is a relatively simple technique that is far easier to apply for field-oriented breeders and agronomists than other methods used previously, and it can feasibly be applied to hundreds of samples at modest cost. Viable low nitrogen field sites in partner countries will be established for the evaluation of breeding lines and in some cases, landrace germplasm. A population of common bean recombinant inbred lines (RILs) segregating for SNF traits has been re-sequenced and will be explored for its potential. Some recent studies in soybean have suggested an impact of domestication and cultivation on nitrogen fixation. Therefore it is important to identify those genetic factors that are associated with bottleneck of domestication and cultivation to impact nitrogen fixation.

We are all familiar with the concept of a “yield gap” resulting from limitations imposed by a sub-optimal environment. SNF is similar to yield in the sense that a legume may have substantial potential to fix nitrogen, but the potential is severely limited by environmental factors including drought, heat, low soil phosphorus, soil pH and flooding. SNF is more sensitive to stress than other plant processes like photosynthesis. The consequence is a severe nitrogen shortage under many abiotic stresses. However, genetic variability for reduced sensitivity of SNF is known (e.g., in the case of soybean and drought). A series of trials with soybean under the N2Africa project suggested that some soils are “non-responsive” to phosphorus and inoculation, indicating that the limiting factor remains to be identified. We need to address the “SNF gap” by defining better the limiting factors in a given farming system, and alleviating these limitations, either genetically or through crop management. Over the past two decades there has been modest to good progress in introducing different types of stress tolerance into some legumes (e.g., drought tolerance and low phosphorus tolerance). Selection for drought tolerance in common bean appears to have improved SNF capacity (Devi et al. 2012). It is time to return to the issue of SNF to determine if such tolerance has influenced SNF in stressful environments. Other evidence suggests a hypothesis that common bean is “lazy” and shuts down its SNF prematurely in the face of stress. How can the crop be made to continue to invest in SNF under stress? Different grain legume species have different SNF capacities. Can comparative physiology reveal traits that support SNF, for example, in a high fixer like faba bean that can serve as a model for other grain legumes, and for a better-targeted search for traits within a species?

A persistent question revolves around the potential of SNF to contribute to system sustainability. Work in this area has been carried out by the Tropical Soil Fertility Institute (formerly TSBF) of CIAT, and will be an area of interaction with the N2Africa project and with Dryland Systems and HumidTropics, supplying colleagues with unique and superior legume germplasm and associated rhizobium inoculum. Positive effects on system nitrogen and maize yields have already been reported with soybeans, and with common beans of climbing growth habit that are becoming popular and are increasing yields in East Africa, and particular attention will be dedicated to these. Animal nutrition is another important contribution to the farming system. Large differences in the haulm nitrogen concentration in groundnut (1.94-2.88%) have been found, with potential for superior fodder quality with no trade-off to haulm or pod yield.

Table 13. Targeted countries for Product Line 4.

<table>
<tr><th colspan="6">Target</th></tr>
<tr><th rowspan="2"><i>Traits</i></th><th rowspan="2"><i>Crops</i></th><th rowspan="2"><i>Regions</i></th><th colspan="3"><i>SC1 & SC5 Countries</i></th></tr>
<tr><th><i>SC2 Countries</i></th><th><i>SC3 Countries</i></th><th><i>SC4 Countries</i></th></tr>
<tr><td rowspan="12">SNF</td><td rowspan="3">Chickpea</td><td rowspan="3">SSEA, Africa</td><td colspan="3">India, Pakistan, Ethiopia</td></tr>
<tr><td></td><td colspan="2">Tanzania, Myanmar</td></tr>
<tr><td></td><td></td><td>Malawi, Morocco</td></tr>
<tr><td rowspan="3">Common bean</td><td rowspan="3">Latin America, Africa</td><td colspan="3">Rwanda, Honduras</td></tr>
<tr><td></td><td colspan="2">Kenya, Uganda</td></tr>
<tr><td></td><td></td><td>Burundi, DR Congo, Cameroon, Malawi, Mozambique, Tanzania, Guatemala, Haiti, Mexico</td></tr>
<tr><td rowspan="3">Faba bean</td><td rowspan="3">Africa, CWANA</td><td colspan="3">Ethiopia, Egypt</td></tr>
<tr><td></td><td colspan="2">Morocco</td></tr>
<tr><td></td><td></td><td>Syria</td></tr>
<tr><td rowspan="3">Soybean</td><td rowspan="3">Africa</td><td colspan="3">Mozambique, Nigeria</td></tr>
<tr><td></td><td colspan="2">Malawi, Uganda</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Targets

Five-year outputs

- High SNF potential germplasm identified from screening of germplasm reference collections of climbing beans, soybean and chickpea identified and characterized
- Main edaphic factors limiting SNF identified and SNF potential of elite breeding lines assessed

Ten-year outputs

- Germplasm with high SNF potential under stress conditions identified, demonstrated on-farm and made available to the stakeholders
- SNF efficient cultivars (with at least 30% higher efficiency) developed and made available to NARS

Activities

- Identify environmental factors limiting SNF in chickpea, soybean and climbing beans
- Standardize screening protocols for SNF in target legumes
- Identify sites to evaluate germplasm under drought for SNF and low P availability
- Assess genotype by environment interactions for SNF
- Develop agronomic practices for higher SNF in different agro-ecologies
- Evaluate the residual effect of SNF on the succeeding crop
- Identify the genes/genomic regions associated with SNF in chickpea
- Isolate and evaluate high nodulating and nitrogen fixing indigenous rhizobia
- Identify the rhizobia by molecular means (by 16S rDNA analysis)
- Develop mass multiplication protocols for efficient rhizobial strains
- Strengthen capacity of stakeholders in SNF research and development

Output targets

- Factor(s) limiting SNF in different production environments/crops identified (SC1)
- Improved sources of SNF with tolerance to other stresses identified (SC2)
- Breeding methods that permit selection for SNF developed (SC2)

- Knowledge of genotype by environment interactions of SNF across crops/production systems generated (SC2)
- Genomic regions/ genes associated with high SNF identified (SC2)
- Climbing bean cultivars that result in 30-40% better yield in subsequent crop developed (SC2)
- Agronomic practices for enhancing SNF developed (SC2)
- High nodulating and nitrogen fixing indigenous rhizobia identified and characterized (SC2)
- Efficient mass production technologies for rhizobial strains developed (SC2, SC4)
- Capacity of partners for high quality *Rhizobium* inoculum production enhanced (SC5)

Partnerships

University of California-Davis (USA), Florida International University (USA) and ICRISAT are collaborating with College of Agriculture, Sehore (India) and Punjab Agricultural University (India) on N-fixation analysis in *Cicer* species through a USA National Science Foundation project. The Dry Grains Pulse CRSP has an active component on studying SNF through association mapping on germplasm from the USA. We will collaborate with the CRSP in extending this effort to tropical germplasm. It will be important to work with N2Africa, although N2Africa does not work with all the same crops as Grain Legumes. We will explore contacts with inoculant producers to share impact pathways.

Impact pathway

Outputs of improved cultivars will follow standard seed based technology dissemination, but in this case a special effort would be made to link the dissemination activities of N2Africa and the private sector working with inoculants, since one technology potentiates the other. The products from this PL will feed into the impact pathways of Dryland Systems and HumidTropics.

Managing key biotic stresses

The combined effect of insect pests, diseases and weed infestations on grain legumes causes an estimated 37-70% of total yield losses. Negative impacts of biotic stresses are most damaging to chickpea, cowpea and pigeonpea (Table 14). In response, PL5 improves the production performance of these 3 legumes most affected by biotic stresses.

Table 14. Associated legumes and productivity constraints of Product Line 5.

	Legume Crop								Target Region				
	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	LAC	ESA	WCA	CWANA	SSEA
Productivity Constraints													
Biotic													
Insect pests	12	19	37	34	16	6	34	8	9	19	20	13	16
Diseases	17	23	18	28	44	25	28	35	20	26	33	25	26
Weeds	8	7	5	8	8	24	8	5	10	7	6	17	13

Product Line 5. Insect-smart chickpea, cowpea, and pigeonpea production systems

Rationale

Chickpea, cowpea, and pigeonpea are devastated on the farmers' fields by insect pests, particularly the pod borers, *Helicoverpa armigera* and *Maruca vitrata*. They cause an estimated loss of over US$ 1 billion annually, despite application of insecticides costing over $500 million annually (ICRISAT 1992; Sharma 2005). The levels of resistance to pod borers in the cultivated germplasm are quite low, and hence, there has been little progress in developing cultivars with adequate levels of resistance to the target pests in these crops. However, wild relatives of these crops do have high levels of resistance to these pests (Sharma et al. 2005, 2009). Other pests of economic importance, with geographical differences, are heteropteran pod sucking bugs, *Clavigralla* spp. in cowpea and pigeonpea; pod fly, *Melanagromyza obtusa* in pigeonpea; and flower thrips in cowpea and pigeonpea. Our vision for the Product Line 'Insect-smart production systems' is to use an Integrated Pest Management (IPM) approach that will integrate the application of genetic engineering and genomic tools, wide hybridization, and rational application of biopesticides and synthetic pesticides to guide decision-making in pest management. The integration of transgenic plants with high levels of resistance to pod borers and management approaches will act as a major game changer to provide a sustainable solution to these intractable pest problems. This approach will be based on a thorough understanding of pest biology, behavior, population dynamics and migration patterns in relation to biotic and abiotic mortality factors and climate change, providing a systems perspective in relation to cropping systems where these crops are grown, instead of focusing solely on the crop plants *per se*.

Identifying novel genes and traits to confer resistance to the target pests, and assessing their suitability as candidate genes for genetic engineering in chickpea, cowpea, and pigeonpea will be important for developing a package for sustainable protection of these crops. Platform technologies for resistance to the target insect pests will be developed using novel resistance genes from *Bacillus thuringiensis* in combination with lectin and protease inhibitor genes. Efficient gene-promoter combinations will be the key to develop insect-smart transgenic plants in chickpea, cowpea, and pigeonpea, and for identifying novel genes and traits for insect resistance for sustainable protection of these crops from the ravages of pod borers. The potential of RNAi approach will also be harnessed to develop insect-resistant transgenic pigeonpea and chickpea by expressing double stranded RNA for some of the vital genes that play an important role in insect-host plant interaction, growth, development, and reproduction. Introgression of resistance genes from the wild relatives and novel sources using genomic and genetic engineering approaches will provide the major breakthrough in making host plant resistance an effective and a viable option for pest management in grain legumes. A platform will be established to gain a better understanding of the relationships between the insect pests, their plant hosts, and the environment. A combination of field data overlaid by GIS tools and population modeling can be used to predict pest outbreaks (in conjunction with climate change scenarios) to better target pest control interventions. Individual components of the IPM approach will be developed and validated in different crops and agro-ecologies. Information technology assisted approaches will be employed for information sharing with the NARES scientists, extension staff and farmers to ensure that the flow of information in both directions is sustained efficiently.

Table 15. Targeted countries for Product Line 5.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Insect resistance	Chickpea	SSEA, Africa	India, Ethiopia		
				Myanmar, Tanzania	
					Syria, Malawi
	Cowpea	Africa	Nigeria, Burkina Faso		
				Senegal	
	Pigeonpea	SSEA, Africa	India, Myanmar		
				Kenya, Malawi, Tanzania	

Targets

Five-year outputs

- Improved germplasm with higher levels of resistance to pod borer in chickpea, flower thrips and pod bugs in cowpea, and pod borer and pod fly in pigeonpea developed
- Chickpea, cowpea, and pigeonpea transgenic events with high levels of resistance to pod borers developed and characterized
- Insect specific forecasting models developed and validated for target regions

Ten-year outputs

- Chickpea, cowpea, and pigeonpea cultivars with high levels of resistance to pod borers developed
- Effective IPM systems in chickpea, cowpea and pigeonpea developed

Activities

- Evaluate germplasm of cultivated and wild relatives for resistance to the target insect pests
- Study mechanisms and genetics of resistance, and identify genes conferring resistance to the target insect pests using genomic and metabolomic approaches
- Develop breeding line with resistance/tolerance to the target insect pests in chickpea, cowpea and pigeonpea
- Develop platform gene technologies based on different promoter-gene combinations and transgenic events for resistance to pod borers in chickpea, cowpea and pigeonpea
- Study biology and population dynamics of the target insect pests in relation to biotic and abiotic mortality factors
- Study effects of climatic change on geographical distribution, natural enemies, and insect – host plant interactions
- Identify natural enemies with a potential to minimize the pest population, and develop technologies for mass-rearing of natural enemies for use by the farmers
- Produce neem and essential oils (pilot scale) and viral entomopathogens (cottage industry) for use in IPM
- Develop IPM packages based on agronomic practices, pest-resistant cultivars, and need-based application of selective pesticides for sustainable production of grain legumes

Output Targets

- Information on insect-plant host-environment interactions generated for better targeting of the pest control interventions, and to mitigate the effects of climate change (SC1)
- Diverse sources of resistance to the target pests identified, and information on mechanisms and inheritance of resistance generated (SC2)
- Interspecific derivatives of chickpea, cowpea, and pigeonpea with high levels of resistance to the target pests developed (SC2)
- Chickpea, cowpea, and pigeonpea cultivars with high levels of resistance to target insects through integrated breeding methods developed (SC2)
- Biosafety of transgenic chickpea, cowpea, and pigeonpea to the non-target natural enemies assessed (SC2)
- Industrially produced quality solid/liquid formulations of emulsifiable neem oil and entomopathogens developed, and potential natural enemies for inundative releases identified for use in farmers' fields (SC4)
- An IPM system based on rational application of pesticides, agronomic practices, and pest-resistant cultivars developed (SC2)
- Capacity of the stakeholders enhanced in research on host plant resistance (including genomics and transgenics) and IPM (SC5)

Partnerships

The main R4D partners will be NARS in the prominent chickpea, cowpea, and pigeonpea growing countries, as indicated in priority setting. NARS scientists will participate in the development and validation of the technological innovations, while extension agents, NGOs and farmer groups will participate in on-farm evaluation and dissemination of information. Also, SROs and policy makers will be instrumental in supporting the dissemination and scaling out of the technologies. On-going strong research partnerships will be strengthened with the Dry Grain Pulses CRSP (for the development of IPM-omics, biological control agents, bio-pesticides, and training videos), African Agricultural Technology Foundation (AATF) for Bt cowpea, Tropical Legumes I and II projects (particularly for the development of common screening protocols, and insect-resistant varieties), and ICAR and SAUs in India, as well as with advanced research institutes worldwide (mainly for genetic engineering, genomic s and bioinformatics)

Impact pathway

For improved varieties, the impact pathway will follow standard procedures for sharing of information and seed delivery mechanisms. For biological control agents and biopesticides, strong collaboration with NARS and extension systems facilitating demonstration and dissemination of the technologies will be an important factor for successful adoption leading to impact. Also, championing start-up industrial production of beneficial organisms, even at the ‘cottage industry’ level, will be necessary for fueling the value chain with the needed inputs. It is therefore imperative that capacity building, exchange of knowledge and awareness – from the producer to the policy maker – are given due attention for efficient and sustained demonstration and dissemination of IPM technologies for effective pest management in grain legumes.

Generating new opportunities to intensify cropping systems

Better production performance of grain legumes can motivate increased cultivation of grain legumes in farming systems currently with *and without* grain legumes. Due to their inability to compete with other agricultural activities, lentils, faba bean and chickpeas are perceived to have been pushed out of many farming systems (Table 16). Despite an apparent importance of harvest difficulty in cultivating soybean, the PLs do not include efforts to increase the mechanizability due to the availability of private-sector initiatives. Difficulty in harvesting greatly affects three legumes soybeans, faba bean and lentil. Improved traits such as earliness, herbicide-tolerance, and ability for machine harvest can reduce scarce and expensive inputs such as land and labor. For pigeonpea, substantial yield increases are foreseen in the next ten years ranging from 14% in Myanmar (1230 to 1400 kg/ha) to 100% in Mozambique (340 to 700kg/ha). In India, the largest pigeonpea producer, yields are expected to increase 50% (730 to 1100 kg/ha). Such large productivity increases are expected to intensify farming systems where pigeonpea is grown.

Table 16. Associated legumes and productivity constraints of Product Lines 6, 7 and 8.

	Legume Crop								Target Region				
	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	LAC	ESA	WCA	CWANA	SSEA
Productivity Constraints													
Biotic													
Insect pests	12	19	37	34	16	6	34	8	9	19	20	13	16
Diseases	17	23	18	28	44	25	28	35	20	26	33	25	26
Weeds	8	7	5	8	8	24	8	5	10	7	6	17	13
Abiotic													
Drought	14	21	18	18	14	16	18	23	20	16	17	17	16
Heat	7	7	5	0	5	8	0	5	13	5	6	8	7
Waterlogging, salinity	12	13	0	0	0	10	0	0	0	9	0	11	10
Soil Fertility													
pH, phosphorus, micro-nutrients	30	9	17	12	13	11	12	24	28	17	18	8	12
Adoption and Use Barriers													
Production													
Harvest difficulty/mechanizability	2.2	2.3	2.0	1.1	1.1	2.9	1.1	2.8	2.0	2.1	2.1	2.8	2.6
Legume 'pushed out" of system	1.3	1.8	2.0	1.1	1.2	2.0	1.1	1.1	1.7	1.4	1.1	1.9	1.9
Threats													
Bad legume policy context	1.7	2.1	2.3	2.3	2.7	2.0	2.3	2.0	2.5	2.0	2.3	2.0	2.3

Product Line 6. Extra-early chickpea and lentil varieties

Rationale

South Asia’s farming systems are dominated by two cereal systems: rice-wheat (9.77 m ha) and rice-rice (2.12 m ha) systems. In the Indo-Gangetic Plain (IGP), expansion of more productive wheat in northern India and boro-rice in eastern India and Bangladesh has resulted in substantial reductions of chickpea and lentil cultivation. With cereal yields projected to double over the next 30 years (Specht et al. 1999), legumes are likely to be pushed out, unless extra-early varieties of chickpea and lentil are developed that can fit in these cropping systems, and thus increase legume production and sustain productivity of the rice-based system (Rahman et al. 2009). Extra-early varieties (90-100 days) escape end-of-season drought and heat stresses in addition to fitting the crops in available short windows of these cropping systems (Gaur et al. 2008).

Improved production performance also require basic resistance to major diseases in the IGP, including Botrytis gray mold (BGM), Ascochyta blight (AB), Collar rot (CR) and Fusarium wilt (FW) in chickpea and Stemphylium blight (SB), CR, rust (R), and Fusarium wilt (FW) in lentil (Pande et al. 2005). In addition, increased adaptability to marginal soil conditions and matching water availability during the critical growth stages will also be required. Matching integrated crop management (ICM) practices for these legumes will also require refinement.

Some available improved agro-technologies for legumes have already shown promise and tremendous potential exists for expansion in the rainfed rice fallows and similar new niches (Pande 2007, 2009). For example, area under chickpea increased significantly from 2.3 million ha to 5.6 million ha in central and south India mainly due to the introduction of short duration wilt resistant varieties (Ali and Kumar 2009). The extra-early kabuli chickpea variety ICCV 2 expanded the production of kabuli chickpea in the tropical environments and is a leading variety in Myanmar (Than et al. 2007). A similar success can be achieved in the eastern IGP with the development of appropriate extra-early varieties of lentil and chickpea with resistance to key diseases and pod borer of the region and matching ICM technologies. The staggered planting of extra-early chickpea cultivars can ensure the availability of fresh pods consistently for a longer period for market (Gaur et al. 2008), where green grains of chickpea are used as vegetable or snack (raw or roasted). This Product Line will address multiple challenges in order for farmers to increase cultivation of these crops, thereby improving performance and sustainability of cereal based cropping systems in South Asia.

Table 17. Targeted countries for Product Line 6.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Earliness, Disease resistance	Chickpea	SSEA, Africa	India		
				Pakistan, Ethiopia	
					Malawi, Tanzania
	Lentil	South Asia	India		
				Bangladesh	
					Nepal, Ethiopia

Targets

Five-year outputs

- Extra-early varieties of chickpea and lentil with adaptation to short season environments of SSEA available
- Location specific integrated crop management practices for extra-early varieties of chickpea and lentil developed for the target cropping systems

Ten-year outputs

- At least 500,000 ha area of rice-fallows in South Asia brought into double-cropping by introducing extra-early varieties of chickpea and lentil

Activities

- Study components and genetics of crop phenology
- Identify diverse sources of earliness, establish allelic relationships, and identify genes for earliness
- Develop extra-early varieties of chickpea and lentil with tolerance/resistance to key biotic and abiotic stresses and improved grain quality for different regions
- Develop and refine crop management practices for extra-early varieties in the emerging cropping systems

- Multi-environment evaluation of extra-early varieties in short season windows of existing and evolving cropping systems
- Demonstrate improved varieties and crop management practices on farmers' fields in different agro-ecologies and cropping systems
- Strengthen formal and informal seed systems to ensure quality seed supply
- Assess yield gains, varietal adoption, opportunities and market value chain analysis
- Build capacity of stakeholders in development and cultivation of extra-early varieties

Output Targets

- Constraints and opportunities for extra-early chickpea and lentil varieties in target areas and cropping systems identified (SC1)
- Extra-early diverse germplasm with resistance to key biotic and abiotic stresses identified (SC2)
- Novel genes for earliness and molecular markers linked to these genes identified (SC2)
- Extra-early breeding lines with adaptation to different short season environments and improved grain quality developed (SC2)
- Integrated crop management practices for extra-early varieties of chickpea and lentil for short season environments developed (SC2)
- Seed availability of extra-early varieties enhanced (SC3)
- Enhanced marketing of chickpea for immature green grains as vegetable (SC4)
- Capacity of stakeholders on aspects related to the development and cultivation of extra early legumes strengthened (SC5)

Partnerships

CG centers (ICARDA and ICRISAT) and NARS will be involved in development of technologies, while NARS, government and non-government extension agencies, NGOs, public and private seed agencies, and farmers in target countries (India, Bangladesh, and Nepal) will be involved in final evaluation and dissemination of technologies. We will also collaborate with GRiSP to assess this product line in cropping system mode.

Impact pathway

This product line will provide extra-early maturing germplasm and breeding lines of chickpea and lentil to NARS partners. Molecular markers linked to genes for earliness will be identified for use in breeding for development of extra-early varieties. These will be shared with NARS partners. NARS will have enhanced capacity on aspects related to the development and cultivation of extra-early legume cultivars. The adoption of extra-early cultivars and associated crop production technologies will be enhanced through farmer-participatory varietal selection and improved seed systems. The extra-early varieties will fit in new niches where narrow cropping window is available for these legumes. Thus, farmers will gain from crop diversification and receive extra income. The inclusion of legumes in cereal dominated cropping systems will have beneficial effects on soil health and overall productivity of the cropping system.

Product Line 7. Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties

Rationale

Weeds (parasitic and non-parasitic) continue to be a major production constraint to grain legume production. Non-parasitic weeds compete with crops for light and nutrients, often leading to significant yield losses of up to 40% in legume crops (Tepe et al. 2005; Ali and Gupta 2012). Manual weeding has become uneconomical and impractical for many smallholder farmers due to competing on- and off-farm activities and high labor wages. Although specialized post-emergence herbicides are available, they often have unsatisfactory effects on legumes due to serious phytotoxic effects. While existing selective herbicides do not harm the crop, they are not very effective in eliminating some important types of weeds. Use of non-selective herbicides is effective in removing all types of weeds in a single application; however, a herbicide resistant varieties must still be developed.

Transgenic crops resistant to herbicides are currently available in several crops, i.e., soybean, maize and cotton (Bhat and Chopra 2006). Non-transgenic approaches, either by exploiting the existing genetic variability within the germplasm or by inducing novel mutations, have shown promise for development of herbicide-tolerant varieties in the recent past. For example, varieties with improved tolerance to herbicide metribuzin were developed by screening the advanced breeding lines for herbicide tolerance in narrow-leaf lupins (Si et al. 2008) and soybean (Hartwig 1987). Genotypic differences have been reported for tolerance to Paraquat in groundnut (Johnson III et al. 1993) and imidazolinone class of herbicides in chickpea (Taran et al. 2010). Greater success in development of herbicide tolerant cultivars has been achieved through mutation breeding (chemical mutagenesis). Commercial herbicide-tolerant crops developed from herbicide-tolerant mutants include imidazolinone-tolerant maize, rice, wheat, oilseed rape, sunflower, and lentil; sulfonylurea-tolerant soybean and sunflower; cyclohexanedione-tolerant maize; and triazine-tolerant oilseed rape (Duke 2005). Herbicide-tolerant varieties have also been developed in some grain legumes, such as narrow leaf lupins (Si et al. 2009) and lentil (Slinkard et al. 2007).

The development of herbicide tolerant legume varieties holds great promise to expand conservation agriculture in different parts of the world where temperate and tropical legumes are important components of the cereal based cropping systems. Besides common weeds, parasitic weeds like *Orobanche* have also emerged as a major threat especially to faba bean and lentil production in WANA region and East Africa, leading to substantial reduction in area and production (Rubiales et al. 2006). Genetic tolerance has been discovered in these crops to manage parasitic weeds (Fernandez-Aparicio et al. 2008, 2009). Integrated broomrape management practices that also include herbicide-tolerant faba bean cultivars have been developed for WANA region. Thus, exploiting the genetic variability, both existing and induced, can be a potential approach to develop herbicide and parasitic weed tolerant legume varieties. In addition, metabolic detoxification approach will be exploited in target legumes using “biological herbicide safeners” by over-expression of genes encoding herbicide metabolizing enzymes (Hatzios 1989; Farago et al. 1994; Riechers et al. 2005) such as glutathione S-transferases (GSTs), and cytochrome P450 monooxygenases (P450s).

Manual harvest of legume crops is becoming increasingly uneconomical because of the rising labor cost and shortage of labor at the peak harvest time. Delaying crop harvests leads to significant losses of legume grains and their quality. While harvesting of legume crops is mechanized in the developed world, developing countries largely hand-harvest due to a lack of improved varieties amenable to machine harvesting. In order to use combine-harvesters, legumes varieties need to be modified for machine harvestability. This requires development of varieties with erect and tall plants, strong stems, top pod bearing habits, synchronous maturity; and tolerance to lodging and pod shattering. Genetic variability for these traits exists in the germplasm. Mutants with upright growth habit have been identified and used for development of improved breeding lines in chickpea (Dahiya et al. 1990, Sandhu et al. 1990, Lather 2000, Gaur et al. 2008) and lentil (Erskine and Goodrich 1991). An elite tall chickpea breeding line with upright growth habit yielded about 4 t ha^{-1} under high density planting (50 plants m^2 compared to normal planting 33 plants m^2) and was suitable for mechanical harvesting as the fruiting zone started at about 20 cm from the base (Lather 2000). In lentil also, Idlib 2 variety has been found to be suitable for machine harvest (El-Ashkar et al. 2003). The utilization of available genetic variability for plant traits in breeding programs will help in the development of improved breeding lines suitable for mechanical harvest. In addition, cultivars suited to mechanical harvesting with herbicide application will reduce costs of production and enable smallholder farmers, especially women, advance other activities.

This product line will focus on development and delivery of both, genetic and non-genetic options for weed management. In genetic options, simple and efficient herbicide tolerance screening techniques will be developed and novel sources of herbicide tolerance identified from both existing and induced genetic variability and used in breeding programs for developing herbicide tolerant breeding lines. The research on non-genetic options will include identification of herbicides with less phytotoxic effects on legumes; development of effective methods for application of herbicides, and identification of cultural measures, compatible genotypes and crop rotations for integrated management of weeds (mainly parasitic weeds on faba bean and lentil). Traits amenable for mechanized harvesting will be integrated so that the genotypes are suitable for intensified management.

Table 18. Targeted countries for Product Line 7.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Herbicide tolerance, Orobanche resistance, Machine harvestability	Chickpea	SSEA, Africa, CWANA	India, Turkey, Ethiopia		
				Malawi	
					Pakistan, Syria, Iran
	Faba bean	Africa, CWANA	Morocco		
				Egypt, Ethiopia	
					Syria
	Lentil	South Asia, CWANA	India, Turkey		
				Iran	
					Syria, Bangladesh, Nepal, Ethiopia

Targets

Five-year outputs

- Sources for tolerance to herbicides and parasitic weeds and traits required for amenability of crop to mechanical harvesting identified, and breeding lines developed
- Cultivars suitable to mechanical harvesting developed and evaluated on farmers' fields

Ten-year outputs

- Improved cultivars with herbicide tolerance and machine harvestability developed and evaluated
- At least 10% of crop area in target regions brought under the improved varieties amenable to mechanical harvesting

Activities

- Ex-ante assessment of utility and profitability of weed control through herbicides and mechanical harvesting of legumes and their implications on reducing drudgery of women
- Identify/induce sources of tolerance to various groups of herbicides and parasitic weeds and traits required for mechanical harvesting
- Identify candidate genes and molecular markers for herbicide and *Orobanche* tolerance
- Functional validation of herbicide metabolizing genes in addition to their tissue specific expression in legumes through transgenic approaches
- Identify/develop varieties with herbicide tolerance and amenability to mechanical harvesting
- Develop suitable agronomic practices for improved varieties tolerant to herbicides and/or amenable to mechanical harvesting
- Monitor herbicide tolerant weed species and changes in weed composition
- Capacity building of NARES partners, farmers, service providers, NGOs and extension agents

Output Targets

- The scope and implications of the cultivation of herbicide tolerant cultivars and mechanical harvesting of legumes assessed and documented (SC1)
- Screening methods for tolerance to herbicides and parasitic weeds standardized (SC2)
- Germplasm sources for tolerance to herbicides and parasitic weeds, and traits required for suitability of crop to mechanical harvesting identified (SC2)
- Candidate genes and molecular markers for herbicide and parasitic weed tolerance identified and validated (SC2)
- Breeding lines/cultivars combining herbicide tolerance and machine harvestability developed and disseminated (SC2, SC3)

- Crop-specific economical machine harvest systems and integrated weed management modules developed and tested on elite lines (SC2, SC4)
- Capacity of NARS in research on herbicide tolerance and machine harvest amenability in grain legumes enhanced (SC5)

Partnerships

CG centers (ICARDA and ICRISAT), ARIs and NARS will be involved in development of technologies, while NARES, government and non-government extension agencies, NGOs, CBOs, Farmers' groups and farmers in target countries will be involved in evaluation and dissemination of technologies. This work will also be done in conjunction with producers and suppliers of herbicides and other agro inputs.

Impact pathway

This product line addresses the emerging requirement of mechanization of agriculture in developing countries for increasing profitability and reducing drudgery of women. The herbicide tolerant and machine harvestable grain legume cultivars will reduce the production cost. This product line will have several intermediate products, such as standardized screening methods for herbicide tolerance, sources of herbicide tolerance and traits required for amenability of plants to mechanical harvesting, and novel breeding methods and improved germplasm, which will be shared with NARS partners. The NARS partners will have improved capacity for developing legume cultivars with herbicide tolerance and amenability to mechanical harvesting. The improved cultivars developed having these targeted traits will be disseminated to farmers by enhancing seed availability through both formal and informal seed systems. Adoption of these cultivars will reduce drudgery of women, increase farmers' income, and improve food and nutritional security of smallholders.

Product Line 8. Pigeonpea hybrid and management practices

Rationale

Pigeonpea is an important grain legume crop in South Asia, and East and southern Africa. While area under pigeonpea cultivation has an annual growth of about 2% over the past 50 years, its productivity remains low at 700 kg/ha (FAO 2010). A lack of high-yielding cultivars (Singh et al. 2005), and losses due to insect pests (Sharma et al. 2010) and diseases (Reddy et al. 1998) are the major constraints for increasing and stabilizing pigeonpea productivity.

The successful development of hybrids based on cytoplasmic male-sterility (CMS) (Saxena et al. 2005) has opened up new avenue for enhancing the yield potential of pigeonpea (Saxena 2009). Considerable progress has been made in developing a seed production system for large-scale deployment of pigeonpea hybrids. Extensive testing of pigeonpea hybrids has shown over 40% yield advantage over the pure line varieties in farmers' fields in India (Saxena and Nadarajan 2010).

Since pigeonpea is grown as a rainfed rainy season crop, it is frequently subjected to both drought (intermittent and terminal) and temporary waterlogging (Chauhan 1990). By virtue of their greater root mass and high levels of genetic resistance to water-logging, drought, and diseases (*Fusarium* wilt and sterility mosaic), pigeonpea hybrids have shown greater yields stability across seasons and locations than the non-hybrid cultivars. However, flower and pod damage by pod borers (*Helicoverpa armigera* and *Maruca vitrata*) continue to be the major bottleneck in realizing the full potential of hybrids. Pod fly (*Melanagromyza*) and flower thrips are also important constraints in northern India and East and southern Africa. In addition to pod borers, hybrids and their parents could be vulnerable to new diseases such as *Phytopthora* blight, which is becoming a serious threat as a result of climate change (Pande et al. 2011).

A cost-effective, grower-friendly hybrid seed production technology has been developed to suit different agro-ecologies. The outstanding performance of hybrid ICPH 2671 in farmers' fields has led to its release for commercial cultivation in India, both by a private seed company (as 'Pushkal') and a state university (as 'RV ICPH 2671'). A simple, rapid, and cost effective hybrid seed quality testing based on molecular markers has also been developed to monitor seed quality (Saxena et al. 2010). The magnitude of realized heterosis for yield in pigeonpea is quite high, and under the well-managed conditions, yields can approach nearly 4,000 kg/ha (Kumar et al. 2012). To improve the accessibility of hybrid seed to farmers in India and Myanmar, both public and private seed sectors are being encouraged by providing quality parent seed and training.

Promotion of seed business ventures in villages is one of the options for creating sustainable seed businesses through agri-business incubation.

Table 19. Targeted countries for Product Line 8.

Target					
Traits	***Crops***	***Regions***	***SC1 & SC5 Countries***		
			SC2 Countries	***SC3 Countries***	***SC4 Countries***
Hybrid vigor, Disease resistance	Pigeonpea	SSEA, Africa	India, Tanzania, Myanmar		
				Kenya, Malawi, Uganda	

Targets

Five-year outputs

- Hybrid parents with high levels of resistance to major biotic and abiotic stresses, genetic and cytoplasmic diversity developed
- Hybrids with high levels of resistance to major biotic and abiotic stresses, and high and stable yields developed, and hybrid seed production technology standardized

Ten-year outputs

- Pigeonpea hybrids cultivated in over 500,000 ha with appropriate crop management practices

Major Activities

- Develop and evaluate different CMS systems for hybrid production
- Identify genes/QTLs for fertility restoration
- Introgress pest and disease resistance genes from the cultigen and wild relatives into hybrid parents
- Develop genetically engineered hybrid parental lines for resistance to pod borers and sterility mosaic disease
- Develop hybrid parents and hybrids with resistance to key biotic and abiotic stresses
- Develop seed production package for hybrids and their parents for optimizing yield in different agro-ecological conditions
- Promote promising hybrids in target agro-ecologies and cropping systems
- Build capacity of partners in pigeonpea hybrid and seed production technologies

Output Targets

- Different CMS systems for hybrid production developed and evaluated (SC2)
- Genes/QTLs for fertility restoration identified (SC2)
- Hybrid parents with resistance to key biotic and abiotic stresses developed and characterized (SC2)
- Pigeonpea hybrids with at least 25% higher yield than the commercial cultivars and with high levels of disease/insect resistance developed (SC2)
- Seed production systems for hybrid parents and hybrids refined for different agro-ecologies (SC3)
- ICM technologies for pigeonpea hybrids developed and promoted (SC2)
- Commercial hybrids cultivated on over 100,000 ha (SC3)
- Post-harvest processing technologies for pigeonpea refined and disseminated (SC4)
- Capacity of stakeholders in pigeonpea hybrid research and seed production enhanced (SC5)

Partnerships

The partners will include ICAR and SAUs for the development and testing of hybrids and seed production technology, public and private seed companies for promoting and creating a sustainable marketing system; and farmers’ groups and NGOs for on-farm evaluation of the new hybrids.

Impact Pathway

New breeding tools such as genetic engineering and maker-assisted selection will be used for the development of hybrid parents with resistance to biotic and abiotic stresses. The new hybrids will have market preferred traits and resistance to wilt, SMD, *Phytopthora* blight, and pod borers. The breeding materials and finished products will be shared with the NARS and seed companies. The human resource will be trained in the latest developments in seed technologies to optimize production of quality hybrid seeds. The partnerships with public and private seed companies, NGOs and self-help groups will be strengthened to take hybrid technology to the doorsteps of farmers in India and Myanmar. High yielding pigeonpea hybrids will be identified for different production systems and agro- ecological conditions, followed by their on-farm evaluation to identify specific areas of adaptation. The hybrid seed production technology will also be fine-tuned to suit different agro-ecosystems. Impact of hybrid technology on crop production and livelihoods of the farmers in the target areas will be assessed after five years.

Strategic Components (SCs)

Many methods and issues are common across Product Lines. Some issues such as economic analysis are discipline-based, others are needs-based such as seed and technology dissemination. These are manifested in Strategic Components (SC) that are supporting activities that are brought to bear on each PL in some specialized way. SC1 offers guidance on the future direction of legumes, compiling and interpreting data that will impinge on research priorities and policy decisions. SC2 is the backbone of much of the CRP, and exploits methods and opportunities for more efficient genetic improvement. SC3 seeks ways to make seed delivery more efficient – a common and urgent need for seed-based technologies in all the PLs. SC4 looks at ways to enhance market opportunities, both for immediate benefits of increased income and as an inducement for crop management innovations leading to greater aggregate production. SC5 focuses on capacity building and offers tools for enhanced communication, both within the established circle of researchers and with specialized disciplinary groups such as nutritionists. One can visualize SC1 to SC4 as a continuum, from decision making, to product development, to dissemination and marketing, and with capacity building of SC5 at each step. This process is carried out within each Product Line, where the tangible outputs of the CRP are created.

Strategic Component 1. Analyzing demand and setting research priorities

Overview

SC1 will deliver evidence-based decision support and information resources for grain legumes research targeting and priority setting. For the eight grain legumes, SC1 will analyze international and national production, consumption and trade trends.

In conjunction with Policies, Institutions and Markets, an information system will be developed to track the introduction, adoption and impact of grain legume technologies. High resolution spatial socio-economic and biophysical data will be generated to modify global research domains, construct crop typology for legume crops and apply integrated modeling tools for estimation of global research benefits and spillovers. This will complement the central data warehousing system developed under the CRP on Policies, Institutions and Markets in which all the data required for the impact assessment, targeting and priority setting will be stored and given access to users. The database would include spatial data on weather, soil, agro-ecology, cropping systems, meso-level data on area, yield, production, trade and prices of legumes and competing crops, longitudinal micro level data on adoption, income, legume consumption, nutrition and health aspects, and other complementary databases developed in CRP on Policies, Institutions and Markets. Key partners will be trained in standardized survey design and data collection methods, and analysis of the dynamics of adoption and impact.

Rationale and objective

To face the challenge of understanding the implications of improving diverse grain legumes cultivated in many farming systems, identification of target regions and priority research actions and products is essential. Many factors limit the production and competitiveness of grain legumes: their fit within farming systems, a lack of effective delivery mechanisms, limited access to capital, poor infrastructure, weak linkages between producers and input and product markets, and a lack of appropriate policy support. SC1 will apply methodologies developed in Policies, Institutions and Markets for evaluating ex-ante and ex-post impact assessment of grain legume and crop management technologies in different household and farming system contexts.

Research approach

Interventions for improving productivity and/or reducing production risks for smallholder grain legume farmers is more effective with better characterization and targeting of production environments (research domains and crop typology). A variety of factors affect productivity including environmental stresses, socio-economic conditions, the extent of and constraints to adoption, market access and stakeholders preferences along the value chain. Often a secondary crop, grain legumes need to fit into farming systems. Analysis of farming systems along with requirements of the grain legumes (e.g., rainfall and days to maturity, can reveal windows of opportunity to plant grain legumes and threats arising from changing climate (e.g., Thornton et al. 2009). GIS tools will be used to develop maps of target areas for technology delivery and diffusion, and situation and outlook reports will be prepared for grain legumes in the WCA, ESA, SSEA, LAC and CWANA regions.

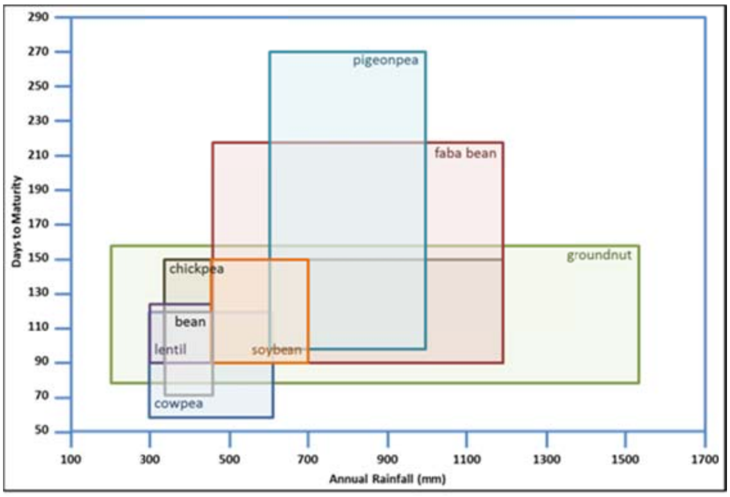


Figure 3. Factors that affect the fit of priority legumes within farming systems.

Coordination of research activities with partners will aim to stratify data acquisition and analysis per gender and wealth category. Per farming system, SC1 will review current yields and adoption rates of modern varieties, examine the relative importance of production constraints, barriers to sales and consumption, and future threats.

SC1 will use results from DIVA in sub-Saharan Africa, TRIVSA in south Asia and other quantitative analyses to (i) review and refine initial studies based on expert opinion, and (ii) reconcile FAO estimates of national yield with those of distinct farming systems. To better forecast CRP impacts in 10 years, additional consultation with experts will also enable continued critical review and refinement of estimated future yields, adoption rates, and constraints/barriers/threats.

SC1 priority setting also includes targeting investments in capacity building. Given the wide range of skills required to advance the CRP, reviews of existing capacity per Strategic Component will continue in each country. Results of the pan-legume analysis are presented in SC5. Although SC3, 4 and 5 depend greatly on the performance of CRP partners, evaluation of the associated constraints will inform collaboration activities, funding allocation decisions and acquisition priorities.

Combining qualitative and quantitative information enable the CRP to examine the performance of grain legumes along the entire value chain. Expert opinion is a valuable source of information despite being subjective. By conducting assessments in a transparent manner it is possible to review, critique, debate and refine the analysis. Assessments along the value chain by different types of actors and stakeholders can also reveal biases and misconceptions, where discussion can improve understandings and trust amongst actors, thereby potentially improving performance along the entire value chain. To illustrate, different types of questions can be posed to producers, marketers and processors, for example:

- Do R&D priorities match the most crucial constraints-barriers-threats?
- If a large increase in national yield is expected, are they substantiated by CRP efforts to improve technologies and adoption?
- If a large production increase is expected, through yield or adoption increases or both, will the storage, processing, marketing and promotional capacities be sufficient?

In collaboration with Policies, Institutions and Markets, SC1 will develop an integrated modeling framework and tools and collect spatial and temporal biophysical and socioeconomic data required for better targeting of the CRP on Grain Legumes research and to advance opportunities by promoting appropriate technologies and innovations. Specifically, diverse data will be collected on the eight priority grain legumes and associated crop management systems, such site-specific weather and soil information for calibrating and validating biophysical models. Links with Policies, Institutions and Markets will aid in collecting sub-national level data on area, production, yield, trade, market access, consumption and utilization to calibrate economic models. The results of the biophysical model will be integrated into the economic analyses developed under Policies, Institutions and Markets for better quantification of trade-off between socio-economic (e.g., gender equity impacts) and environmental objectives (e.g., effects of increased herbicide use on water supplies and health). Integrated models will be used to identify the most promising combination of technologies and policy interventions and investment strategies for grain legumes.

The impacts of early adoption of technologies and innovations and their drivers, will be monitored and documented using multi-dimensional indicators (productivity, equity, income, profitability and food and nutrition security). In collaboration with SC5 (and the USAID-funded University CRSPs), the capacity of partners will be enhanced through training in survey design and data collection methods, integrated biophysical and economic models and analysis of dynamics of technology adoption and impact of grain legumes.

Innovative contributions

SC1 will capitalize on new science tools and models to capture and analyze spatial-temporal data, including process based spatial crop models using High performance cluster (HPC) computer, poverty-yield gap model, and global spillover models. To track adoption and real-time intermediate impacts, farm surveys data will be collected using computer-assisted processing instruments (CAPIs) and a project portal using cloud computing that effectively serves as a platform for disseminating and retrieving data. Partners with competencies in new science tools will be strategically involved for spatial analyses, and data management and warehousing (Microsoft or other resources) to enhance impact assessment, synthesis, documentation and data dissemination. The Grain Legumes Data Warehouse will be an international public good (IPG) which will foster social science research, promote understanding of dryland agriculture and better linkages between CGIAR institutes, public agencies and the private sector.

Partnerships

This component will be a multi-disciplinary partnership, involving economists and crop scientists, to systematically generate a global knowledge base of key indicators. Key partners for SC1 include counterpart groups engaged in agricultural research and development and stakeholders across the grain legumes value chain. Also, partners with special competencies in using advanced research tools, including modeling, GIS and spatial analysis, as well as in data management and warehousing will be associated. Local entities, such as well-established and emerging farmers' associations, will play important roles in identifying farmers' needs and opportunities in specific zones or regions. Major research and/or development partners with specific competencies in socioeconomic and policy analysis will also be involved. At this point, the following partnerships are envisioned.

The national agricultural research organizations, including ICAR in India, IER in Mali, IAR and NCRI in Nigeria, ISRA in Senegal, INRAN in Niger, INERA in Burkina Faso, various NARES in CWANA, ESA and Asia, where grain legumes are major sources of livelihood for millions of poor smallholders will be involved in SC1. Their roles will include: identification of target entry points, e.g. clusters of villages for implementing project activities; baseline primary data collection; monitoring and follow-up surveys relating to proposed interventions; inputting and validation of data and analysis. The NARES partners will also be involved in conducting experimental yield trial in identified locations, collection of soil and weather information to characterize target production domains and validate biophysical models. Such groups and organizations will take the lead in their respective countries, with harmonization of procedural frameworks and data aggregation being done at the regional and CRP level primarily by CIAT, ICARDA, ICRISAT and IITA.

Advanced research institutions and universities, such as ACIAR and CLIMA (Australia), North Carolina State University, University of Florida - Gainesville, Cornell University and Purdue University (USA), IRD/CIRAD (France), among others will be engaged to help establish and/or adjust research priorities, analyze aggregated data and information, and assess impacts and policy implications.

Public and private seed companies that can provide unique perspectives as well as data on legumes seed production, sales and marketing will be involved in producing all three outputs. They are well placed to validate data and information gathered and have a strong interest in helping shape evidence-based seed policies in our target countries.

Gender experts and practitioners in international and national organizations, such as partner CGIAR centers and organizations, FAO and other UN Agencies, and an array of rural development NGOs will help design, and in many cases implement, gender-sensitive data gathering tools and processes and ensure the validity of the data and results obtained, including gender-responsive policies.

National agro-industries and private firms involved in grain legumes processing and marketing, most of which are listed under SC4 will assist in shaping research priorities and contribute ideas and perspectives relative to policy recommendations.

Outcomes

The outcomes of SC1 will be improved socio-economic and biophysical data quality and availability to researchers and policy planners, use of evidence based outputs by different stakeholders for priority setting and better targeting of research investments for grain legumes and enabling mainstreaming of pro-poor policies. The enhanced capacity of researchers, managers, policymakers and practitioners to access and use strategic foresight scenarios will result in influencing policy decisions. The better coordination and integration of characterization, prioritization and targeting amongst CRPs, CG centers and other NARS partners for strategic research will result in result in a focused agenda and an efficient research mechanism.

Strategic Component 2. Developing productive varieties and management practices

Overview

SC2 will work with partners to develop farmer- and market-preferred grain legume cultivars and associated crop management practices that optimize productivity in smallholder farmer fields. SC2 consists of three subcomponents: a) Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement, b) Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers, and c) Identifying and promoting crop and pest management practices through farmer participatory approaches for sustainable legume production.

The crop improvement efforts will capture the richness in the global legume genetic resources using modern molecular, phenotypic and informatics tools and approaches. These will feed into globally coordinated breeding programs for each targeted legume species that utilize contemporary informatics and molecular-based breeding approaches. It will leverage existing knowledge in certain species to make faster progress for similar constraints in other species. Integrated pest management practices, including use of genetic engineering, RNAi technology, and wide hybridization, especially for the pod borers, *Helicoverpa* and *Maruca* will be developed in close conjunction with the breeding efforts (PL5). Crop management, especially weed control and mechanical harvesting (PL7), and symbiotic nitrogen fixation (PL4) will be enhanced to optimize the productivity of the improved varieties under subsistence farming conditions in the targeted agro-ecosystems.

Rationale and objectives

Genetic resources are the building blocks for any breeding program. SC2 will focus on characterizing (in partnership with the CRP on Genebanks) the genetic resources of chickpea, common bean, cowpea, faba bean, groundnut, lentil, pigeonpea, and soybean for traits addressing the key constraints of each Product

Line. Recognizing the importance of modern breeding tools and methodologies, and the potential to develop a global breeding program for grain legumes, the CRP on Grain Legumes will develop and deploy molecular- and informatics-based tools to establish a global crop improvement program for enhancing the efficiency and reducing the time to develop new cultivars. Given the importance of proper phenotyping and understanding the mechanisms of resistance/tolerance to different biotic and abiotic stresses, one of the major activities will be developing phenotyping platforms and screening tools to identify germplasm that possess resistance to abiotic and biotic stresses. For complex constraints such as drought, heat, insect pests or stress combinations, the innovation will involve combining stress adaptation mechanisms/strategies, the use of crop simulation across time and locations, and the use of molecular markers to transfer these key stress-environment-specific adaptation mechanisms into high yielding cultivars with adaptation to different agro-ecosystems. Three of our Product lines (PLs 1, 2 and 3) deal with addressing abiotic stresses and climate change effects, one (PL4) with capturing the unique SNF ability of legumes, one (PL5) with managing the key biotic constraints, and the remaining three (PLs 6, 7, and 8) with generating new opportunities to intensify cropping systems. All PLs have resistances to major diseases as a basic requirement in all breeding lines developed.

Using the enhanced genetic diversity, elite breeding lines with higher yield potential, greater stability (due to improved resistance to biotic and abiotic stresses) and enhanced nutritional and commercial value will be developed. Special emphasis will be placed on using improved genomic tools and the Generation Challenge Program's Integrated Breeding Platform to bring efficiency and precision in selection. These elite breeding lines will be shared with partners for further selection, evaluation and possible release by NARES partners for cultivation in different farming systems across the five priority regions of Grain Legumes.

To realize the full potential of improved cultivars, the CRP will develop integrated crop and pest management modules that can alleviate the yield reducing constraints, and thus, stabilizing and increasing legume yields in the farmers' fields. These include improved SNF by addressing the primary constraints of SNF on-farm (PL4), enhanced nutrient and water use efficiency (PL1), weed management and mechanical harvest (PL7) and integrated pest management practices (PL5). Much of the management research will be conducted in collaboration with Dryland Systems, HumidTropics, and WLE in different farming systems and agro-ecological conditions, for example, where early maturing legumes fill a short season niche (PL6).

Research approach

Many breeding programs globally (including IARCs and NARES) have used less than 1% of germplasm accessions available in the genebanks (Upadhyaya et al. 2006, 2011), mostly due to inadequate data and information on characterization of economic traits. The CRP plans to reverse this trend – by improving the availability of appropriate sets of germplasm that represent the diversity contained within the entire collections. The "Focused Identification of Germplasm Strategy" (FIGS) is being used in crops with robust geographical data sets. FIGS employs information about the environment from which germplasm accessions are collected to predict in-situ selection pressures. The strategy has proven successful at capturing very low frequency adaptive traits such as salt tolerance, and resistance to insect pests and diseases (Bayuelo-Jiménez et al. 2002; Bhullar et al. 2009; El-Bouhssini et al. 2009, 2010). Core collections (consisting of about 10% of an entire collection), mini-core collections (consisting of 10% of core or 1% of entire collections) and reference sets (Upadhyaya and Ortiz 2001, Upadhyaya et al. 2008; Mahalakshmi et al. 2007) have been used to identify sources of resistance to diseases, tolerance to drought and other abiotic stresses and enhanced quality traits (Tohme et al. 1995; Upadhyaya et al. 2009). Molecular genotyping with SSRs has been completed for 1000 to 3000 accessions in most of the legume species (Upadhyaya et al. 2008, Upadhyaya et al. 2011; Varshney et al. 2010) and opportunities now exist to carry out a larger number of assays with less-expensive high throughput sequencing and more comprehensive genetic markers such as SNPs (Varshney et al. 2009a) and opening the door for allele mining. As sequencing costs continue to decline, whole genome sequencing of significant number of accessions will be feasible, providing even more detailed discrimination and identification of diverse subsets (Varshney et al. 2009b). We anticipate that this new information would help harness potential useful traits from "exotic" germplasm, while avoiding linkage drag of negative agronomic attributes, and encourage breeders to use more diverse germplasm resources in their programs. Such large data resources require appropriate information systems. While systems like SINGER (SINGER.cgiar.org) have provided initial germplasm information as IPGs, newer and more robust information systems must be employed to adequately handle the large amount of information produced. Information systems are key to provide global public access to all characterization data. Geo-referenced genetic resources can be the common denominator for all genotypic and phenotypic data in the future. Databases need to contain highest quality, comprehensive and dynamically curated data on germplasm.

Where diversity is lacking for critical traits in cultivated germplasm, tapping wild relatives can be employed, particularly for resistance to insect pests and diseases. Wide-hybridization offers opportunity to introduce diversity from wild relatives (Upadhyaya 2008) and to create novel diversity in polyploidy species such as groundnut (Mallikarjuna et al. 2010).

Since the value of resistance sources depends upon levels and stability of their resistance, a complete understanding of resistance-associated factors for critical traits in the available germplasm surely has a potential to bring them together in a selection index. Hence one of the objectives of this CRP is to unravel the underlying resistance mechanisms in wild species as well as other resistance sources by determining the causal role of resistance associated factors/genes and assessing their suitability as breeding markers as well as candidate genes for genetic engineering options. While genetic engineering provides opportunity to create novel materials containing new and/or greatly improved characteristics of economic importance, molecular tools will provide effective methods to evaluate and follow such introgressed segments in breeding programs with precision (Fonceka et al. 2011, 2012; Glaszmann et al. 2010). Methods for successful transformation are available for several species and transgenic soybean has been deployed globally (James 2010). Environmental and bio-safety and public acceptance are important issues that must be considered before moving forward. NARES need to take the lead to assure public acceptance of genetically engineered crops.

Phenotyping is critical to fully appreciate diversity and identify useful sources of resistance to biotic and abiotic stresses for use in crop improvement. It is critical to recognize that phenotyping for complex traits are not panacea, but a research approach to fully understand plant adaptation mechanisms and their interaction with the environment. Opportunities to coordinate efforts across centers in the CRP are high, and this will build on recent efforts in the Tropical Legume project in which mechanisms for drought adaptation are assessed across species, using same protocols (e.g.: Belko et al. 2012a, 2012b; Zaman-Allah et al. 2011a, 2011b; Ratnakumar and Vadez 2011). Use of germplasm subsets has been successful in various species and for several important traits. High-throughput phenotyping offers opportunities to screen much larger numbers, and when combined with molecular fingerprinting, can provide trait-marker associations. Finally, breeding programs must consider using much larger amounts of data in deciding on the best materials to continue with and use more diverse trait-specific germplasm to develop improved cultivars with a broad genetic base.

Conventional and advanced tools such as remote sensing and GIS will be used to quantify the distribution of, and losses due to, important and emerging insect pests and pathogens across cropping systems (Christian et al. 2010). Culture independent methods such as denaturing gradient gel electrophoresis, ELISA, and DNA barcodes will also be used to identify crop pests and their natural enemies. Pest-resistant cultivars derived through expression of toxin genes from the bacterium, *Bacillus thuringiensis* and RNAi technology will also be used as a component of pest management, as and when these become available (Meister and Tuschl 2004; Sharma 2009). Recent technological advances will be used to significantly enhance our ability to identify and characterize resistance-associated proteins for various biotic traits (insect-pest and aflatoxin contamination). RNAi technology will be used as a new approach to control plant diseases (viral and fungal) through host induced gene silencing or trans-silencing (Nowara et al. 2010; Tinoco et al. 2010). Likewise, emerging genomic and information technologies (IT) will also be used for developing robust IPM systems (Ba et al. 2009). Application of IT in IPM will involve the use of information and communications technologies, both to collect critical information on pest populations, and to deploy practical IPM solutions through decision support systems (Agunbiade et al. 2011). Application of modern biotechnological approaches for pest management requires that these be evaluated for their biosafety to the environment (Sharma and Ortiz 2000). Standardized protocols will be followed for evaluating the biosafety of insect-resistant transgenic plants for pest management (Sharma et al. 2008; Sharma 2009).

For biological control, our approach is 'discovery-to-deployment' pipeline. Using the example of the pod borer, *M. vitrata*, regional and international partners will identify better-adapted natural enemies against this pest (Srinivasan et al. 2007). At the same time, efficient system for rearing of the natural enemies will be developed for each of the promising candidates, together with innovative ways of sensitizing the farmers about the new approaches by disseminating the information through cell-phone ready animation videos. In addition to their conventional application, we will investigate the application of microbial endophytes for pest management (Vega et al. 2008) to enhance plant defenses to insect pests and pathogens. Crop and region specific IPM modules will be designed using prevention-based systems, and intervention approaches which pose the lowest environmental, human and animal health risks. To expand the use of biological control, business models for commercialization will be developed and private sector partners involved in commercial production of biocontrol agents. We will also work on enabling policy and institutional issues (e.g., awareness, regulations, etc.) for enhancing adoption of biocontrol for pest management.

Innovative contributions

SC2 will employ a more integrated approach across grain legume genetic resources, and aims to develop a global grain legume genetic resource system to provide researchers information on, and access to genetic and genomic resources. Genome sequencing and other genotyping technologies are expected to become less expensive and higher-throughput. The application of genomic and genetic engineering approaches for crop improvement will be important for developing improved cultivars for providing resistance to biotic and abiotic stresses in future; however, given that the technology is still in its infancy in many legume species, the CRP will evaluate the feasibility of the technology in those species where the technology is robust, building on recent experience in Tropical Legumes project. It will consider how best to apply the successes in these species to the other legumes.

Grain Legumes provides a unique platform for establishing a global breeding program for grain legumes. The Integrated Breeding Platform, promoted by the Generation Challenge Program, will be an important gateway to integrate and coordinate efforts across legume crops. Since a complete understanding of the host resistance mechanisms in these crops is critical to harness their cumulative or complementary benefits, this will be accomplished by employing comparative "omics" strategies (viz. genomics, proteomics and transgenomics) to identify resistance-associated proteins/genes and their contribution to host plant resistance which is essential to devise appropriate strategies for grain legume breeding. The core partners will work together to build such an innovative approach to legume improvement by employing coordinated genotyping and phenotyping services, an integrated informatics platform, a coordinated set of trial sites on-station and on-farm, and specific platforms for trait assessments. Given that many NARES partners have only a few legume scientists, such a coordinated approach will provide for better interactions with the NARES, where multiple Centers will not be approaching the same scientists, but will coordinate such linkages via the CRP.

Innovation will include integrating and coordinating efforts undertaken so far on individual crop. For example, crop species clearly share similar mechanisms of adaptation to terminal drought (Belko et al. 2012a, 2012b; Zaman-Allah et al. 2011a, 2011b; Ratnakumar and Vadez 2011; Kholova et al. 2011; Fletcher et al. 2007). Grain Legumes offers the enormous potential to compare species and capitalize on what makes a given species better against similar constraints. Innovation will come from using information on GxE interactions as an opportunity, and use crop simulation modeling to determine the prevalence of environmental conditions for deciding on the best breeding targets. Breeding will then evolve from a "broad-based" approach for adaptation to large agro-ecological zones, to "niche-based" breeding of genotypes for specific conditions.

Partnerships

The CRP on Grain Legumes will work closely with the CRP on Genebanks by providing additional genotypic and phenotypic characterization of the accessions being conserved and distributed for use in crop improvement. Linkages with Dryland Systems and HumidTropics will provide opportunities to better understand the role of grain legumes in cropping systems and to evaluate the technology packages (cultivars + management) being developed by Grain Legumes under smallholder farming conditions. Close interactions with the other CRPs on crop improvement (MAIZE, WHEAT, GRiSP and RTB) will provide opportunities to share experiences in employing genomics, genetic engineering and informatics approaches in germplasm characterization and development of improved cultivars. Joint phenotyping for common traits (e.g., drought, heat and soil fertility) will be feasible to capture efficiencies at scale.

Genotyping services provided by companies such as BGI and KBiosciences will be availed to provide the necessary high-throughput germplasm characterization and breeding genotyping. Advanced research institutes (e.g., UC-Davis, UC-Riverside, U of Georgia, The Waite Institute, etc.) are already engaged in research with one or more of the core partners and this research partnership will be continued and focused on the priority research areas in the CRP. The Platform for Translational Research on Transgenic Crops (PTTC) at ICRISAT can be an effective mechanism for advancement of transgenic products.

The Dry Grain Pulses CRSP will continue to be a partner of choice for the development and implementation of IPM technologies on cowpea. Also, partnerships with projects such as Tropical Legumes I and II, USAID-support CRSPs and research institutions such as The World Vegetable Center (AVRDC) and ICIPE will be sustained and enhanced.

NARES in the targeted countries will be fully involved in germplasm characterization, crop improvement and crop/pest management research. These institutes will provide laboratory and field sites where research and evaluations can be conducted, and become part of the global breeding effort for grain legumes envisioned under the CRP. Special attention will be given early in the CRP's life to provide the necessary support and capacity building to enable the NARES to be active and effective partners.

Outcomes

This SC is both knowledge and product/practice intensive. Legume scientists will have access to well characterized diverse germplasm with desired agronomic and quality traits, and enhanced resistance from well managed collections. Knowledge generated on mechanisms, genes, and markers-trait association will lead to efficient breeding methods which will be used to develop cultivars preferred by farmers and end-users more rapidly. Farmers grow market preferred legume cultivars with improved resistances and nutritional composition and use integrated crop management practices to realize higher and stable yields, and thereby get higher net returns. Legume cultivation also becomes more women-friendly, because of nutritious varieties amenable for processing, machine harvest and reduces drudgery.

Strategic Component 3. Facilitating legume seed and technology delivery systems

Overview

While grain legumes are grown by millions of subsistence and smallholder farmers across developing countries, legume production practices are highly variable among regions, countries, and even within a country (Abate 2012). Demand for staple cereal production has displaced food legumes to marginal areas, and this has increased the production risks, and acts as disincentive for farmers to invest in improved technologies like seeds, fertilizers and pesticides (Byerlee and White 2000). Breeding and seed delivery processes are complicated by the diversity of legumes, as they come in many shapes, sizes and colors with strong consumer preferences for specific quality traits. Despite their economic importance, relatively limited attention is given to the legumes seed supply system (AwHassan et al. 2003) compared to cereals that are considered 'strategic' food crops.

Agricultural innovations (new cultivars and associated production technologies) can increase crop productivity and production, improve rural livelihoods and ensure food and nutritional security of subsistence farmers. Adoption studies have shown that improved bean varieties generate yield increases of 30 to 50% compared to local varieties in Africa (Kalyebara and Andima 2006). Similar yield increases were also reported for chickpea (Mazid et al. 2009) and lentil (Aw-Hassan et al. 2003) in West Asia. Large-scale on-farm technical demonstrations conducted in India have shown that adoption of improved varieties and management practices can increase legume production by 13 to 42% (Ali and Gupta 2012).

Despite a large number of released varieties in grain legume crops, their impact has yet not fully realized by resource-poor farmers due to inadequate supply of quality seed as a result of absent or weak formal seed system (Teshale et al. 2006; Aw-Hassan et al. 2003). Abate et al. (2011) categorized the constraints of the legume sub-sector across Africa and south Asia as technical and institutional issues including seed production and delivery system. Availability of, access to and use of seed of adapted and farmer preferred varieties is key for realizing the impacts of investments in agricultural research and in realizing better rural livelihoods.

Rationale and objectives

Inadequate supply of quality seeds and other production inputs at affordable price is identified as the major bottleneck in bridging the yield gaps in grain legumes at farmers' fields. The existing seed replacement rate in grain legumes is less than 5% in most of the countries as against the desired level of 25%. This is mainly due to limited bottlenecks in the seed production chain from breeder seeds to foundation and certified seeds by the formal seed system. Currently, the supply of certified seed is less than 5% in major grain legume producing countries of Central and West Asia and North Africa (Bishaw *et al*. 2008) such as Ethiopia (0.1-1.5%), Morocco (1-5%), Iran (0%), Syria (2.2%) and Turkey (1-2%). More than 95% of lentil seed in India comes from the informal sector (Materne and Reddy 2007). The situation with respect to tropical legumes is similar across countries in Sub-Saharan Africa and South Asia (Abate 2012). To date there are several technical, institutional, regulatory and policy constraints in the legume seed industry (Abate et al. 2011; Rubyogo et al. 2007; Bishaw et al. 2008). Unavailability of sufficient quantity of seeds coupled with lack of information are the most important constraints for adoption of improved legume varieties (faba bean, field pea, chickpea, lentil) in Ethiopia (Kelemework and Bedane 2006; Dadi and Bekele 2006; Semane 2006; IFPRI 2010), India (Ali and Gupta 2012), and Tanzania (David et al. 2002). Therefore, establishing a well-functioning legume seed system is expected to provide farmers with seed of adapted and preferred varieties in adequate quantity and quality, at the right place and time and at affordable price. Therefore, SC3 will have the following objectives:

- Enhance decentralized seed systems using appropriate models,
- Upscale small seed pack delivery model for enhancing adoption of improved varieties,
- Link formal and informal seed sectors for sustainable seed delivery to farmers,
- Motivate small and medium seed companies to enter legume seed business, and
- Engage national and regional policy makers for supportive seed policies.

Research approach

In the absence or weak formal seed sector, non-commercial (Grisley 1993) and commercial (Byerlee and White 1997) approaches have been suggested for legume seed delivery. Participatory Variety Selection (PVS) coupled with local seed production by farming community has been suggested as one of the approaches to improve legume seed delivery (Sperling and Scheidegger 1995; Almekinders et al. 2007; Nasirumbi et al. 2008; Abate 2012). Under the Tropical Legume II project, several seed production and delivery models were tested (Abate 2012). However, there is need for a regular supply of quality seed of new legume varieties coming from both conventional and participatory crop improvement research. Hence strengthening of formal seed sector entities through adequate incentives for public seed enterprises or private seed companies (Bishaw et al. 2008), coupled with establishing decentralized community/village seed production and marketing enterprises (Srinivas et al. 2010) is a prerequisite.

With the CRP, the legume seed system research will focus on a thorough understanding and critical assessment of the status of existing seed sector (both formal and informal), their bottlenecks and comparative advantages and complementarity. The research methodology will combine both comparative analytical studies across countries as well as specific country case studies along the 'seed chain' to assess the functioning of the legume seed system to derive successful models with potential spillovers for adaptation to specific country situations. Variation in seed sector development among countries will provide a huge wealth of information for comparative analysis of the legume seed sector in selected developing countries where lessons learnt could be used to design better seed delivery options. A macro-level study will be initiated targeting selected counties to review and analyze the structure and performance of the legume seed sector. An effort would be made to include countries at different stages of seed sector development targeting some countries where policy reforms made tremendous impact through private sector participation particularly for other crops like cereals but not for legume seed delivery.

Innovative contributions

Public-private research partnerships in the legume seed sector are recent. Partnerships can be forged between multinational companies and domestic seed companies, CG centers and national seed companies, and NARES and small seed companies. Such partnerships may include accessing new technologies (including biotechnology) and/or technology transfer through non-exclusive license to multiply and commercialize cultivars resulting from the partnership, subject to conditions. Some of the innovations in public-private partnership will be implemented. Efficient seed delivery system will be an integral part of the impact pathway of the proposed product lines in the CRP on Grain Legumes.

The presence of market-oriented and/or export-led commercial agriculture remains one of the major driving forces for the development of vertically organized and sustainable legume seed industry of cool season legumes like chickpea, faba bean, and lentil in some of the developed countries. Integration and commercialization approach for the success of legume sector in developing countries in necessary for research impact (Byerlee and White 2000). Given the importance of legumes as potential commercial crops, a value chain analysis would be useful to derive evidence based policy advocacy to promote the legume seed industry in developing countries. The comparative analysis of the legume seed system would contribute to this goal.

Currently, a few viable models are available for legumes seed production and delivery. The availability of hybrid seed of certain legume crops (e.g. pigeonpea) presents an opportunity for private sector seed companies to engage in legume seed business, similar to the Hybrid Parents Research Consortium at ICRISAT.

Despite the availability of improved legume varieties in some countries, it is yet unclear whether lack of effective demand or lack of seed is the foremost constraint. Country case studies will be conducted on the technical efficiency of seed production and marketing. Understanding the seed markets and developing effective distribution networks involving local agro-input dealers or traders or developing alternative innovative options where infrastructure is limiting to reach farmers remain critical in building seed delivery.

Partnerships

The seed systems research for development will be carried out along the seed value chain through multidisciplinary and multi-stakeholders process by catalyzing partnerships based on comparative advantage for realizing impact. These partners include national policy makers and national/regional seed services, national agricultural research systems, agricultural development and extension services, public/private seed sector, civil society (NGOs and producers organizations), farmers and others such as grain traders, exporters or processors.

The national agricultural policy bodies and seed services will need to create conducive environment for the development of a sustainable legume seed sector while national seed regulatory services facilitate cross-border seed trade through harmonized regulatory systems for seeds (variety release system, seed certification scheme, phytosanitary measures).

The CRP partners will facilitate innovative approaches for developing and fast tracking release of farmer and market preferred legume varieties and ensure their maintenance and seed production, including efficient multiplication technologies (Rubyogo et al. 2010). The production of breeder and foundation seed of improved varieties will be mainly handled through NARS partners and/or shared with seed producers as the case may be. The public seed sector (e.g. different forms of public seed enterprises) and the private sector (e.g. small to medium scale seed companies) will be involved in foundation and certified seed production and marketing to farmers. The agricultural development agencies and extension services will promote and popularize new legumes varieties to create awareness and demand for seed by farming communities. The private grain trade sector will be engaged to stimulate grain market that will drive seed production, and market chain development for a range of products of grain legumes.

The farmers' groups and village communities will also be involved in decentralized seed production and marketing of seed (certified seeds, quality declared seed and truthful labeled seed). The informal seed system will be promoted through individual farmers and farmers' groups. Agriculture Departments Agencies and Extension Services, NGOs, community-based organizations, farmers' cooperatives, private entrepreneurs will help further to multiply, market and diffuse seed in decentralized zones of actions –

where the target communities reside. They will also be major players in knowledge empowerment of farmers.

Outcomes

The major outputs of SC3 include comparative analysis and specific country case studies to understand the constraints of the legume seed sector and propose alternative options; adoption of successful seed production and delivery models; availability of and access to quality seed of legume crops of improved grain legumes varieties; establishment of a mix of public sector seed enterprises, small to medium private seed companies and alternative farmer/community based seed enterprises engaged in seed production and marketing to meet the diverse need of grain legume farmers.

Strategic Component 4. Enhancing post-harvest processing and market opportunities

Overview

The cultivation of grain legumes is dominated by smallholder farmers with limited access to input supplies, processing technology, and output market opportunities. These constraints are further aggravated by inadequate infrastructure such as post-harvest management practices and technologies, lack of primary processing, sorting, grading and basic storage facilities (Monitor Group 2012). Institutional frameworks including farmer associations and cooperatives that can (i) help the farmers with better access and capacities to engage with value chain stakeholders, (ii) negotiate fair prices for their harvests, (iii) access to new technologies and inputs such as fertilizer, financial credit and crop insurance, and (iv) enable participation in environmental service markets that compensate farmers for reducing greenhouse gas emissions are inadequate. Innovations in processing and new market opportunities will directly impact not only women but also their children and families. Markets for grain legumes emphasize different marketable characteristics ranging from a nutritious staple food to imported traditional or exotic food, ready-to-eat snack food to ecologically-efficient protein source, or crops that are resilient and reduce effects of climate change. Research is needed to determine the existing size of markets, most equitable and efficient purchase-sale arrangements, and potential growth as a result of coordinated advocacy efforts amongst public and private sector organizations.

Rationale and objectives

Major inefficiencies exist in smallholder-scale grain legume value chains, necessitating the need to provide farmers with practical, cost-effective technologies and new market opportunities. Smallholders are especially disadvantaged because they have limited access to markets and often sell immediately after harvest, when prices are lowest. Processing losses are high due to inefficient tools and lack of appropriate processing machinery. Farmers have little access to information on prices, and supply and demand conditions, forcing them to sell to middlemen who pay them the lowest possible price. Moreover, women tend to be marginalized from the higher-income generating processes of the value chain.

Grain legume harvests have numerous destinations ranging from farm households to local, national regional and international markets, revealing distinct distribution patterns of end-use (Figure 4). While household consumption is important for many smallholder farmers, increasing access to larger/distant markets could increase demand and improve product prices (see section on Innovations below).

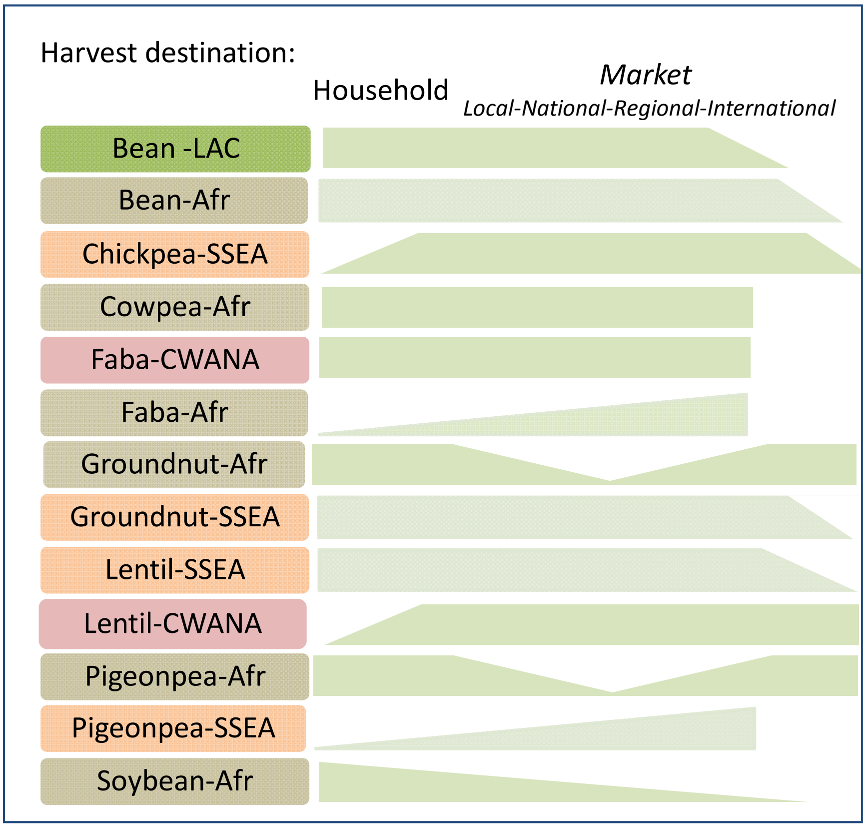


Figure 4. Destinations of legume harvests: Estimated relative distribution per legume and region.

Trade-driven value chain examples include the export of pigeonpea and chickpea from East Africa to India (Jones et al. 2002; Simtowe et al. 2010), lentil and bean export from Ethiopia (Ferris and Kaganzi 2008), and regional West African cowpea trade (Langyintuo 2003). Considerable effort is being made to improve the domestic cowpea value chain in Nigeria, including the development of new commercial food enterprises (Lowenberg-DeBoer and Ibro 2008). Such successful interventions using the value chain approach result in enhanced benefits for the smallholder grain legume farmers, especially women. These justify relevant interventions at the farm level to minimize post-harvest losses, develop and provide primary processing technologies for value addition, enhance quality of produce, organize farmers into cooperatives to leverage on the collective strength and enhanced capacity to engage with different stakeholders. This ultimately would link the farmers to the local markets, thereby linking them to the overall grain legumes trade.

Given the above background and approaches, SC4 shall address objectives including the enhancement of grain legume value chains for the poor, especially women, identification and piloting institutional innovations to engage poor farmers with input and product markets, developing and implementing post-harvest technologies/practices and value-added products benefiting women, and the identification or development of drudgery and cost-saving small-scale machinery for grain legume processing. The successful interventions in value-chain for legumes leading to market linkages will be important components for achieving the overall goals of Grain Legumes.

Research Approach

Some key lessons have been learnt from past efforts to improve the value chain and improve post-harvest management practices and processes to smallholder farmers:

- Value addition to produce starting with simple innovations like drying, sorting and grading can reduce post-harvest losses at the farm level and can go a long way to improve farm productivity.
- Innovation is possible when all stakeholders in the value chain are fully aware of the benefits of new technology/product in a clear and transparent manner.
- Studies such as that of PH Action (Global Post-harvest Forum) suggest a systems approach to address post-harvest losses that should include analysis of post-harvest systems and the impact of these systems on food security, food quality, and value-addition as a contribution to rural livelihoods. Thus

there is a need to document, integrate, implement and asses the best post-harvest technologies and practices to benefit the grain legume farmers especially women.

- Very few processors are involved in processing activities targeted to the consumer-ready market. Besides lack of secondary and advanced processing, the current technologies and capacities of primary processing at the farm-level needs to be upgraded.
- Limited efforts have been made to understand and develop effective technologies that can reduce drudgery of women involved in pulse production activities as compared to other crops. Clear benefits for women by interventions at various stages of pulse production and reduced drudgery would increase time available for other productive activities.

Considering these lessons learnt, this SC addresses the following R4D questions:

- What adjustments to conventional value chain analysis are required to delineate the roles of and benefits received by the poor, especially women? In terms of current monetary and other values associated with the major products from grain legumes, current and prospective innovations in the chain?
- Which high-profit processes in grain legume value chains are appropriate for increased smallholder involvement through specific institutional (formal or informal) mechanisms, and how these contribute to Grain Legumes priority setting processes?

Appropriate analysis of legume value chains shall be carried out in a systematic manner involving suitable partners (especially with CRP on Policies, Institutions and Markets) and experts in the field. It is envisaged that such partners shall carry out activities such as identifying appropriate models of linking farmers to spot, future and financial markets, develop contract farming models with pre-determined price, quality based pricing, models with intermediaries, formal and informal contractual agreements etc.

Regional and ethnic domains differ significantly for gender roles. While men tend to dominate cereal production in many societies, women are more likely to take a major role in the growing of legumes, especially in Africa. Hence, adapting the value chains for legume crops can have significant gender effects, where women will play a central role as actors and suppliers of services to support the legume value chain. Since women generally carry out weeding and harvesting, interventions to make these activities less arduous shall particularly benefit them.

Post-harvest interventions for each of the legumes shall be identified after thorough understanding of the characteristics and post-harvest behavior of each legume to identify appropriate protocols for harvesting, transportation, drying, storage and primary processing operations. Socio-economic factors, such as availability of labor, gender roles, access to credit, and access to markets shall be evaluated in order to develop appropriate post-harvest intervention models for each legume. Profiling of varieties of each legume, for specific nutritional and processing traits, leading to diverse uses of legumes in food and feed applications shall form an important basis for their breeding.

Field-level shellers or decorticators will be evaluated for further refinement to enable on-farm shelling operations, thereby reducing the drudgery of carrying bulk produce to storage. Development of cost-effective tools and equipment will be undertaken in association with local machine manufacturers, besides capacity building programs for imparting necessary training to develop skills for handling these equipment. Mechanisms will be explored, in partnership with financial institutions, in order to secure finance for procuring these tools by the farmers.

Innovative contributions

Empowering grain legume farmers especially women

Institutionalization of the role of women in simple value addition activities like winnowing, grading etc. can help them reap the benefits of value addition and becoming equal partners in the value chain cycle. It is expected that increased participation of women, enabled by access to suitable technologies and capacity building in the value chain would result in their increased involvement in higher level economic activities like marketing, managing end-product enterprises and decision making.

Promoting institutional innovations

To empower the farmers and increase their bargaining capacity, several innovation models of linking them to markets/end-users need to be explored. Innovative partnership models involving commodity exchanges, local government and private sector partners (traders and exporters) shall assure appropriate storage facilities besides pipeline of products based on market trends. Identifying and linking to appropriate partners and experts in this field shall be the key in SC4

Post-harvest technologies and value-added activities

Smallholder incomes, particularly for women can be significantly enhanced by improving post-harvest and processing technologies. Using legume haulms to provide high quality animal feed and legume seed as an important source of protein and other nutrients for feed rations will be explored. The processing and marketing of perishable food products shall be explored by involving women who usually dominate the fresh food processing and marketing.

Cost effective machinery for reducing drudgery, especially of women

Efforts to reduce human drudgery especially that of women, in handling and processing of legumes at all stages of production are critical. Implementation of small-scale mechanization at the farm level can result in saving valuable time for the farm households. While the small-scale mechanization allows timely operations, it not only increases the profitability of growing a crop by reducing production costs, but also allows the development of new legume products and markets.

Weeds are another major problem for smallholders where hand-weeding and mechanical control is frequently impractical. While herbicides are a possible alternative, it is important to apply herbicides, particularly residual herbicides at the correct rate. The partners of this CRP shall explore linkages with post-harvest researchers/experts and small-scale machine manufacturers involving farmers' cooperatives, SHGs, NGOs etc. in order to identify and ensure the adoption of appropriate, cost effective farm machinery with focus on reducing drudgery of women.

Partnerships

The key to successful implementation of the objectives under SC4 will depend on how the research partners are able to engage with different stakeholders, especially non-traditional partners. Such non-traditional partners shall be entities involved in the manufacture and transport of inputs, collective action of women, commodity exchanges, local government and private sector partners (traders and exporters), postharvest processors and wholesalers, retailers, entrepreneurs and others that influence value chains. Hence, it is important to focus on developing mechanisms to engage with appropriate partners. Mechanisms such as the Agribusiness and Innovation Platform (AIP) at ICRISAT will be strengthened. As a part of SC4, many key actors along the grain legume value chains will play a specific role, contributing to the development of the value chain. Small-scale mechanization and cost effective postharvest processing technologies and value added processing technologies and products need partnerships with NGOs and community-based organizations such as women's self-help groups to ensure the adoption of new technologies and market linkages by farmers, especially women. To enhance the market potential through innovations in dry seed processing, linkages of farmer cooperatives shall be established with grain processors and exporters, the international grain legumes trading associations. The Centers shall play a key role in engaging with the governments in order to influence favorable market policies to promote marketability of grain legumes and their products.

Outcomes

Specific outcomes of the SC4 include: (i) Poor smallholder farmers, especially women benefiting from more efficient value chains and market linkages, (ii) Higher farm productivity and better quality and value addition to grain legumes farm produce; (iii) Farmers equipped with better post-harvest technologies and practices, (iv) Women empowered with knowledge on processing, reduced drudgery and new income opportunities.

Strategic Component 5. Fostering innovation and managing knowledge

Overview

To be effective in achieving its goals, Grain Legumes must have the required capacities to actively participate in, and derive benefits from, research and development. SC5 will employ effective and efficient capacity building strategies across the Strategic Components, Product Lines and partners to achieve the stated goals. Capacity building will benefit many CRP stakeholders at various levels, from technicians working in the labs and fields, to undergraduate and graduate students, to scientists, extension agencies, industry, NGOs, and other key actors involved in production, processing and marketing of grain legumes.

An initial analysis of existing capacities has shown considerable capacities across the legumes, regions and Strategic Components (Table 20). Only a few national partners have sufficient capacity in genetic improvement (SC2a), fostering innovation, and managing knowledge (SC5). Capacities are also limited in analyzing demands, establishing research priorities (SC1), enhancing post-harvest processing and market opportunities (SC4). All other SCs require some level of support from CRP partners. SSEA and LAC have relatively better capacity, while WCA is perceived to be the least trained overall. This analysis has formed the basis for discussion among the CRP partners.

Table 20. Status of capacities and knowledge: Summary results per SC, legume and region.

1=existing capacities / state of knowledge are OK

2=existing capacities/knowledge requires support

3= no existing capacities

Legume / Region	SC1	SC2a	SC2b	SC2c	SC3	SC4	SC5	Average per legume/region
Bean	2.4	2.6	2.1	2.4	2.1	2.2	2.2	**2.3**
Chickpea	1.9	2.1	2.0	1.8	1.9	2.2	2.1	**2.0**
Cowpea	2.5	**3.0**	2.8	2.6	2.7	2.6	2.7	**2.7**
Faba bean	2.0	2.1	2.1	2.0	2.1	2.0	1.8	**2.0**
Groundnut	2.1	2.4	2.4	2.1	2.3	2.0	1.9	**2.2**
Lentil	2.1	2.0	1.9	1.7	1.9	2.3	**2.9**	**2.1**
Pigeonpea	2.5	2.3	1.8	1.8	1.8	2.5	**3.0**	**2.2**
Soybean	2.6	**2.9**	**2.8**	2.8	2.6	2.4	2.7	**2.7**
LAC	2.5	**2.8**	1.5	2.0	1.3	2.3	2.3	**2.1**
ESA	2.2	2.5	2.5	2.3	2.3	2.2	2.2	**2.3**
WCA	2.6	**2.8**	2.7	2.6	2.6	2.4	2.5	**2.6**
CWANA	2.4	2.1	1.8	1.8	1.8	2.5	**2.7**	**2.2**
SSEA	2.0	2.0	1.9	1.7	1.9	2.3	2.2	**2.0**
Average per SC	2.3	2.4	2.2	2.1	2.2	2.3	2.4	

* SC2a= genetics, SC2b=breeding, SC2c=crop management

Within the CRP, a coordinated approach to capacity building is envisioned where training programs and workshops for the target grain legumes in a region with the partners will be organized collectively, focusing on the highest priority needs. The CRP also plans to establish a scholarship program to attract qualified and committed students for grain legume research in different disciplines.

Farmers will be involved, not only in training on participatory varietal selection methods and other topics of interest, but will also be trained to provide knowledge/expertise to others. Courses and programs will be designed and conducted for exchanging ideas and find solutions to intractable problems, with opportunities for learning while doing. Emphasis will be placed on individual hands-on learning experience for technicians and scientists. If no local or national organizations have sufficient capacity to coordinate post-harvest research/market networks, the CRP initially will do so or provide support, and over time, develop the national capacities.

The CRP will produce diverse types of data from the research and development activities. While such data will be available as international public goods (IPGs), meta-data, and associated analyses will also be shared globally. The CRP will use modern ICT to make datasets, generated across the CRP, accessible to participating researchers. Information on crop improvement and crop management will also be shared through fliers, information bulletins, research reports, and research papers published in international peer-reviewed journals. ICT will also be explored in partnership with communication providers to reach farmers and other clients with the knowledge and information they require to optimize production of grain legumes in diverse farming systems.

Rationale and objectives

Capacity strengthening interventions have evolved along with the broadening of the scope from mere research to research for development. There is a paradigm shift from a relatively narrow focus on training for crop production through extension systems to the current more systemic approaches that focus on rural innovation systems through multi-stakeholder platforms.

This evolution towards research for development raises many issues around the need to effectively reach multiple end-users. Reflections on the lack of impacts has led social scientists to seriously question the pipeline approach used to resolve the “farmer’s problems” with scientifically proven technologies. Several participatory approaches have been developed and researched to convert the technology transfer pipeline into a learning cycle, where next and the end users of research processes learn together, support partnerships and stakeholder engagement, and thus, increase the chances of research being put into use. The participatory learning mode, where responsibilities are shared, and all actors contribute, makes for a system that is less dependent on one individual or institution, and potentially becomes more sustainable.

The involvement of a wide range of actors requires the creation of a shared context (Snowden 2002), where advances in information and communication technologies (ICTs) that make technologies truly participatory can contribute to the way we communicate, share knowledge and solve problems. These interventions will strengthen both individual and organizational capacity. Therefore, the major goal of this SC will be to design and develop ICT enabled knowledge sharing and innovation platform along with the conventional approaches, that facilitates knowledge at the CRP research partner institutes fuses with extension, education and training.

Research approach

Periodical workshops and training programs will be organized at various levels to capacitate the CRP partners, scientists, farm and lab technicians, graduate students and practitioners. Farmers’ field schools and innovative participatory extension approaches will also be used to exchange knowledge among the NARS, NGOs, and the farmers.

ICT mediated knowledge sharing and innovation platform will be designed and developed to bring community members and information and knowledge resources together across vast distances to enhance collaboration and improve access to knowledge efficiently in a cost effective manner. Courses and workshops that cut across crops, regions and partners will be organized collectively focusing on the highest priority needs. The CRP also plans to establish a scholarship program to attract committed and dedicated students for research in grain legumes. The ICT enabled knowledge sharing and Innovation platforms will include a wide array of ICT components – Grain Legumes Net, Connect, Open-courseware Platform with Learning Objects repository, Data Analytics and M&E platform, and extension & outreach component with wide variety of ICT tools – ranging from mobile phones, web based knowledge network tools, radio and television with VSAT dishes – for knowledge aggregation and dissemination. Other means of knowledge sharing such as newspapers, fliers, information bulletins, research reports, and research papers published in international peer-reviewed journals will also be used for dissemination of information on grain legumes.

Innovative Contributions

Grain Legumes Net

CRP Grain Legume Net is premised on the assumption that virtual knowledge networks, mediated through the contemporary knowledge and communication technologies, being facilitated by CRP partners will enable exchange of information and knowledge sets among and across the crops, regions and partners. A state-of-the-art ICT mediated dynamic virtual knowledge network model will be created to connect communities of student learners, scientists, entrepreneurs, policy makers, and practitioners; and formulate unique or multi-disciplinary virtual communities to facilitate exchange of research information and knowledge among and across crops, regions and partners. A special effort will be made to draw nutritionists working on legumes into the international scene and to interest them in research relevant to the developing countries on topics not covered under A4NH. Through *Grain Legumes Net,* the most interesting projects, cutting-edge research, and fascinating stories will also be highlighted to the global audience. This will allow experts across the globe to share their experiences and research results for discussion, review and rapid dissemination. All the stakeholders will have access to the technical experts and the latest scientific innovations in Grain Legumes.

Training and open courseware platform for grain legumes

In yesteryears, the formal education, capacity building and knowledge transfer activities were conducted through residential, face-to-face mass training and education. This approach, although effective, is costly and has limited reach and follow-up opportunities. The new approach to capacity building envisions easy access to share the information, knowledge and skills— anywhere and anytime — in a cost effective manner. Keeping this in view, an open courseware platform will be developed to host information on Grain Legumes related courses conducted from time to time in different regions for students, scientists, farm and lab technicians, farmers, practitioners and entrepreneurs. The courseware, a combination of text, pictures, audio and video of each course, will be treated as a reusable learning object, and deposited in a repository for dissemination to other stakeholders, and for developing electronic learning materials to minimize the time and cost. The design and development of courses and training materials will follow instructional designing principles, electronic learning standards and open distance learning methods for enhancing the learning outcome.

It will enable CRP Grain Legumes Net members to share several education, training and capacity strengthening related activities across regions. Moreover, the platform will also encourage all the CRP Grain Legumes Net members to use learning resources available in the repository for rapid production of learning materials, and allow them to create new reusable learning objects to enrich the repository with new learning resources. Innovative open distance learning approaches will be used to deliver the courses and also enable interactions through Learning Management Systems, CDs, ICT enabled communication tools.

Grain Legumes Open Access Repository will store reports, research papers, methodologies, and case studies. In addition to sharing of knowledge through fliers, information bulletins, research reports, and research papers published in international peer-reviewed journals, contemporary ICT mediated document management and publishing system will also be used to allow CRP Grain Legume Net members to post/upload documents to the Open Access Repository to allow the global community an easy access them.

Grain legumes data analysis, monitoring and evaluation platform

The proposed data management platform will provide CRP partners and the global community with access to data and new ideas from in-country networks, and information on what works and what doesn't.

ICT mediated extension and outreach platform

Although ICT mediated platforms have shown a new direction to Extension and Outreach, many of the existing ICT mediated extension approaches are unable to establish the last mile connectivity because of the infrastructure (most of the smallholder farmers in developing countries cannot afford computer and Internet), literacy, and language issues. Therefore, we will strive to develop an integrated ICT mediated extension and outreach platform that uses a combination of ICT tools to establish the last mile connectivity with various stakeholders through voice messages regarding seed availability, planting times, pest appearance and their control, and fertilizer use to the farmers; and text messages to extension agents, entrepreneurs, practitioners etc.

Student scholarships

Student scholarship program will be designed to recruit the meritorious and committed students to work with the scientists on CRP Grain Legumes research activities. Discussions are already underway with the Dry Grain Pulses CRSP to establish a joint scholarship program to attract students from developing countries to be associated with US universities and conduct joint research in the CRP at the target sites.

Partnerships

The Dry Grain Pulses CRSP, in collaboration with the Advanced Research Institutes and universities, will design, develop and offer courses, workshops and virtual learning opportunities. The use of virtual teaching will be employed to reduce travel times and provide for a broader range of scientific expertise in the courses.

Several of the CGIAR centers work in common countries and with the same partners. In several countries, legumes are grouped together in a single National Legume Program, such that the same program leader finds him or herself dealing with several international centers researching on legumes. Interaction with national partners will be coordinated through consultations as described in the section on "Demand Driven Impact Pathways" but at the level of national coordinators and international centers.

Outcomes

Specific outcomes of the SC5 include sharing of knowledge and information through: i) trainings and workshops for the stakeholders in different regions, ii) fliers, information bulletins, research reports, and research papers in international peer-reviewed journals, iii) community of virtual knowledge networks involving students, faculty, and partners via long-distance learning; iv) a knowledge repository to disseminate accumulated information to stakeholders in a way that supports discovery and analysis; v) monitoring and evaluation of the efficacy of strategies used to enhance student, extension agents, and practitioners learning, and impact on farmers; and iv) effective strategies to communicate between project participants and smallholder farmers.

Demand-driven Impact Pathways

Impacts of agricultural research and development involve a multitude of partners, institutions and other external factors. To ensure a focus on impact, Grain Legumes research and development activities are guided by a demand-driven impact pathway framework. The framework is a description of the process by which the research outputs lead to outcomes and ultimate impacts.

One can easily visualize a chain of events that lead to impact. Better availability and utilization of genetic resources contribute to breeders generating a steady flow of improved varieties. Seed producers receive improved varieties and disseminate them through improved seed systems. Improved varieties, crop management practices, and integrated nutrient and pest management are all complementary innovations that allow grain legumes to be intensified by smallholder farmers for greater production and productivity. These research activities comprise SC2 and SC3.

Better information on end-user demands including those of local households, nearby processing industries and national/international marketers, can help ensure that smallholder farmers can obtain good prices for their grain legume harvests. Householder preferences can be many such as: color, shape, taste, storability, cooking time, etc. Value addition and processing technologies will enable higher value capture by the smallholder farmers particularly women.

Examples exist to illustrate the major determinants of adoption and impact of grain legume technologies by farmers:

- Participatory methods to improve relevance and adoption of technologies (Chamango 2001; Snapp et al. 2002);
- Farmers' access to information and awareness of improved legume varieties and crop management technologies (Bhatia et al. 2006; Ndjeunga et al. 2008; Shiferaw et al. 2008a; Kristjanson et al. 2005);
- Availability and accessibility to new technologies, especially legume seed, due to the absence of an adequate seed system (Sperling et al. 1996; Phiri et al. 2000, Tripp 2011);
- Market access and opportunities (performance of input and output value chains);
- Access to credit and other policies to enable farmer investment in new technologies; and
- Effective research-for-development partnerships and linkages in the impact pathway will ensure that various development partners will facilitate farmer access to information and innovations to stimulate adoption and scaling up of successful innovations.

New legume varieties do spread from farmer to farmer (Grisley and Shamambo 1993; Kormawa et al. 2004; Alene and Manyong 2006b), and grain markets, which are a very important seed source for many legumes, can help dissemination of a new variety (Jones et al. 2001; Tripp et al. 1998; David 1997). The Tropical Legumes II project emphasizes improving seed systems (http://www.icrisat.org/tropicallegumesII/pdfs/BTL4-2011.pdf). Nearly 93,000 metric tons seed of common bean, chickpea, cowpea, groundnut, pigeonpea and soybean were produced across target countries during 2007-2010. But more significant was the execution of systematic research on multiple models of centralized and decentralized seed production including: public-private partnerships focused on marketing seed in smaller quantities that are within reach of poor legume producers; revolving funds for seed production; and seed-for-grain trade schemes in collaboration with local institutions. Improved varieties reached over 1 million farmers with small pack seed distribution during the last three years in Ethiopia (ca. 465,000) and Kenya (ca. 637,000) (http://www.icrisat.org/tropicallegumesII/pdfs/BTL4-2011.pdf, Phiri et al. 2000, Chirwa et al. 2007). The key factors for success include: affordability of seed; increased awareness, especially targeting women; assured seed quality; and involvement of private sector seed companies and local traders. Not surprisingly, one size does not fit all and different models are more suitable to different settings.

Other examples of rapid adoption of improved cultivars and impacts on crop productivity that resulted from enhanced awareness of farmers about improved cultivars and the strengthening of seed systems include:

- Short-duration chickpea varieties developed through ICRISAT-Indian NARS partnership were adopted in more than 90% of the area within a period of ten years in Andhra Pradesh state of India (ICRISAT

2010). The availability of high yielding, short-duration and heat tolerant varieties suited to short-season environments of Andhra Pradesh; knowledge empowerment of the farmers; and strong partnership of research institutions with public seed sectors and farmers/farmers' groups were the key factors.

- During 2004-05, improved varieties covered about 82% of total chickpea area in Myanmar leading to a remarkable increase in chickpea yields and production in Myanmar. During 1995–96 to 2004–05, the chickpea area in Myanmar increased by 24% and yields almost doubled (from 588 to 1171 kg/ha) (Than et al. 2007).
- A project supported by IFAD and implemented by ICARDA in collaboration with national programs in Egypt, Sudan and Ethiopia focused on enhancing adoption of improved faba bean, chickpea and lentil cultivars and production technologies. Key elements of success included enhanced collaboration of researchers with extension personnel, increase in seed availability by research organization, and greater awareness of the role of food legumes in crop rotations and in household nutrition.
- In Turkey, a new drought and Ascochyta blight tolerant kabuli chickpea variety, Gokce, developed by ICARDA resulted in increased yields from 860 kg per hectare in 2000 to 1070 kg per hectare in 2006. Availability of quality seed through efforts by the Exporters' Union Seed and Research Company (ITAS) drove success (New Agriculturist: http://www.new-ag.info/07/05/brief.php; African Agriculture: http://www.africanagricultureblog.com/2007_09_01_archive.html).
- In Syria, improved winter chickpea varieties have been widely adopted (ranged from 33% to 61% across all provinces), leading to an increase in farm income by US$ 220 per hectare (Mazid et al. 2009). The success is attributed to the superiority of new varieties and efforts by the General Organization of Seed Multiplication to enhance seed availability and awareness through mass media and extension services.

However, such a list of actors, events and conditions in itself does not constitute an impact pathway, nor does it fully explain the *process* of adoption, much less innovation. An "impact pathway" can be visualized as an interacting group of actors in a network of "supply and demand" relationships. An open forum offers the opportunity for demand to be expressed and identified, and this sets the tone for the suppliers of technology. A farmer may be a demander of technology in one instance, and a supplier of technology to another farmer. Passage of technology from one actor to the next requires that each actor knows what is available, and what demand exists from others. For example, seed producers or service providers such as NGOs often do not have complete knowledge about what cultivars are available from researchers. Furthermore, those same seed producers will not have a sense of the potential demand for cultivars that are still unknown to farmers, and thus will be reluctant to produce seed. Farmers in turn don't have a way to express their demand for products about which they have no knowledge. An impact pathway should facilitate communication among the several actors, in such a way that each can plan his or her actions in relation to other actors above or below in the impact pathway (Figure 5).

Thus, an impact pathway is not only a series of events and actors with specific functions, but also a web of social relationships in an interactive, dynamic and participatory process. The fuel that drives the supply-and-demand relationship at each step is communication between the respective parties, within a social structure or *social network*. Continuity and stability of that structure facilitates more effective communication as trust and mutual responsibility grow between actors. As the structure consolidates, it can attract additional actors, such as providers of credit. What might start as a relatively simple value chain, for example, to market grains or some other product, can become an *innovation platform* in which the actors participate voluntarily and with power of decision; in which providers of other inputs or technology options such as simple mechanization can enter. The innovation platform ensures free flow of information and delivery systems among all stakeholders working towards a common goal. These outcomes in turn will contribute to: (i) increased incomes; (ii) improved food security; (iii) improved health, nutrition; and (iv) reduced environmental and resource degradation.

The Sub-Saharan Africa Challenge Program (SSA-CP) studied such processes and relationships at its Lake Kivu site at the juncture of Rwanda, D.R. Congo and Uganda, with a focus on market led pathways. Findings on methods and practices for the establishment of innovation platforms were documented (http://www.ciat.cgiar.org/work/Africa/Documents/2010_SSA_CP_internal_review_Final_Report_Aug_2010_.pdf). Some of its findings are:

- The **Market-led Innovation Platforms** work better than research-led Innovation Platforms;
- Win-win scenarios attract **non-traditional actors** such as providers of credit;
- An **iterative process** of planning, action and reflection enhances capacity of stakeholders;
- Alternative sources of income already exist in the region for **diversification,** such that an innovation platform can broaden and give space to those options;
- Linking farmers with markets creates awareness about **product quality**;
- Additional interventions such as **financing** are required to sustain collective sales among farmers; and
- The Innovation Platform method is **REPLICABLE**.

The SSA-CP worked across twelve value chains in the Lake Kivu site, compiling common experiences and methods. Nevertheless, the challenge of social networks is scaling out to a national level. Replicability is the first step in this direction; boots on the ground is the second. Who is in the position to do this?

The Pan-African Bean Research Alliance (PABRA), facilitated by CIAT, has applied lessons from the SSA-CP with facilitation of consultations among the various actors along the impact pathway, starting with experiences in seed dissemination. PABRA puts great emphasis on bringing end-users in the technology development process early and keeping them involved even in the central decision-making. In a very real sense, an impact pathway starts with the planning of research. This is not participation for the sake of ensuring participatory approaches; it is what makes the difference between adoptable and non-adoptable technologies. One of the more comprehensive thrusts has been in the field of participatory plant breeding (PPB) for which PABRA was the pioneer (Sperling 1989; Sperling et al. 1993). PABRA brings not just women and men farmers systematically into the variety screening process, but also local seed/grain traders, who help ensure that emerging varieties meet much-desired marketing traits (CIAT 2008).

A strong feature of PABRA has been to actively catalyze regional collaboration in seeking solutions to problems faced by the bean sub-sector. This is done through joint priority-setting, planning and agreed division of responsibilities; all facilitated by CIAT. Hence, PABRA operates within a common Pan-Africa R4D framework, which is based on partners' national interests, shared regional vision and objectives. Partnerships constitute the core of PABRA operations, translating into cost-effective and enduring gains at multiple levels: a) partnerships between and among CIAT and National Agricultural Research Systems (NARS); b) partnerships with actors all along the varied bean product value chains, and c) partnerships with technology end-users, including the poor and women. Built-in mechanisms (e.g. network and alliance steering committees) ensure that partners across the impact pathway are interconnected.

Research technologies and other outputs are shared among countries, avoiding unnecessary costs and duplication of efforts. Partnerships among NARS help countries compensate for the inevitable uneven resource endowment of the national bean programs and also to focus/capitalize on comparative advantages. All twenty-eight member countries in PABRA implement the same logframe and framework, which helps to harmonize research on beans and harnesses synergies among national bean programs on the continent. By bringing on board a range of NARS partners offering complementary skills and services, and often operating in different agro-ecological and socio-economic environments, PABRA ensures that the impact of bean R4D are felt well beyond the specific countries or locations where activities are implemented.

PABRA's model is employed in turn within the several participant countries. Within each NARS, researchers, regulatory agencies, extension agents, seed producers, health workers, large and small NGOs, and community based organizations – all are convened to a meeting at a national or sub-national level. The national legume research program typically serves as convener, applying in a national context the same lessons from the SSA-CP. It is the national program that is assuming the role to cultivate innovation platforms, often on a sub-national level, and sometimes for narrower niche markets with specific value chains. The regions of a country constitute the impact zones for the technologies, where the technologies are widely tested, adapted, disseminated, and adopted. In the different impact zones of a country, the national coordination with some national level actors support and coordinate the zonal based actors to disseminate the technologies. On a local level, a range of actors may interact with researchers (CBOs, seed companies of different range of operation, NGOs etc.). Information on technology on offer is shared and interested parties can express their willingness to participate in its implementation, or pose their own demands. Consultation in a participatory mode makes these platforms demand driven, which is to say, market driven, contributing to their sustainability. In some cases, public-private partnerships have been critical for the successful generation, promotion and delivery to farmers, as clearly illustrated by the case of Ethiopia (Rubyogo *et al.* 2011). In the first year of testing this mode of action for seed dissemination, 58 Memoranda of Understanding were signed among the participating institutions, at the initiative of the participants and *without* the mediation of PABRA. Such national consultations are now carried out routinely in several countries. The role of PABRA as agent of an international center has been and continues to be one of capacity building, and serving as channel for knowledge and experiences among national programs.

Beyond facilitating the communication among actors, the greater challenge of developing an impact pathway is to "institutionalize" the communication space – albeit informally – so that the participants can count on information sharing on a regular basis, and so incorporate that information into their planning process as a routine procedure. When this process matures and is consolidated, it can be called an "innovation platform". When this occurs, the several components cited in the diverse experiences above, and the "so-called" drivers of adoption can operate in a replicable and systematic fashion.

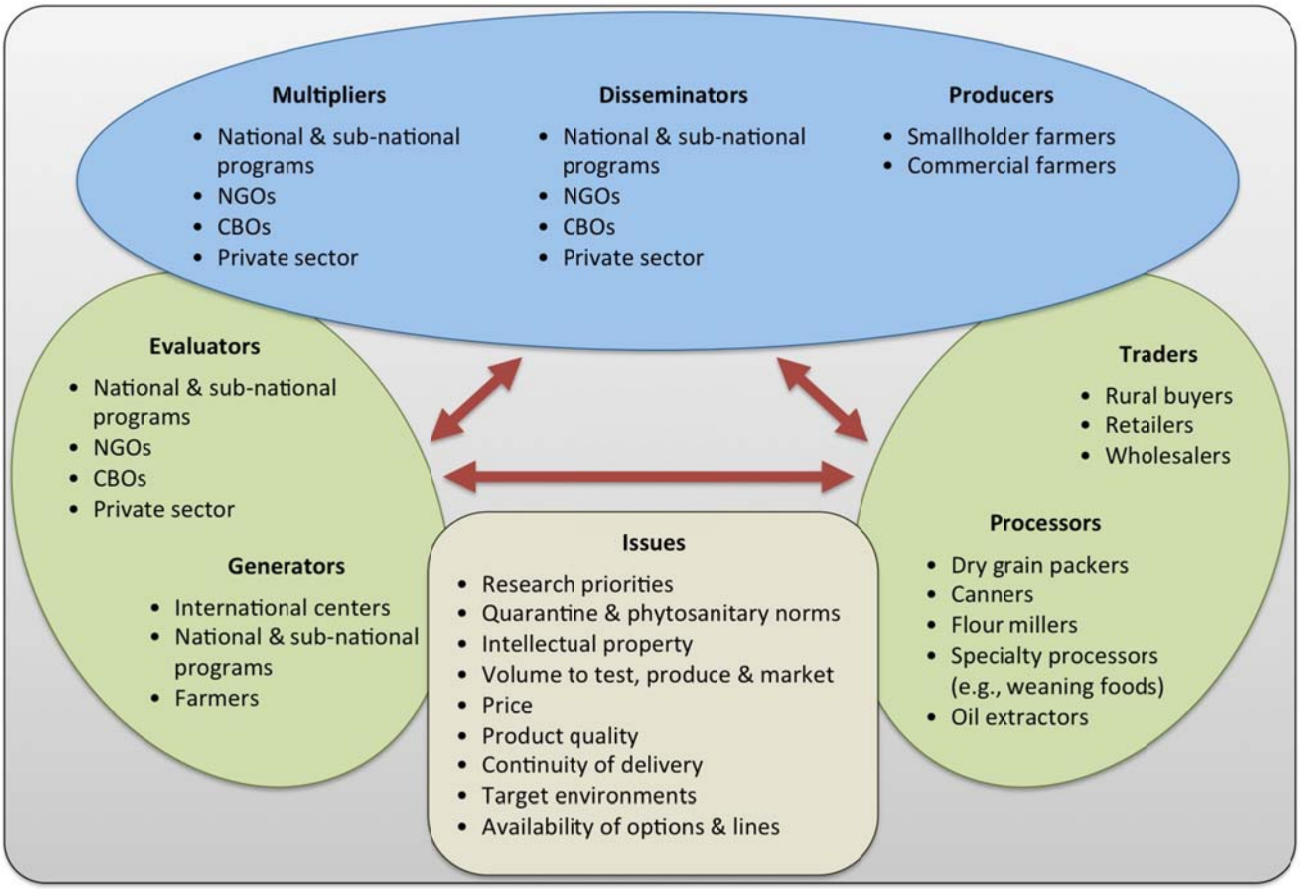


Figure 5. Actors in a demand-driven innovation platform and issues to be resolved among them.

Partnerships and Networks

Partnerships and networking are crucial to CRP Grain Legumes, as the CRP focuses on facilitating R4D activities among a wide array of partners. CRP Grain Legumes with partner with (i) national agricultural research systems (NARS) in the target countries in ESA, WCA, SSEA, CWANA and LAC, (ii) regional R4D networks, (iii) advanced research institutes (ARI) in both developed and developing countries, (iv) private sector R&D institutions and companies, and (v) non-governmental organizations (NGOs) and farmers' organizations.

National Agricultural Research Systems (NARS): CRP Grain Legumes will be working with the NARS in each target region to ensure that the international public goods (IPGs) generated by the CRP are fine-tuned to meet the local needs and conditions, and subsequent adoption by smallholder farmers. The NARS will be involved in (i) evaluating the germplasm and using modern tools to enhance efficiency of breeding, (ii) co-develop, evaluate and disseminate high yielding legume varieties, (iii) evaluate and disseminate integrated crop management technologies, (iv) identify and enhance improved seed delivery models, and (v) enhance capacities of men and women for grain legume R4D innovations.

Regional R4D networks: CRP Grain Legumes will harness the strength of well-established regional networks as they are very effective for accelerating impacts and strengthening capacities. CRP Grain Legumes will work with the regional networks to widen their scope and impacts along the legume value chain. Being regionally based, the networks are close to the socio-economic and biophysical context in which adoption and impact occurs. These networks will also provide feedback on regional/national knowledge, data, information on grain legume issues, trends, priorities and expectations. In addition, the networks will be: (i) sharing evidence, best practices, innovative ideas and problem-solving expertise across crops and regions; (ii) sharing facilities and services among those best equipped to carry out different tasks; (iii) coordinating and fostering inter-disciplinary and cross-crop project collaboration; (iv) mentoring and training of young scientists and providing them opportunities for professional development; and (v) creating scientific consensus of opinion to informed policy-making. Unfortunately, some networks have become dormant or are at low-level of activity in the past decade due to lack of resources. CRP Grain Legumes will attempt to provide support to these networks, because of the strength they have to exploit new opportunities.

Advanced Research Institutes (ARI): The CGIAR centers are already involved in research collaboration with many ARIs in both developed and developing countries. CRP Grain Legumes will strengthen and enhance partnership research in the following areas: (i) new tools and methods to identify trait-specific germplasm, (ii) technological support in using modern biotechnology (genomics and genetic engineering) tools, (iii) high-throughput phenotyping and genotyping platforms, (iv) strategies to improve existing seed systems models and policies, (v) developing post-harvest and value-addition technologies, and (v) capacity building of partners in R4D innovations.

Private Sector: Research and development investment by the private sector, especially in biotechnology related areas, is likely to further increase in the coming years. CRP Grain Legumes will partner with relevant private sector (PS) R4D institutions for mutual benefit, without compromising the CGIAR principles and interests. The private sector has been very active in seed production and delivery systems, but mostly in industrial crops and hybrids. Considering that PS involvement in grain legumes has been low, CRP will work closely with both national and multinational seed companies to increase their role in legume seed business. CRP Grain Legumes also envisages partnership with PS companies in the area of seed systems, post-harvest processing and value-addition.

Non-Governmental Organizations (NGOs) and Farmer' Organizations (FO): Grain legumes are mostly grown by smallholder farmers in marginal areas, with limited access to inputs, technologies and markets. Many of the NGOs operate in remote areas and in the drylands where grain legumes are extensively cultivated, and work closely with marginal and smallholder farmers. CRP Grain Legumes will work with local NGOs and FOs for on-farm testing and evaluation of improved legume varieties, promoting proven and best-bet crop management technologies, facilitating village cooperatives for seed production and delivery, help in seed-business incubation, enhance awareness on post-harvest processing technologies and value-addition, and linking farmers to markets.

Gender Strategy

Rationale

Legumes are generally considered as women's crops because women's contribution to growing secondary crops such as legumes and vegetables is usually greater than in producing the world's staple crops – rice, wheat and maize (Kumar 1985; FAO 2007a, b). A corollary of this statement is that women should play a prominent role and be full-fledged partners in planning, partnering, capacity building and information sharing. In parts of Africa where legumes are purely subsistence and semi-subsistence crops, women are more visible in the production roles, marketing of perishable products like leaves as vegetables, and seed and small-scale processing (e.g., groundnuts for home and local sale), while men tend to dominate in the marketing of grain in the value chain (Bationo et al. 2011). Men also dominate in the legume value chains (integrating production and marketing) in the few highly commercialized production contexts such as common bean in the central rift valley of Ethiopia and the lowlands of northern Tanzania. In Asia, women integrate the production, processing and marketing activities of chickpea, groundnut and pigeonpea. The gender division of labor in Asia appears to be changing in response to changing economic opportunities in urban areas. When men leave agricultural communities in search of employment opportunities, women assume many tasks that were earlier done by men. Women are also increasingly involved in soybean processing and product development, such as akara (fried fritter), dan dawa, moin-moin (soybread), soy-cake, soy-milk and soy-cheese, indicating that women may also be the direct beneficiaries of economic gains from soybean value chain enhancement (FAO 2007b).

However, women still face more extreme challenges in accessing farm inputs and services – land, seeds, fertilizers, pesticides, farming knowledge, technologies, credit and market organization. This is because men tend to take most of the household decisions that affect women's access to land for production, income from marketed surplus and occasionally household labor (Kumar 1985). Past experiences have shown that men often take over women enterprises after they become profitable. There are also examples of women being given poor lands to cultivate crops and once the lands become fertile (say after growing legumes for a few years), the men take them over for growing high value crops. Limited access to credit is disproportionately high among women because they lack control over land that is usually demanded as collateral. Even with the advent of microfinance due to which women form the largest percentage of those reached, they receive very small loans (quantities), and in aggregate the fewer men reached by microfinance receive a higher proportion of loans than the many women put together. For instance in Africa, women receive less than 10% of the credit to smallholder farmers and only 1% of the total credit to agriculture (Bullock 1993). Gender differences in technology choices have also have been reported in participatory legume variety studies (e.g., Kolli and Bantilan 1997). Similarly, women's participation in and benefits received from value chains have been particularly neglected. A notable exception is the Dry Grain Pulses CRSP (Bernsten et al. 2009; Mazur et al. 2009). Illustrating the potency of this approach to deliver particular benefits to women, their value chain research has identified cowpea flour as a critical bottleneck in the sustainability of women's small-scale enterprise in the post-harvest preparation and sale of products such as moin-moin in Nigeria (Lowenberg-DeBoer and Ibro 2008). The Dry Grain Pulses CRSP will be an important partner in the CRP. A number of countries and institutions are increasing their efforts identifying promising agricultural value chains for investment, as in Kenya (Value Chain Finance Center 2009), Nigeria (UNIDO 2010) and Malawi (USAID's Feed the Future).

The critical importance of women in legume production and the fact that their access to necessary resources and appropriate technologies is often constrained by gender barriers is now a recognized fact across participating CGIAR centers, stimulating the centers to incorporate gender issues in legume research and development, and increasing the efforts to overcome the gender barriers. For example, CIAT has for many years hosted the Participatory Research and Gender Analysis (PRGA) Program, and its work on beans over the last decade has had a strong focus on empowering rural women to manage their natural resources and access to markets. In technology development across centers, both women and men's concerns are continually being integrated in breeding criteria through participatory plant breeding (PPB) and participatory variety selection (PVS). This has enabled breeders to not only develop well adapted and acceptable varieties, but also achieve the desired varieties faster. For example, Sperling et al. (1993) observed that the participation of women in bean variety development led to a faster identification and adoption of improved bean varieties suited to small production niches in Rwanda. Other gender related efforts have been focused on gender characterization and improvement of policy, community development projects and capacity building among partners. Building capacity included but was not limited to training, changing of research approaches to be multi-disciplinary, and engaging other players such as gender experts in research.

Grain Legumes recognizes that women have accumulated a wealth of legume specific knowledge and expertise that should be tapped in legume research and development. Lessons learnt from previous legume interventions and elsewhere also indicate that positive and negative gender-specific impacts are possible, and if not monitored and timely addressed, could undermine the ultimate goal of improving socio-economic welfare of the poor. A few examples from the past bean and groundnut evaluation research elaborate on this. Adoption of fast cooking bean varieties in Tanzania has reduced the workload on women in terms of time spent in search of firewood, cooking, and foraging for wild vegetables during the dry seasons (David and Sperling 1999), and general consumption of annual firewood reduced by about 10% (Nkonya et al. 1998). On the other hand, the negative impacts were observed in the form of increased workload on women by the adoption of soil improvement technologies, such as planting and incorporating green manure alongside varieties. In other communities, new high yielding varieties attracted more men in production, with diverse consequences that varied from antagonistic and competitive to complementary situations, depending on the context. ICRISAT's study also shows that the increase in groundnut production resulting from new varieties and technologies led to increases in household incomes, but a greater workload for women in shelling the increased production (Feldstien 1998). These and other examples indicate that overall gender specific effects could be negative or positive especially on women, depending on which outcome is stronger. These examples clearly point out the importance of incorporating gender research and analysis, and other gender-related issues at all levels of planning and interventions that will steer efforts towards achieving reduced gender disparities and increased gender-equitable impacts.

Objectives

The over-arching *research-for-development challenge* to be addressed by Grain Legumes is to apply crop improvement with related high-priority value-chain interventions to maximize the benefits that grain legumes offer to smallholder farmers, of whom women form a large bulk of the population, securing their food supplies, improving their nutrition, sustainably intensifying their farming systems, and increasing their incomes. Thus, gender is a cross cutting thematic area in which analysis is used to inform and deepen the relevance of other research themes under all Product Lines and Strategic Components.

Impact pathways

Success for the CRP requires women as well as men to benefit from its expected overall impacts of poverty reduction by enhancing livelihoods in a gender equitable manner through (i) increased incomes; (ii) improved food security; (iii) improved health, nutrition; (iv) and reduced environmental and resource degradation for millions of resource-poor men and women dependent on rural livelihoods. The CRP's theory of change for expecting its research outputs to contribute to these outcomes and impacts is that engagement with and free flow of information and delivery systems among a cross-section of key stakeholders for the co-development and use of its key knowledge, technologies developed and capacity building outputs will enhance the uptake process and finally lead to the impacts.

Fueled by the drivers of change, the proposed impact pathway will accelerate the adoption of improved technologies and innovations by increasing women and men farmers' awareness as also improving access, availability and affordability of quality seed particularly to women

Involvement of both women and men farmers in participatory varietal selection (PVS) will facilitate the selection of improved varieties that fit in their fields and growing conditions and socio-economic environment. Women's participation in PVS will particularly lead to selection of improved varieties with quality traits that will decrease women's time and drudgery. Improved grain legume value chains with a focus on women's roles and knowledge/skills will lead to an enhanced local capacity to manage production and market risks and generate new opportunities for women's employment. Increased and focused participation of women in the value chains will increase their involvement in higher level economic activities like marketing, managing end-product enterprises and decision making. Focused gender and capacity building activities will lead to increased national capacity for technological and institutional innovations and accelerated translation of outputs to impact. These will progressively lead to economy-wide social and environmental impacts that contribute to sustainable intensification, poverty reduction increased income and better food security for both women as well as men in the face of population growth and climate change.

The gender dimension of the CRP impact pathways is summarized in Table 21.

Table 21. Grain Legumes gender outputs, outcomes and impacts.

Research Outputs	Research Outcomes	Development Outcome	Impact
More and improved germplasm, genes, methods, cultivars	Enhanced knowledge on traits that are important for users, particularly women (e.g. mechanically harvestable legumes, herbicide tolerant varieties to minimize drudgery, etc.)	Women and men farmers access more germplasm with improved agronomic and quality traits of their preference, enhanced resistance and broader genetic base as varieties; legumes cultivation becomes more women friendly with drudgery reduction for women in their tasks	Reduction of poverty through increased income for men and women farmers; asset accumulation, improved health, particularly of women and children through better nutrition
Improved crop, pest and soil management technologies	Crop and pest management technologies used by delivery systems	Adoption of enhanced skills and knowledge of women and men farmers for managing crops, pests and soil –specific to their tasks	Food security increased for both women and men increased production for home consumption.
Better seed systems through decentralised seed system	Better seed systems, including decentralised system, adopted by development partners	Availability, accessibility and affordability of seed to women as well as men farmers. Increased involvement particularly of women farmers in small scale seed business	Reduction of poverty through increased income for women and men farmers through higher incomes
Efficient post-harvest practices/technologies and value added products and processes benefitting identified women	Partners use new skill, and knowledge	Less drudgery, especially for women, and higher farm productivity	Reduced poverty, higher farm incomes and gender equity

Activities

The gender research strategy will be two-fold (Kauck et al. 2010): gender analysis will be integrated as a cross-cutting issue in all Strategic Component relevant activities; while strategic gender research on the dynamics of women’s participation in technology development and adoption and the impacts will be undertaken to examine the dynamics of women’s participation in the entire process of technology development and document whether key technologies developed are (or are not) benefitting women to the degree expected. Gender approaches will be adopted during the design, validation, implementation and evaluation of this CRP. Empirical gender analysis will be integrated into the CRP SC research using a range of methods and tools. The program will conduct joint socio-economic studies (as and when needed) with other CRPs (especially the system CRPs and Policies, Institutions and Markets) during the first phase to analyze specific contributions of men and women to socio-economic processes of legume cultivation and processing, differential access to and control over resources, and the rewards they gain from these contributions in the target production contexts. Such gender analysis will generate a deeper understanding of the gender issues, and strategic gender interests for change in the division of labor, access and control of assets (resources and benefits), constraints, and opportunities for their full participation in the production pathways as well as post-harvest value addition processes upstream. The results will inform the development of strategies to address gender inequalities in access to and control over resources and services. Other pro-active approaches will be adopted when necessary, to target interventions and ensure gender-equal outcomes.

Active participation of women and men farmers in technology development process

Multi-stakeholder participatory action research will be an important component of technology development through which men and women stakeholders will be systematically consulted in research and in technology evaluation to identify their own priorities, varietal preferences, success stories, lessons learned, tools and mechanisms. Data will always be gender disaggregated, enabling the gender specific analysis of preferences and incorporation of that analysis in the future breeding strategies. In addition, specific targeting of women to involve them in the selection of varieties that suit both their food security and nutrition and market needs will be emphasized and given priority in breeding for improved nutrition. These efforts will complement the body of in-depth strategic gender research mentioned above and elaborated below under section on strategic gender research.

Gender specific studies

In order to further analyze gender preferences of crop traits some gender specific studies will be designed in collaboration with Policies, Institutions and Markets for contexts where information is scarce. These studies will be based on various gender sensitive participatory research approaches using both qualitative and quantitative tools and methodologies.

Targeting of women

Traits that benefit women will be given prominence in varietal development. Farmers' participatory varietal selection (FPVS) approach currently in use across centers will continue to actively involve both women and men farmers of different social classes to increase their influence on the breeding criteria. Specific targeting of various women groups will be emphasized during the selection of varieties where potential trade-offs between traits (i.e. micronutrients, commercial value, drudgery) exist to ensure that the program does not stray from their concerns, or is able to adjust to any changes in these concerns. Legume cultivars with such women-preferred traits would thus enable closing of gender gap in agriculture that would generate significant gains to the society. Qualitative assessment of trait preferences will be complemented with quantitative assessment of trait trade-offs for each gender group to ensure that gender targeting is achieved while maximizing welfare gains.

The opportunities to build upon the advantages of women's participation in technology development and value chains of legumes with effective access to input and product markets because of their crucial role in household economies and welfare will be enhanced. This will be facilitated through identification and involvement and training of women extension agents, and organized focused group meetings and workshops to ensure that gender mainstreaming is internalized by partners. Other participatory techniques at the community level will be used to promote appreciation and understanding of the importance of gender roles, and thus help communities develop strategies to enhance their livelihoods through increased participation of women. Equity will be promoted at the community level, while encouraging individual, community, and group initiatives to take ownership and responsibility for implementation of activities.

Emphasis will be given to seed production and delivery systems, and tools that capture priorities of both women and men participants as well as giving them equal opportunities for participation. Joint gender analysis with Policies, Institutions and Markets will help in identifying the specific nature of support (and where it will be needed) for women as equal participants in these initiatives. However, deliberate support will be extended to potential women to undertake decentralized seed production/supply enterprises of improved varieties in hard-to-reach areas where farmer-to-famer seed exchange and market grain/seed acquisition are still the most prevalent seed supply channels and being carried out by women (Bishaw and van Gastel 2008).

Capacity strengthening activities

The CRP will also include capacity strengthening activities to empower women and other disadvantaged groups. Such activities will include a range of trainings and context-specific activities such as collective action that will lead towards empowerment.

Gender considerate skills and knowledge enhancement strategies

Such activities will be developed and conducted in areas of seed systems to facilitate an equitable participation of women and men. Considering that a certain number of farmers have limited literacy, information systems and communication strategies will be established to enable equitable access information about varieties and seed quality to both illiterate and literate. These strategies include decentralized demonstration/field days, study tours, variety posters and integration of traditional information systems.

Targeting women's groups

Women groups and associations of women groups will be targeted for building their capacity to organize produce and market collectively to different markets. Product development and identification of agro-enterprises is to be done by gender to ensure that products that are more accessible to women are developed with them in a participatory process. Past experiences have shown that men often take over such enterprises after they become profitable and that social organization helps to protect women's interests. Therefore, the CRP will forge partnerships with gender interest groups to advocate to changes that favor women interests while ensuring that interventions do not create community conflicts.

Capacity building among implementers

It has been observed that while awareness of the role and importance of gender in agriculture has improved greatly, the actual incorporation of gender into agriculture research has been uneven across institutes (Poats 1991). The major reason behind this is the lack of necessary capacity and skills. Lessons from past efforts show that training of researchers in gender issues result in substantial impacts on gender analysis among the researchers that were trained (Feldstein 1998). Thus, addressing gender issues will require partner organizations with adequate skills. Capacity strengthening in gender analysis will be an important component.

Training of staff in IARCs, NARS and private sector partners in the basics of gender analysis and mainstreaming will continue to be supported and expanded to cover a wider scope of participants, both within and across institutions. Equal opportunities will be provided to women and young research staff to improve their knowledge, tools and skills in gender mainstreaming. Women and young adult farmers and traders will be mobilized and supported to actively participate in organized training meetings on gender mainstreaming. Training will also focus on the existing staff and stakeholders and implemented through various arrangements that include workshops to encourage interactions among the participants, knowledge sharing platform and mentoring. Shared positions for experts in gender issues to mentor staff in gender analysis and audit progress will be promoted and supported across centers at sub regional levels.

The CRP will also work with gender experts to develop tools to guide implementers on 'how to mainstream gender in the legume R4D thematic priorities'. For gender equality and advocacy at a wider community, the CRP will partner with relevant gender interest groups to support advocacy for establishment of formal gender equality where this does not exist and help bridge any gap between the formal situation and the actual enjoyment of equal rights and well-being.

Gender-balanced staffing

Gender-balanced staffing in the Centers involved in this CRP will be pursued in line with equity principles and also because in societies with a strong gender-based organization, both women and men researchers, extension officers and community facilitators will be needed to ensure the participation of women and men farmers in research activities. Women in partner organizations and women extension agents will be encouraged to participate and will be involved in research and also benefit from capacity building activities. All CGIAR Centers in the CRP consider gender a high priority, and are making strong efforts to achieve higher gender balance in their staff.

Strategic gender research

Participation of farmers, both women and men, in technology development and their adoption of the technologies form the core of the CRP to achieve the outcomes and the impacts. Given the current scenario in agricultural R4D, the participation of women farmers is relatively less than that of men farmers, which naturally has led to varied impacts on the technologies on women and men famers. The reason for this is the various socio-cultural norms and practices that deeply influence the way agriculture R4D is implemented. Therefore, a strategic gender research in this area will be of critical importance and significance. Since women farmers form a large bulk of the smallholders and since legumes are cultivated more by women, the strategic gender research will be designed to examine the dynamics of women's participation in technology development and document whether key technologies developed are (or are not) benefitting women to the degree expected, particularly in terms of drudgery reduction, nutrition, and incomes. Examining the dynamics of women's participation and understanding the adoption behaviors include understanding constraints and opportunities, gender relations and roles in the community and household, household decision-making, extent of involvement in technology development and dissemination, that technology adoption is highly contextual, has temporal and spatial dimensions, and agricultural tasks are gender segregated. Furthermore, examining the impacts of the adoption of the technologies on women, particularly in terms of drudgery reduction, nutrition and income goes beyond gender disaggregation and look must into more nuanced issues relating to gendered power relations, behavioral/attitudinal changes, changes in practices and processes of decision making, dietary patterns, and changes in gender norms and relationship, especially in terms of work patterns.

Monitoring and Evaluation

A participatory gender-explicit monitoring and evaluation is proposed for the CRP. Such monitoring and evaluation will integrate local- and gender-specific indicators for monitoring outcomes. Monitoring will focus not only on equality of treatment for women and men, but also ensure that the intervention outcomes provide benefits for both men and women in an equal way. To ensure this, all data from intervention activities, and M&E processes should be disaggregated by gender and analyzed, provide feedback lessons for better mainstreaming of gender into the activities, programming and implementation process of the CRP as well as inform policy.

It is also proposed that the gender sensitive participatory M&E system in each center be guided by a performance measurement framework that integrates local and gender specific indicators for monitoring project outcomes. This will ensure that these are measured both with technical indicators as well as local men and women generated indicators. Outcomes and outputs will be monitored for the extent to which they have affected both men and women.

The CRP will work jointly with other relevant CRPs while consulting with gender experts in adapting the performance measurement framework to identify and integrate gender specific monitorable indicators relevant for legume research and development interventions.

Annual reviews by stakeholders and gender specific audits will be periodically organized to review the progress toward gender mainstreaming and evaluate gender specific social impact on well-being.

Innovations

Grain Legumes constitutes a major innovation in partnership. It will overcome institutional and disciplinary barriers, and enhance cross-institution, cross-region and cross-crop learning. It will streamline the CGIAR and partner interface with grain legume clients in each region. It also presents an opportunity to share facilities and operations and gain a critical mass of scientists and research competencies. Ultimately, these improvements will accelerate progress against important and difficult challenges such as seed system bottlenecks, diseases, insect pests, drought, low soil fertility, changes in cropping systems and climate variability and change.

Comparative Genomic Analysis

Grain Legumes has the novel characteristic of bringing together multiple species within a common botanical family, but with even more contrasting evolutionary histories among these species. This represents a unique opportunity to understand how genomes that could be quite similar (e.g., cowpea and common bean are close relatives) have adapted to contrasting environments. Physiological research will reveal patterns of adaptation that can offer models across crops. Genomic cross-crop learning will have a particularly strategic role to play. Following the principle of gene synteny, it can reveal the genetic and functional control of traits in one crop that can provide valuable lessons for application in another grain legume species. Genetically mapped genes for resistance to diseases that attack several grain legume species can be used to identify alleles that might be 'awakened' in susceptible crops. This will help to manage similar pest management strategies over different legumes. As large-scale genomic resources, including genome sequences, become available in several legume crops (Varshney et al. 2010), resistance genes to a range of diseases across the legumes will be mapped using linkage mapping or association mapping approaches. These genes or markers associated with the genes may be used for screening the breeding lines as well as introgressing resistance in leading varieties, if they have become susceptible, or by pyramiding resistance genes with other traits through molecular breeding approaches. Mining of genome sequences available for several legume crops and model legume species for disease resistance genes and their characterization can identify candidate genes. These candidate genes can be used for screening the subsets or entire collection of germplasm of legume species in the genebanks for the identification of superior haplotypes for enhanced resistance to diseases.

Furthermore, the integration of genomic knowledge management systems with conventional breeding systems across crops will create a more efficient, powerful platform for progress in technology deliveries. Successful implementation of molecular markers in breeding programs requires not only integrated data systems but also the tools necessary to rapidly and easily monitor marker-trait linkages in the breeding process (Varshney et al. 2005). For example, the Integrated Breeding Platform (IBP) aims to provide both the means for data integration and the tools necessary for the detection of marker-trait correlations, and to assist in their implementation in breeding. Genome-wide selection (GWS) is a novel approach compared to traditional marker-assisted selection where selections are made based on few markers. Rather than seeking to identify individual loci significantly associated with a trait, GWS uses all marker data as predictors of performance and consequently delivers more accurate predictions. Selection can be based on genomic selection predictions, potentially leading to more rapid and lower cost gains from breeding. Genomic prediction combines marker data with phenotypic and pedigree data (when available) in an attempt to increase the accuracy of the prediction of breeding and genotypic values.

Exploiting primary and secondary gene pools as sources for variability and adaptation traits

Wild *Arachis* species show wide diversity at the molecular, genetic and phenotypic level and constitute an important resource for variability for various adaptation traits; however utilization of wild *Arachis* species needs pre-breeding efforts to eliminate the linkage drag. Genome-wide introgression of a small genomic region from wild species while keeping the genetic background of the cultivated is a good means to explore the largely untapped reservoir of useful alleles of interest in wild species. This approach has been widely utilized for introgression of favorable QTLs for various traits in tomato (Fridman et al. 2004), rice (Xu et al. 2005), wheat (Liu et al. 2006) and barley (Schmalenbach et al. 2009). The *Phaseolus* genus includes species that span the ecological range from arid deserts to tropical rainforests, and the species that can be crossed with common bean cover most of this range. These sister species are pools of genetic diversity that can help confront the looming challenges of climate change. In chickpea, nine annual species exist in the primary and secondary genepool of which only two species (*Cicer reticulatum* and *C. echinospermum*) are currently widely exploited. In lentil, eight species exist in the primary and secondary genepool of which only *Lens orientalis* and *L. odemnenis* are exploited.

Integrated cross-legume approach to stress tolerance including crop modeling

Water is limiting in many of the environments where grain legumes are grown. The success of crops across an array of environments with different water availability needs to balance water use to water availability. Therefore, in each environment, cultivars would have a set of “optimum” characteristics with regards to water use that make them the most suited to each specific environment. Innovation will consist of combining a physiological approach of understanding critical traits that affect plant water use with crop simulation modeling to decipher and identify when and where any of these traits, or trait combinations, lead to a significant yield improvement. ICRISAT and North Carolina State University are collaborating in an effort to model adaptive traits in soybean and groundnut that are critical to drought tolerance across legumes. These traits and the methods to evaluate them are already being tested in common bean.

Current research, using both a water-centered framework and crop simulation modeling, point to several plant traits that could have a major role to play for the crop’s adaptation to climate change and/or drought conditions (Sinclair et al. 2010; Zaman-Allah et al. 2011; Vadez et al. 2011). For example, on-going crop simulation modeling clearly indicate in soybean (Sinclair et al. 2010) and chickpea (Vadez et al. unpublished) that the sensitivity of transpiration to vapor pressure deficit contribute to major water savings and lead to yield benefits under drought conditions. While germplasm having these characteristics in soybean have been identified, there is only limited evidence of the same in chickpea, although common bean shows potentially useful genetic variability (Devi et al. 2012). Therefore, there is a need for a systematic simulation testing of the value of several putative adaptive traits in different crops, followed by a systematic search in the germplasm collection for such characteristics. Since some potential germplasm would likely have some undesirable agronomic characteristics, there will be a need for pre-breeding of desirable characteristics (possibly from wild species) into suitable background.

Other knowledge regarding mechanisms of reproductive stress tolerance for drought, heat and salinity across crops can be used to identify marker-trait associations that can be screened in breeding populations. Knowledge gained from cowpea, pigeonpea and chickpea drought tolerance research, both in physiology and in identification of genomic regions governing drought tolerance, can serve to improve drought tolerance in common bean and soybean. Salinity tolerance in chickpea is largely explained by differences in how reproduction (flowering, podding and seed set) occurs under salt stress, with tolerant genotypes having a larger number of flowers, tertiary branches and a lower seed abortion rate (Vadez et al. 2012). Under heat stress, reproduction also appears to be the factor most affected, whereas biomass production seems to be less affected (Wahid et al. 2007; Beebe et al. 2011). Under drought, the functions of pollen, and particularly the style, are disrupted (Salem et al. 2007). Desi chickpea appears to have better tolerance to salinity and drought than kabuli types. Furthermore, as reproduction is affected by these different abiotic stresses, elucidation of the sensitive components/mechanisms of tolerance, and whether genotypes could have “cross-stress tolerance” of reproduction under abiotic stress, need to be evaluated to provide the basis of future breeding programs for stress tolerance. Elucidating the reproductive processes most susceptible to heat, drought and salinity stress will lead to testing whether mechanisms of tolerance are common for different abiotic stresses, and whether the same mechanisms operate across crops. This knowledge will aid breeders to enhance stress tolerance in sensitive crops.

Crop and agro-ecosystem modeling and computer and electronic application in agriculture are other areas ready for cross learning. ICARDA’s application of the Focused Identification of Germplasm Strategy (FIGS) system and ICRISAT’s mini-core approach help to identify useful material in the vast germplasm banks or even in the field. CIAT has a strong geospatial capability developed together with the GCP that will help all Grain Legumes partners to more effectively diagnose grain legume systems and accompanying social variables of poverty and nutritional status.

Utilize bio-economic modeling to understand the climate resilience potential of heat and drought tolerance

The analysis described above is essentially a genetic-physiological analysis. This can be expanded to estimate the effects of heat and drought tolerance in legumes on climate resilience, on household welfare, and on quality of natural resources such as soil, water and biodiversity, under a set of biophysical conditions (soil quality, length of growing period, pest and disease incidence and drought) and socioeconomic factors (access to market, policies and institutions). The bio-economic models are capable of simultaneously addressing the various dimensions of agriculture, technology changes and the resulting trade-offs among economic, environmental and sustainability.

Explore the potential use of natural enemies of insect pests

Introduction and use of natural enemies of insect pests across continents can have both positive and negative consequences. Fungal entomopathogens can directly regulate populations of various insects. For example, the entomopathogen *Beauveria bassiana* can influence growth and fecundity of insect herbivores, and has been successfully used to control the Sun insect pest in wheat in West Asia. Another entomopathogen, *Metarhizium anisopliae,* using soybean oil formulation is being used for the control of cotton stainer bug, *Dysdercus peruvianus,* and can be explored for the control of pests of legumes crops. Perhaps best known, *Bacillus thuringiensis* (a bacterial biological control) has been used commercially to control pests of Lepidoptera, Diptera and Coleoptera. Also, the genes encoding the Bt-toxins have been successfully transferred into cotton, corn, soybean and rice conferring resistance to insect pests. This technology is considered to be one of the most successful models in agricultural biotechnology. These entomopathogenic bacteria represent a new and rich source of secondary metabolites that needs to be explored.

Model seed systems to overcome obstacles for quality seed supply

In most countries, well over 95% of legume seeds are managed by farmers. Thus, informal seed systems are important for legume seed supply chains. Country/location and crop specific sustainable seed systems need to be developed and promoted. Several players such as researchers, farmer associations, NGOs, seed agencies, government agencies, private sector and linkages among them and with formal seed systems have a crucial role in legume seed supply systems. The dynamics arising from them need to be identified and addressed.

Research on multiple models of legume seed systems and multiple legumes was initiated under the Tropical Legumes II (TL II) project. Under Grain Legumes, research will extend the results of TL II to additional countries and contexts. Dissemination of multiple and diverse models of seed systems is an innovation that has not been attempted previously. Any research on seed systems must take into account how seed systems operate, and strengthen them to increase the supply of new materials. Ideally, the program will reflect farmers' knowledge and experience, and will strengthen the linkages between farmers and researchers from different areas to serve dynamic and changing needs. Seed systems involve many actors and this raises the issue of modeling interactions between social dynamics (decisions or practices of actors or groups of actors, exchanges or communications between these actors or groups of actors), and physical dynamics (natural dynamics of the resources).

Induced mutations for herbicide tolerance

Weeds are a problem across crops, and legumes are no exception. Weeds compete with the crop for light and nutrients; and often lead to significant yield losses. Selective herbicides that do not harm the crop are often not effective in eliminating all types of weeds. Non-selective herbicides are effective in removing all types of weeds in a single application, but a pre-requisite is to have herbicide resistant varieties. Transgenic-based resistance to herbicides is currently available in several crops, e.g., soybean, maize and cotton (Roundup Ready, active agent: glyphosate; and Liberty Link, active agent: glufosinate). Non-transgenic approaches could also be used and are likely to have better acceptance and use. Herbicide tolerant genotypes can be identified by exploiting already available genetic variability (spontaneous mutations) in the germplasm or by inducing variability. Mutagens that have been used in *Arabidopsis* to generate herbicide resistance could be used in legumes; the concentrations and time of exposure would need to be optimized.

The availability of non-transgenic herbicide resistant legumes would contribute to a reduction in farm labor and operating costs. Thus, we need to develop mutagen-based herbicide tolerance in several legumes (e.g., chickpea (Taran et al. 2010) and lentil (Slinkard et al. 2007). In parallel, novel herbicides will be tested to provide alternative options to more effectively control weeds in legumes crops. BASF Canada developed the lentil line RH44, which is tolerant to imidazolinone herbicides. This lentil variety was developed through a process of mutagenesis combined with conventional breeding. The variety is promoted under the Clearfield technology that has been applied to a number of crops such as corn, canola, rice and wheat.

Cross-legume databases

The volume of genetic and genomic data that is being generated currently demands great creativity to manage, but at the same time represents an opportunity never before known to legume scientists. The sort of cross legume research that is outlined in the proposal has its complement in cross legume data management. Discussions for the creation of a database for cross legume comparisons are underway with the soybean community in the United States (US$A), and with CIAT, IITA and ICRISAT.

Integration with the legume nutrition community

Another innovative dimension of cross-legume research having vast potential is the further exploration of the beneficial health effects of legume consumption. The research that is necessary to generate these benefits goes beyond the disciplinary capacity of the CRP, and beyond even that of A4NH, and must be accessed in the broader nutrition community.

Specific benefits of legumes are attracting a specialized group of nutritionists who are creating a *de facto* community of practice. These include scientists from Michigan State University, Colorado State University, University of Saskatchewan and University of California-Davis. To date, the attention of most of these scientists has been focused on the developed countries. By establishing communication with these scientists, facilitating linkages with developing-country nutritionists, and supplying the raw material (i.e., the necessary tonnage of specific legumes), it will be possible to leverage the capacity of grain legumes to address worsening health issues in developing countries. This will be accomplished in collaboration with A4NH, but is a specialized area that requires the active participation of legume experts who have access to relevant genetic diversity and knowledge of local preferences.

New markets for grain legume products and services

The abilities of legumes to fix nitrogen, and to intensify and diversify farming systems are valuable benefits for farmers and to the mankind. Reducing greenhouse gas emissions and storing more carbon in soils and vegetation are environmental services that farmers can trade in international markets. Methods of purchase can be via either environmental service markets or higher-value specialty product markets.

Environmental services

The ability of legumes to fix nitrogen and in conserving nutrients for the current and subsequent crops is a major environmental service. Leaf fall from many legumes adds to increasing soil organic matter, and in combination with root mass improves carbon sequestration. Legume root exudates help in phosphorous nutrition of plants. Overall, legumes enhance organic nitrogen, phosphorous, and carbon in the soils, and thereby enhance sustainability of the farming systems and environmental health. Although many hurdles exist before funds flow from purchasers and sellers of environmental services, the CRP on Grain Legumes can make substantial contributions to identifying, quantifying and facilitating such market opportunities. Many financial transactions are already occurring between farmers and purchasers of environmental services. The Clean Development Mechanism was established in 2000, and currently has a portfolio of 4431 projects. More than 150 projects facilitate the improvement of agricultural lands, with many of them increasing the use of legumes (both grain and vegetative) in farming systems.

In addition, many organizations promoting conservation (e.g., World Bank, UN, FAO, Nature Conservancy and Conservation International) are seeking ways to reduce pressure on forest resources by increasing the productivity of agricultural lands. Similarly, developing countries are developing plans to reduce deforestation and forest degradation and increase carbon in forests (REDD+). Grain legumes have important roles to play in (i) providing viable livelihoods to farmers who will not be able to expand agricultural activities into forests, and (ii) increasing productivity of marginal and fertile lands to meet national food needs.

Specialty and high-value products

Smallholder farmers already sell common - yet differentiated - products to high-value markets (e.g., coffee and cocoa). Diverse physical traits of legumes such as color, flavor, size, shape, spots and other attributes such as being women-managed and ecologically-beneficial are attractive to many consumers. Products need not be traded only in crude form. Local processing can transform grain legumes into attractive and healthy food products using winning recipes, thereby meeting demands for specialty, easy-to-prepare and ready-to-eat foods while generating employment opportunities in many developing countries.

In order to connect suppliers with buyers, such products need to be identified, demands located and quantified. Information also needs to accompany products - not only to whet appetites and spur demand - but also to ensure transparency and fairness of financial transactions along the value chain.

Although the start-up, implementation and transactions costs of these market connections can be prohibitive, especially for individual farmers in remote areas, Grain Legumes will work with partner organizations that foster farmer associations and cooperatives, processors and marketers. With its knowledge of grain legume diversity and supplies, Grain Legumes will also link with CCAFS, Markets, Institutions and Policy, the World Bank, the BioCarbon fund, FAO, Eco-Agriculture Partners, Katoomba Group and private sector companies and other organizations advancing the establishment of environmental service and product markets.

Data and analytical results on grain legume nitrogen fixing capacities (PL4), demand analysis and research priorities (SC1), and processing and marketing (SC4) in Grain Legumes are important to these efforts to increase global grain legume consumption.

Interactions with other CGIAR Research Programs

Grain Legumes will complement many other CRPs, especially Dryland Systems and CCAFS (Figure 6). The specific of the linkages with these two CRPs is outlined below. Brief descriptions of the linkage with HumidTropics; Policies, Institutions, and Markets; WHEAT; MAIZE; GRiSP; Dryland Cereals; Livestock and Fish; and A4NH are then provide.

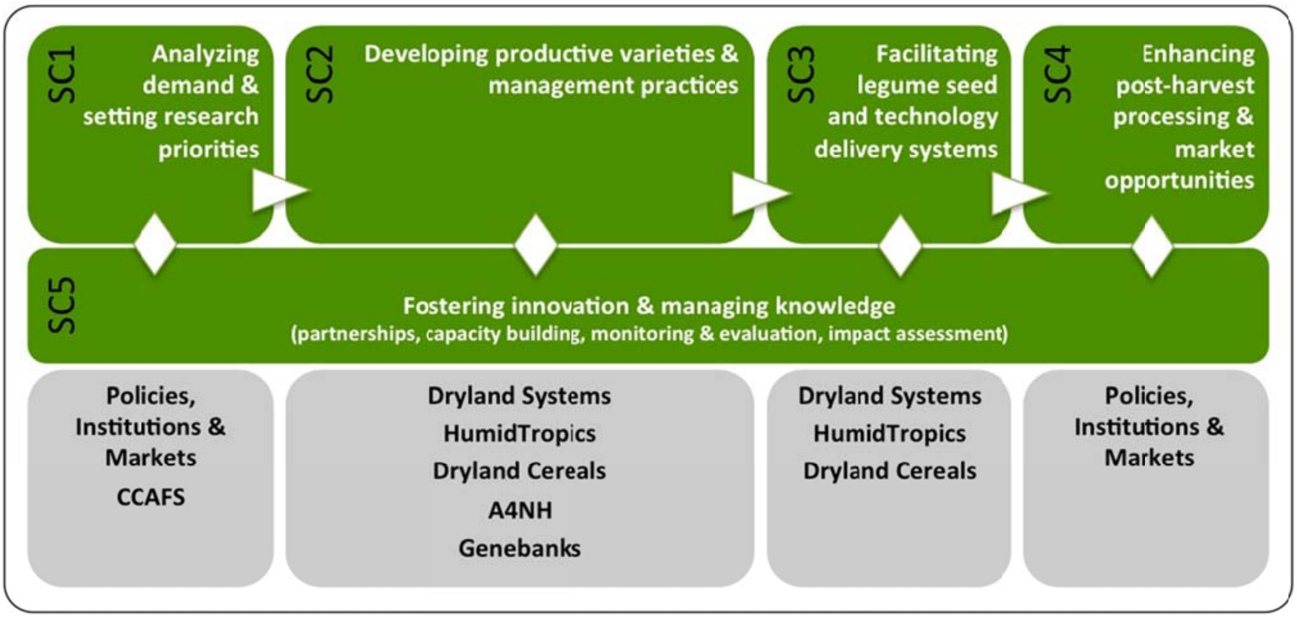


Figure 6. Grain Legumes links with other CGIAR Research Programs.

CRP on Dryland Systems

Dryland Systems is still developing its workplans, and linkages with other CRPs are not fully articulated at present. However, based on the current Dryland Systems proposal (2011), the following areas are identified for linkages.

- Dryland Systems can provide GIS and other information to the other commodities CRPs and provide feedback on CRP outputs that will be used in its Target Regions.
- There will be potential joint research for identifying priority systems and traits required in new cultivars or breeds, as well for joint research on intensifying sustainably dryland systems using the outputs from Grain Legumes.
- Dryland Systems envisages the participation of key grain legume researchers in jointly designing system research and for programming some shared activities of mutual interest.

Dryland Systems action sites are based on rangeland/agro-pastoral systems (roughly LGP <90d) and mixed crop-livestock systems (LGP 90<180d). Based on the latest information, most all of the sites overlap with the proposed target countries for Grain Legumes. Thus, there is good potential that the legume cultivars and associated technology packages will fit well into Dryland Systems.

Boundaries between the two CRPs

Grain Legumes will generate *crop-specific products* in the form of (i) useful genetic variation and cultivars, and (ii) crop-specific pest, disease and natural resource management technologies to maximize genetic performance, i.e. G × E × M (IPM, IDM, ICM). Dryland Systems will *integrate components of systems*, whether crops, livestock or trees. At each action site, Dryland Systems plans to form a Steering Committee with other CRPs to plan and implement joint research.

Dryland Systems will: (i) undertake analysis of agricultural and livelihood systems, including system modeling and trade-off analysis, in the CRP action sites; and (ii) provide insight and feedback on systems in terms of male and female farmer's priorities for species, cultivars and traits; socio-economic and livelihood constraints; cropping system typologies and crop management practices; partners and impact pathways in action sites.

Dryland Systems and Grain Legumes will jointly: (i) test the products developed by Grain Legumes using participatory methods, especially cultivars and feedback on the performance of cultivars; and (ii) develop, test and learn with farmers how to exploit G×E×M for grain legume cultivars.

CRP on Climate Change, Agriculture and Food Security (CCAFS)

CCAFS has four Themes, of which Themes 1 and 2 are most relevant to Grain Legumes. Linkages with Theme 4 will be important in developing tools and data sharing; training on data and modeling approaches to crop, livestock and fish performance. Broadly, the Themes are designed to add value to technology development from other CRPs by providing the climate change context for those CRPs and taking a holistic view to agricultural development plans and strategies under a changing climate. The following is taken from the CCAFS proposal.

Major collaboration is envisaged in CCAFS Theme 1 on Adaptation to Progressive Climate Change, whereby CCAFS supports the development of breeding strategies for major commodities in the face of climate change and subsequently evaluates specific technologies coming out of the CRP on Grain Legumes for their efficacy in adapting to a 2030 world. CCAFS will undertake (i) priority setting for new technologies for adaptation and mitigation, (ii) modeling of virtual crops under a changing climate to identify future priority traits; and (iii) evaluation of potential neglected/underutilized species for adapting to climate change. Grain Legumes will develop new crop varieties and management technologies through climate-change oriented breeding. Both CRPs will jointly test new varieties and technologies within a region specific context to develop holistic adaptation/mitigation strategies, setting breeding priorities, conducting expert workshops and capacity enhancement of partners; and co-development of adaptation options that increase on-farm diversity through inclusion of neglected and under-utilized genetic resources.

Under CCAFS Theme 2 on Adaptation through Managing Climate Risk, Grain Legumes will contribute to climate-resilient crop germplasm and seed systems, and will benefit from analyses of the risk implications of cultivar and crop mixes. CCAFS will (i) develop improved risk management and climate-resilience, and (ii) improved prediction of climate impacts and enhanced climate services. Grain Legumes will be involved in evaluation of improved germplasm under climate change and use the climate impact information for priority setting in R&D. Both CRPs will jointly test options for improved risk management of food system.

Proposed linkages between the two CRPs

CCAFS will primarily be a provider of: (i) climate tools and data and (ii) climate adaptation testing sites. Therefore, the two major areas for collaboration between the two CRPs include:

- Setting breeding targets, phenotyping of traits, and modeling of climate change/adaptation traits; and
- Testing of cultivars in analogue and other testing sites.

CRP on Integrated Systems for the Humid Tropics (HumidTropics)

Grain Legumes will contribute strategic knowledge, technologies and research tools, for example, improved legume varieties and crop management practices (such as IPM/IDM) for different cropping systems and niches in HumidTropics. Improved legume varieties from Grain Legumes will be tested in the HumidTropics at common test locations. Learning gained from HumidTropics on testing of legume varieties will help Grain Legumes revise and improve the relevance of its work. Knowledge sharing and capacity building will be an important activity integrated with HumidTropics.

CRP on Policies, Institutions and Markets

Grain Legumes will work with the CRP on Policies, Institutions and Markets in the sub-themes 1.3 – Production and Technology policies; 1.4 – Social Protection Policies and 2.1 – Policy Processes to identify and understand the policy bias that affects the profitability of Grain Legumes in smallholder farmers.

Along with other CRPs (especially Dryland Systems, HumidTropics, Dryland Cereals, WLE and CCAFS), Grain Legumes will provide inputs to Policies, Institutions and Markets in developing integrated systems modeling framework (e.g. integrated bio-economic household/village level model; multi-market models like IMPACT and DREAM model developed by IFPRI) to assess the policies, institutions and governance structure which constrain technology adoption and also to identify the determinants to increase the farm level profitability of grain legumes. Grain Legumes will establish and maintain regular interaction with Policies, Institutions and Markets strategic activities such as refinement of research domains for grain legumes, applicability of technology across domains, constraint identification, evaluation, feedback to enhance ex-ante priority setting at the CGIAR System level and also for ex-post and ex-ante impact assessment of technologies and crop management systems on welfare, nutritional security of the farm household and the sustainability of the natural resources. Grain Legumes will work with Policies, Institutions and Markets in sub-theme 1.1 – strategic Foresight and Future Scenarios - to develop plausible scenarios for the future of grain legumes in the changing socio-economic and environmental conditions and also provide inputs for integrating bio-physical factors in the ex-ante priority setting exercise, input-output market linkages for reducing transactions costs, agricultural policies and regulations.

Grain Legumes will contribute in-depth practical understanding of grain legume value chains in inputs, technologies and resource management system and to complement the global and methodological value chain work of Policies, Institutions and Markets in analyzing alternative options like market information and intelligence systems, auctions and exchanges; forward and options contracts and innovations in insurance for making grain legumes as a more profitable production system. Knowledge on research methods, models and data on crop productivity, value chain analysis and policy advocacy for identification of new market opportunities for grain legumes will be an important input for Policies, Institutions and Markets to develop policy advocacy and promote conducive markets for more profitable grain legume production systems.

CRP on Wheat (WHEAT)

Breeding methodologies and genomics are major areas of collaboration between the two CRPs. Joint activities with WHEAT would include development of wheat-legume cropping systems in poverty hot spots where wheat is a dominant crop, to enhance sustainability of the cropping system.

CRP on Maize (MAIZE)

Considering that legumes are intercropped or rotated with maize, Grain Legumes will work with the CRP on Maize to test improved legume varieties for varied maize ecosystems, where possible at common test locations/sites. Feedback from MAIZE in terms of crop duration will help Grain Legumes to tailor legume varieties to fit maize crop cycle and vice-versa. Breeding methods and genomic tools from MAIZE will also be helpful for grain legume research.

CRP on Rice (GRiSP)

Grain Legumes will benefit from GRiSP with enhanced knowledge base through newer tools, techniques for genetic enhancement and phenotyping for drought and waterlogging. Grain legumes are a major component in diversification of rice-based cropping systems for improving productivity and sustainability. Grain Legumes will test improved short-duration legume cultivars and production technologies suitable for rice-legume cropping systems, at GRiSP test locations.

CRP on Dryland Cereals

Dryland cereals and the grain legumes are intercropped in many regions of the semi-arid tropics. The CRP on Grain Legumes will test improved legume varieties for intercropping and vice-versa at common test sites. Advances in genomics and molecular breeding, hybrid seed technology, crop modeling and feed quality analysis in many of these crops can benefit similar developments in grain legumes.

CRP on Livestock and Fish

Legume fodder is an important component of mixed crop livestock farming. Legumes with high protein content, low anti-nutritional factors and tannins can increase livestock production and thereby improve the living standard of the resource poor. Grain Legumes will provide dual-purpose legume varieties for evaluation in crop-livestock systems. Supplementing cereals with legume crop residues has high synergistic effects on livestock productivity.

CRP on Agriculture for Nutrition and Health (A4NH)

Common bean is the only legume crop researched extensively in A4NH. Grain Legumes will take experiences of HarvestPlus (housed in A4NH) and extend to other legumes. Grain Legumes works within the criteria set by A4NH/HarvestPlus in other legumes, and in the case of common bean, in other geographic regions that are in need of nutritional improvement. Studies on nutritional impact are not foreseen in Grain Legumes, but we may be jointly engaged with ARIs and A4NH, based on need.

CRP on Water, Land and Ecosystems (WLE)

WLE will complement much of the farm-scale work being done on production systems in grain legumes and provides required inputs such as information on water, land, ecosystems and soil fertility management practices. Grain Legumes will test durable legume-based solutions for addressing water scarcity and land degradation and focuses on developing region specific legume varieties, which improve soil health as well as best bet management practices for different grain legume production systems, using common test locations where feasible.

Governance and Management

We have based the governance and management of Grain Legumes on the principles outlined in the CGIAR Strategy and Results Framework. The CRP is being implemented by four CGIAR Centers – CIAT, ICARDA, IITA and ICRISAT – with ICRISAT as the designated Lead Center. The Generation Challenge Program will play a key role until its termination in 2014. In addition, the CRP will be supported through key partnerships with the Brazilian Agricultural Research Corporation (EMBRAPA), the Ethiopian Institute of Agricultural Research (EIAR), the Indian Council of Agricultural Research (ICAR), the Turkish General Directorate of Agricultural Research (GDAR), the USAID-supported Collaborative Research Support Programs on pulses and oilseeds, as well as other NARS, public and private sector institutes in target and developed countries. We have thus designed a management structure that provides effective governance and oversight by the Lead Center, strategic oversight by key partners, research management by key contributing partners, and independent evaluation and input by outside experts. We recognize that the proposed structure (Figure 7) may require refinements as the CRP develops, both in terms of membership, responsibilities and the configuration itself. Such possibilities will be continually evaluated and changes implemented as required.

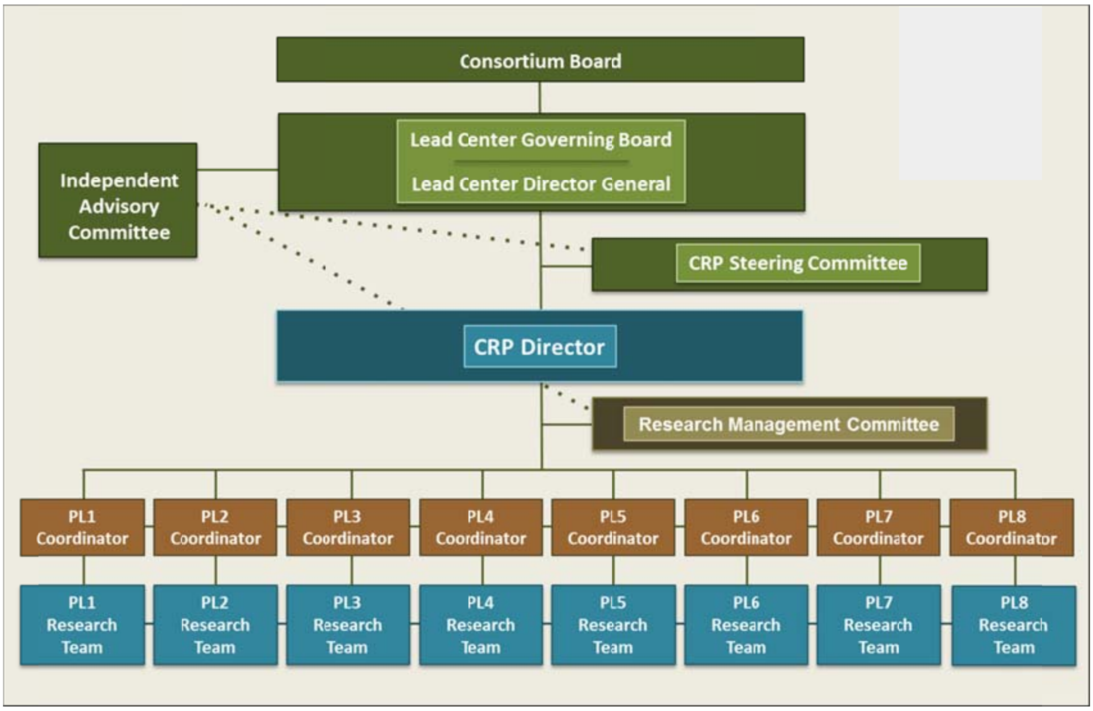


Figure 7. Grain Legumes governance and management structure.

Roles and responsibilities

The **Lead Center** (ICRISAT) will sign a Program Implementation Agreement (PIA) with the Consortium of International Agricultural Research Centers for implementation of the CRP. The Lead Center, represented by its Director General and Governing Board, will be responsible for the overall performance of the CRP by providing a clear vision, direction, priorities and focus through an inclusive, consultative and transparent partnership process. Participant Program Agreements (PPAs) will be signed with all key participants according to Consortium procedures and policies.

The **Governing Board of ICRISAT** will have the fiduciary and legal responsibility and accountability for the implementation of the CRP. Through the Director General, it will monitor management and implementation, including the performance of the CRP Director, Independent Advisory Committee, Steering Committee and Research Management Committee. The governance and management entities of the other partners will be expected to provide similar oversight of their respective institute's involvement in the CRP. This would include ensuring that their institution's policies, vision and mission are in agreement with the CRP, that the

CRP is appropriately reflected in their strategic plans, and that their institution assumes fiduciary and legal responsibilities and accountabilities for implementing the agreed research agenda of the CRP.

The **Director General** of ICRISAT will ensure the success of the Grain Legumes by working with the Directors General of partner CGIAR Centers to:

- Provide oversight on the overall operations of the CRP through the CRP Director,
- Ensure implementation of the CRP, including the effective integration of existing and new bilateral projects,
- Assign required staff to the CRP management teams,
- Appoint and empower the CRP Director and Product Line Coordinators and provide required support, and
- Ensure that performance contracts are successfully managed, including the management of risks.

Overall guidance of the CRP will be provided by a **Steering Committee** that will be chaired initially by the Director General (or designate) of the Lead Center. The Steering Committee will elect a new chair every two years. Membership of the Steering Committee will include the Directors General (or designates) of all CGIAR Centers, initial key partner NARS, and at least one donor representative. The Steering Committee will be responsible for:

- Overall strategic direction of the CRP;
- Monitoring overall progress across the CRP;
- Advising on mechanisms to enhance the operations of the CRP;
- Enhancing strategic alliances with partners;
- Deciding suggested resource allocations across CRP programs and partners; and
- Establishing guidelines for conflict resolution.

An **Independent Advisory Committee**, reporting to the Lead Center Governing Board, will provide input and advice to the ICRISAT Governing Board, Steering Committee and RMC on the quality and relevance of the Grain Legumes research portfolio, priority setting and allocation of resources. The committee will be composed of five to six independent R4D experts with relevant experience and expertise in grain legumes and the target regions, and at least two representatives for the sub-regional organizations in the targeted regions. Nominations will be sought from CRP partners with final appointments made by the Lead Center Director General in conjunction with the Steering Committee. Appointments will be for an initial three-year period. The committee will meet at least once a year in person, with other meetings conducted virtually as required. The committee will elect its chair from among its membership. Written reports will be provided to the ICRISAT Governing Board, with copies provided to the Steering Committee and RMC following each meeting and as part of the CRP annual evaluation.

The Grain Legumes **Director**, who will report to the Lead Center Director General, will be internationally recruited by the Lead Center in consultation with the other partners. The Director will lead the development and implementation of the CRP's R4D agenda with the RMC, ensuring the highest quality and relevance of the program's outputs, and have decision-making authority over the day-to-day operations of the CRP. This position will require a full-time commitment and be compensated accordingly; she/he will be covered by the policies of the Lead Center. The Lead Center Director General will oversee the recruitment, approve the Terms of Reference for, and annually evaluate the performance of the CRP Director. The Director will organize RMC, Independent Advisory Committee and other meetings and reviews for the CRP, chairing such meetings where required. Specific responsibilities will include:

- Developing a clear and shared vision for the CRP among all partners and stakeholders and communicate this vision to all stakeholders;
- Providing intellectual leadership to, and coordinate implementation of, the CRP;
- Developing strong partnerships among participating centers, partners and other stakeholders, including those active in development;

- Representing the CRP in international fora to ensure that the CRP is highly visible and strongly supported by investors and other stakeholders;
- Guiding fundraising efforts for the CRP together with the Centers and other partners; and
- Ensuring that the CRP has well developed and articulated gender and capacity strengthening strategies, defined work plans, clear deliverables, and that the CRP meets its programmatic and financial targets.

A **Research Management Committee (RMC)** will be chaired by the CRP Director and will include the eight Product Line Coordinators (see below), who will be selected to provide effective regional representation across the target regions of the CRP and to provide the scientific expertise across the Strategic Components. Directors of Research (or their designates) from the USAID-supported legume and/or oilseed CRSPs will also be members of the RMC. The RMC will be the key entity responsible for the establishment, execution and monitoring of the CRP research portfolio, strategy, work plans and annual budgets. The RMC will meet regularly, with at least one meeting being in-person. The RMC will:

- Coordinate strategic foresight, planning and reporting of the R4D portfolio;
- Monitor and evaluate research progress across the CRP
- Develop annual research plans and budget allocations;
- Prepare required reports for submission to the Consortium Board;
- Identify necessary resources (financial and otherwise) to meet the goals of the CRP;
- Communicate and represent the CRP globally (e.g., at major events);
- Organize periodic research reviews, including external reviews and impact assessments; and
- Conduct annual meetings of the CRP that include meetings of the Independent Advisory Committee.

A **Program Management Unit** (PMU) will support the CRP Director, who will supervise its staff and operations. The PMU will consist initially of a senior administrative officer and a communications manager (to provide support in various communications matters including the CRP website, newsletters, reports, etc.). ICRISAT will assign a part-time financial manager and contracts officer in its respective departments to provide the required assistance to the CRP Director. Support for resource mobilization will be provided by ICRISAT’s Strategic Marketing and Communications Office, coordinated with similar units in the partner institutes and at the Consortium level. Program evaluation will be assisted by ICRISAT’s Impact Assessment Office and through externally managed reviews and evaluations. ICRISAT and the CRP Director will monitor the requirements for additional administrative assistance and make adjustments as required.

The CRP is structured into eight Product Lines, each of which will be coordinated by a **Product Line Coordinator**, who will be at least a half-time appointment and will continue to be affiliated with their home institution, with the agreement of the institution. It is expected that CIAT, ICARDA, IITA and ICRISAT will host at least one coordinator each, with efforts made to have partner and regional coordination across the Product Line Coordinators. Partners will nominate the Coordinators, with appointments being made by the CRP Director. The Coordinators will ensure that activities for delivering agreed outputs within each region are effectively implemented, coordinated, and monitored/assessed. Coordinators will also maintain close relationships with the CRP Director, participating in RMC meetings, as well as with other Coordinators, relevant partners, donors and stakeholders involved in the CRP.

Dispute resolution among the Grain Legumes partners or with external parties will be handled, if within the domain of R4D (including partnerships), according to policies established by the RMC. If disputes fall in the domain of institutional and legal responsibilities, the Lead Center Director General, in consultation with the Steering Committee, will resolve them in accordance with the principles established in the Consortium Constitution. Should the RMC be unable to resolve any given dispute, the matter will be referred to and resolved by the Consortium in accordance with establish policy set by the Consortium.

Management of Intellectual Property

CRP intellectual property (IP) management is based on the overall CGIAR Consortium Guiding Principles on the Management of Intellectual Property, which are driven by the mission of the CGIAR and the imperative that the products of the Centers' research should be international public goods.

As the CRP will work with a wide range of partners, including national agricultural research systems (NARS), advanced research institutes (ARIs), civil society organizations, private sector companies, and regional and international intergovernmental organizations, the CRP will develop an IPR regime that allows all partners to honor their own IP policies without compromising the CGIAR principles. Ultimately, the Centers must produce, manage and provide access to the products of their research for use by, and for the benefit of the poor, especially farmers in developing countries.

Centers hold their in-trust collections of germplasm for the benefit of the world community, in accordance with agreements signed by Centers and the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). All such germplasm exchanges will be conducted using the Standard Material Transfer Agreement (SMTA). All other material transfers will be done under an appropriate MTA that follows the guidelines of the Consortium's Policy on Intellectual Property.

Knowledge sharing and communications

Knowledge sharing involves a variety of strategies and practices used to identify, create, represent, distribute, and enable adoption of insights and experiences with a wide range of stakeholders. Internally focused knowledge sharing typically concentrates on management-related objectives, such as improved organizational performance, clarity about competitive advantages and innovations, and the sharing of lessons learned. In the context of the CRP, knowledge management efforts will overlap with Monitoring & Evaluation (M&E) and will both reinforce and draw on M&E efforts.

To be most effective and oriented towards impact, knowledge sharing systems need to be aligned towards the users furthest in the knowledge value chain –smallholder farmers. Bioinformatics tools and geo-spatial mapping will be critical components of the CRP's knowledge sharing efforts, but even these high-end information technologies will be oriented towards resolving practical problems arising from the management and analysis of very large amounts of agro-biological data and information.

Agricultural R4D communication is also undergoing a transformation that is driven by the spread of high-speed Internet connectivity; the advent of digital media; the development of new tools, platforms and methodologies; and changes in the ways the world accesses and uses information. We, thus have an opportunity to implement a rapid, highly targeted and efficient transfer of research results into practice and policy – while simultaneously capturing them in peer-reviewed journals and publications.

The CRP Director will have general responsibility for communicating on behalf of CRP partners to a wide variety of audiences, and will help establish and monitor (in concert with the RMC and Product Line Coordinators) the CRP's communication action plan. Implementation of that plan will occur at all levels and will be carried out by many of those involved in the R4D work, but regardless of their organizational affiliation, their communication efforts will rest on the strategic needs, interests and achievements of Grain Legumes.

Communications will be made an integral part of the R4D process, and not be just a by-product of it. The CRP will invest in developing the communication skills of key individuals and partners – especially their ability to interact effectively with the media, particularly the internet–enabled social media. The communications work will be periodically evaluated to ensure optimum impact.

Time Frame

Grain Legumes initiated the proposal development process in 2010 during a brainstorming session with scientists from the major core partner centers. We began with visioning of what we would like to achieve in the next ten years, especially looking at the impacts that we envisage in the smallholder farmers' fields. We outlined our targets for each Product Line in five and ten years. We then focused on the first three years to develop milestones, with a few milestones extending beyond the initial three-year period. Each year, the Research Management Committee with inputs from the Independent Advisory Committee will conduct an extensive analysis of progress achieved relative to projected milestones and in the context of our initial priorities. Based on the results of those annual reviews, we will adjust our priorities, planned activities and anticipated milestones as we go, creating a rolling three-year action plan.

The CRP will continue the extensive discussions that have already been held among the initial partners and, at the same time, bring other key partners on board to help map out specific work plans for first three years of the initiative. In developing this proposal, the current partners identified general areas where they believe collaboration can be more effective. Our focus during the first six months will be elaborating and clarifying relative roles and responsibilities of those involved in order to effectively implement collaborative efforts and more fully realize the potential efficiencies we see, and hopefully identify others. Thus, in the first six months, a detailed workplan will be developed – one that reflects our plans for mainstreaming important gender dimensions of the Grain Legumes R4D, capacity strengthening, and details regarding different R4D activities, technologies to be developed and/or promoted, and the relative roles of different partners and their contribution to achieving the objectives of the CRP.

Mitigating Risks

Grain Legumes is innovative in a number of areas so it is likely that there will be risks involved. The learning curve associated with doing business in new ways involving more diverse partners may slow our progress (at least initially). A streamlined management structure and careful selection of partners involved in the CRP, however, will help manage and mitigate this risk, as will the goodwill and enlightened self-interest that we anticipate all partners will bring to the table.

Related to this is the need to accentuate accountability and promote ownership of Grain Legumes. As many activities related to impact are beyond the expertise and control of our research staff, we must also emphasize the inclusion of development agencies and extension services, NGOs, the private sector companies and processors and traders, and farming communities in planning and implementation. Doing so may increase transaction costs, but should help to mitigate the risk of limited impact on the ground.

As alluded to in other CRPs, the main risks to all CRPs are global in nature, i.e., such things as continued global financial challenges and the resulting political pressure to cut aid financing, especially to agriculture R&D. Strong monitoring and evaluation, broad-based expert advice, and an emphasis on consensus decision-making and conflict resolution should help to ameliorate management-related risks.

Legume production systems in many developing countries are often located in areas that experience high social and political volatility, and these could affect the implementation of R&D efforts, especially adoption of interventions in targeted areas. In such countries, the CRP will emphasize ownership by local partners to minimize this risk. While legume production systems have always been characterized by risk, many of these risks are changing and in some cases increasing. At the same time, the capacity to manage risk has declined as a result of restricted access to resources, lack of information, land degradation and land tenure insecurity faced by the smallholder farmers. Resource conflicts characterize developing country cropping systems and could be severe in some cases (e.g. the availability and control of water resources in Central Asia). Mitigating such risks will be difficult, and will depend on the wise counsel and full participation in activities at the community level, with priorities being driven locally.

Continued government policy bias against the support of smallholder farmers in marginal areas, even in the face of growing evidence of the value and importance of their enterprises, is also an important risk factor. Efforts to speak with a unified voice to policymakers and other influential leaders should help reduce this risk, but policy decisions are usually not made on the basis of well-reasoned arguments or even solid scientific evidence. The CRP partners will therefore need to identify local, regional and even international ‘champions’ who have the ear of key policymakers and who might, over time, influence the course of political decisions that limit legume production, processing and marketing. Finally, important risks to longer-term sustainability of the CRP could include insufficient interest on the part of private sector organizations needed to push commercialization of new technologies, as well as insufficient capacity on the part of national AR4D institutions to sustain the initiative. By including public and private organizations during the early stages of research planning and implementation, we believe that sustainability risks will be diminished due to a stronger sense of ownership and accountability for success. Finally, there are risks associated with climate—erratic rainfall, prolonged droughts or floods, can affect the success of CRP efforts in the target areas, both R4D activities and adoption of technologies by smallholder farmers.

Monitoring and Evaluation System

The Monitoring and Evaluation (M&E) plan for Grain Legumes will follow and conform to the CGIAR consortium framework on 'Monitoring and Evaluation System' that is under development. Monitoring tracks key indicators of progress over the course of CRP implementation as a basis to evaluate outcomes of the interventions. Operational evaluation examines how effectively programs were implemented and whether there are gaps between planned and realized outcomes. Impact evaluation tells us whether the changes in the well-being of the beneficiaries are indeed due to the CRP interventions.

M&E in the context of international agricultural research

Evaluation is a periodic assessment of the relevance, performance efficiency and impact (both expected and unexpected) of the project in relation to stated objectives. The monitoring and evaluation play complementary roles. The donors and the research leaders are interested in the contributions of research according to the CRP committed goals, so as to make key decisions on prioritizing the research products. Accordingly, information on impact is highly demanded by the donors to know the value additions to their investments. In the private sector, there is a well-defined mechanism to capture this. However, in public sector, market feedback channels are limited. As a result, it is imperative that agricultural research evaluation needs to be oriented towards outcomes and impact evaluation.

Monitoring and Evaluation Framework for Grain Legumes

As indicated earlier, the overall monitoring and evaluation system will be fully aligned with the monitoring principles of the CGIAR consortium. The CRP will generate a number of diverse outputs, including genetic and genomic resources, improved crop varieties, crop management technologies, information exchange, capacity building tools, and value added products along the value chain. These outputs, which are detailed in the logframe for each Product Line, should result in desired outcomes that ultimately lead to the intended impacts of reducing poverty and malnutrition, enhancing livelihood security, and reducing environmental degradation. Further definition of the quantitative and qualitative indicators required by the Consortium will be completed during the initial few months once the CRP is fully approved and operational. The Research Management Committee (RMC) will have responsibility for ensuring that proposed outputs are delivered and that expected outcomes are successful. All partners will also conduct their own internal M&E of agreed research activities, with the results presented to the RMC.

Our priorities are based on the CGIAR Strategy and Results Framework and our best assessment of needs and opportunities available during the development of the proposal. Adjustments in these priorities will require formal, annual project evaluations, as well as mid-term and end-of-program reviews by independent experts including evaluation by end users (farmers) and consumers. The RMC will be able to make more minor adjustments, especially in research, on a semi- and annual basis.

The Independent Advisory Committee is expected to conduct focused short-term reviews and provide feedback. Given the breadth and scope of the CRP, additional experts will be commissioned to provide inputs into specific activities. These will be considered by the RMC and required adjustments made as needed in our research planning.

Some of the major indicators to be used for M&E include:

- Enhanced use of genetic resources and new sources of resistance to abiotic and biotic stresses, improved nutritional quality and productivity, and enhanced product quality including palatability and consumer acceptance available as international public goods.
- Cutting-edge scientific knowledge on genetics and genomics of legume crops published.
- Cultivars derived from CRP-developed germplasm released by national programs and grown on a large-scale using recommended crop management practices.
- Efficient private sector and informal seed production and delivery systems/models operating in target countries, supported by harmonized national and regional regulatory frameworks.

- Crop and region specific post-harvest technologies utilized in project regions to increase profitability.
- Novel and innovative value added products identified and pilot tested that increase the value capture by smallholder farmers.
- Capacity-building and technology delivery frameworks enhanced to facilitate farmers' access to validated technology such as quality seed of improved crop cultivars, crop management practices and other farm inputs.
- Farmer and consumer acceptance of final products.
- Publication of peer reviewed research articles, curated data sets and learning materials in granulated form to support use in multiple contexts by the partners and stakeholders.

In addition, the CRP intends to incorporate into our evaluation learning processes tools that provide feedback loops so that lessons learned can be quickly adopted and incorporated in our research planning. M&E is considered a critical component for success and is a part of a larger effort to help set realistic priorities that ultimately lead to impact in the field. Relating M&E to the value chain framework connects it to development drivers that can help reveal key bottlenecks to the uptake and impact of innovations. The Grain Legume Impact Pathway chapter provides examples on how the CRP envisions its research objectives are expected to produce the outputs that will lead to desired outcomes on intended stakeholders (both immediate and final users) leading to impacts at the farm level and finally to regional and national level impacts.

Measurable Results/Outputs

Some examples of measurable results are:

- An increase in profitability over the existing level (20%)
- Improvement in protein intake in diet or reduction in mal-nutrition (5-10%)
- Improvement in crop productivity (20%)
- Reduction in cost of production due to synergy effect such as atmospheric nitrogen fixation IPM, etc.
- Increasing seed replacement ratio (5-20%)
- Improvement in support services like credit, market and others
- Capacity building in production technology, post-harvest management and value addition 1500 households per target country)

Budget

The Grain Legumes budget for the first three-year phase is composed of funding from Window 1 and 2 funding and existing bilateral project funding for CIAT, ICARDA, ICRISAT, IITA and the GCP. Bilateral project activities and corresponding budgets were first allocated across the CRP Product Lines and Strategic Components. Additional funding from Windows 1 and 2 were then allocated based on priorities and projected expenses for each component. Each budget represents the requirements for CIAT, ICARDA, ICRISAT, IITA the GCP and partners to be initially funded by the CRP.

Table 22. Grain Legumes Funding Budget (US$ '000s).

Funding Source	Year 1	Year 2	Year 3	Total	
CIAT					
CGIAR Window 1 & 2: Research	3,600	3,780	3,969	**11,349**	**33%**
Bilateral Funding (secured)*	4,663	2,511	2,364	**9,538**	**28%**
Funding Gap	-	5,878	7,661	**13,539**	**39%**
Totals	**8,263**	**12,169**	**13,994**	**34,426**	**100%**
* includes Other Center Income					
ICARDA					
CGIAR Window 1 & 2: Research	3,330	3,496	3,671	**10,497**	**65%**
Bilateral Funding (secured)*	1,081	570	550	**2,201**	**14%**
Funding Gap	1,059	1,112	1,168	**3,339**	**21%**
Totals	**5,470**	**5,178**	**5,389**	**16,037**	**100%**
* includes Other Center Income					
ICRISAT					
CGIAR Window 1 & 2: Research	4,422	4,643	4,875	**13,940**	**28%**
Bilateral Funding (secured)*	8,429	6,920	3,843	**19,192**	**39%**
Funding Gap	-	5,873	10,792	**16,665**	**33%**
Totals	**12,851**	**17,436**	**19,510**	**49,797**	**100%**
* includes Other Center Income					
IITA					
CGIAR Window 1 & 2: Research	6,342	7,051	7,806	**21,199**	**67%**
Bilateral Funding (secured)*	3,433	3,598	3,260	**10,291**	**33%**
Funding Gap	-	-	-	**-**	**-**
Totals	**9,775**	**10,649**	**11,066**	**31,490**	**100%**
* includes Other Center Income					
Generation Challenge Program					
CGIAR Window 1 & 2: Research	-	-	-	**-**	
Bilateral Funding (secured)*	1,020	1,029	691	**2,740**	**100%**
Funding Gap	-	-	-	**-**	
Totals	**1,020**	**1,029**	**691**	**2,740**	**100%**
* includes Other Center Income					
TOTAL					
CGIAR Window 1 & 2: Research	17,694	18,970	20,321	**56,985**	**41%**
CGIAR Window 1 & 2: CRP Management	1,474	1,547	1,625	**4,646**	**3%**
Total CGIAR Window 1 & 2	**19,168**	**20,517**	**21,946**	**61,631**	**44%**
Bilateral Funding (secured)*	**18,626**	**14,628**	**10,708**	**43,962**	**32%**
Funding Gap	**1,059**	**12,863**	**19,620**	**33,542**	**24%**
Totals	**38,853**	**48,008**	**52,274**	**139,135**	**100%**
* includes Other Center Income					

The CRP is projecting a budget of US$ 139.1 million for the initial three-year period (Table 22). We are requesting that US$ 61.6 million (44%) be provided from CGIAR Windows 1 and 2 (US $56.9 million for research and US$ 4.6 million for CRP management). The Year 1 Window 1 and 2 funding is based on the guidelines received at the time of the initiation of the CRP process. Window 1 and 2 funding in years 2 and 3, is based on a 5% increase over the previous year budget level. Additional funding will come from already secured bilateral projects (US$ 43.9 million; 32%). This leaves a current funding gap of US$ 33.5 million (24%). The funding gap could be met by additional funds being allocated by the Fund Council through the Consortium to Windows 1 and 2, or by the CRP Centers seeking additional bilateral projects if such Window funding is not available. Note that the Generation Challenge Program (GCP) is not requesting financial support through the CRP but will continue to receive funds directly from CGIAR donors until 2013, as indicated in the GCP transition strategy, to ensure a smooth transition of its ongoing research activities and contractual obligations. GCP's financial support to CGIAR Centers is reported under their respective budget as secured bilateral funding and resources reported under GCP indicates funds allocated to non-CGIAR Center partners.

The Grain Legumes research budget (including gender research) represents 97% of the expenses and is based on projected research costs for each Product Line (Table 23). The costs for each PL represent the collective costs for CIAT, ICARDA, ICRISAT, IITA and the GCP. Note that funding for the genebank core activities, except identifying gaps, collecting and conducting training courses and developing germplasm subsets are provided from funds approved in the Genebank Funding proposal for CIAT, ICARDA, ICRISAT and IITA. Support for acquisition, conservation, distribution, and genebank data management is available from genebank funding. A separate budget for gender research and analysis is indicated and more details provided below. For completeness, we have included the CRP management budget in the Table 23.

Table 23. Budget by Product Line (US$ '000s).

	Year 1	Year 2	Year 3	Total	
Product Lines					
PL1 Drought & low-P common bean, cowpea & soybean	9,436	12,137	13,105	**34,678**	25%
PL2 Heat tolerant chickpea, faba bean, lentil & common bean	3,984	4,649	5,227	**13,860**	10%
PL3 Short-duration & aflatoxin-free groundnut	4,535	6,084	6,721	**17,340**	12%
PL4 High nitrogen-fixing common bean, chickpea, faba bean & soybean	4,236	5,658	6,388	**16,282**	12%
PL5 Insect-smart cowpea, chickpea & pigeonpea	6,529	7,417	7,762	**21,708**	16%
PL6 Extra-early maturity lentil & chickpea	2,081	2,482	2,679	**7,242**	5%
PL7 Herbicide tolerant chickpea, faba bean & lentil	2,834	3,187	3,448	**9,469**	7%
PL8 Hybrid pigeonpea	2,232	3,029	3,389	**8,650**	6%
Total Product Lines	**35,867**	**44,643**	**48,719**	**129,229**	93%
Gender Research & Analysis	1,512	1,818	1,930	**5,260**	4%
CRP Management	1,474	1,547	1,625	**4,646**	3%
Total Budget	**38,853**	**48,008**	**52,274**	**139,135**	100%

Each Product Line is based on projected research costs for each crop in each region. Table 24 presents the CRP budget by Product Line and Strategic Component. An indicative gender research budget is provided, which will be further defined as the gender research strategy is developed during the next few months. The CRP management budget has simply been distributed across the Product Lines in proportion to the total research budget (Total Strategic Components).

From the table, the CRP will devote approximately 50% of the funding to the three PLs focused on addressing abiotic stresses and the effects of climate change (PL 1-3), 13% of the budget on biological nitrogen fixation (PL 4), 17% of the budget on insect resistance (PL 5), and the remaining 20% on generating new opportunities to intensify cropping systems (PL 6-8).

Table 24. Total Three-Year CRP Research Budget by Product Line and Strategic Component (US$ '000s).

	PL1	PL2	PL3	PL4	PL5	PL6	PL7	PL8	Total	
Strategic Components										
SC1 Better targeting of opportunities	2,266	1,597	1,598	1,093	1,819	999	1,413	961	**11,746**	8%
SC2 Cultivars and crop management	21,098	8,656	9,871	7,550	11,816	4,113	5,512	3,844	**72,461**	52%
SC3 Effective seed delivery	5,311	1,542	2,883	2,394	2,495	1,117	1,272	1,922	**18,936**	14%
SC4 Post-harvest value and markets	1,324	636	1,442	2,804	1,976	481	636	961	**10,260**	7%
SC5 Knowledge sharing and training	4,679	1,428	1,546	2,441	3,602	533	636	961	**15,826**	11%
Total Strategic Components	**34,679**	**13,859**	**17,340**	**16,283**	**21,708**	**7,242**	**9,469**	**8,650**	**129,230**	93%
Gender Research & Analysis	1,412	564	706	663	884	295	385	352	**5,260**	4%
CRP Management	1,246	498	623	585	780	260	340	311	**4,645**	3%
Totals	**37,337**	**14,922**	**18,669**	**17,531**	**23,372**	**7,797**	**10,195**	**9,313**	**139,135**	100%
	27%	11%	13%	13%	17%	6%	7%	7%	100%	

Partners are critical for the success of Grain Legumes and a total of US$ 20.8 million (15%) of the three-year budget has been allocated for them (Table 25). The budget for the Generation Challenge Program (GCP) is entirely designated for partners (non-CGIAR Centers). Several partners, especially EIAR, EMBRAPA, GDAR, ICAR, the Dry Grains Pulse and Peanut CRSPs, will also make significant in-kind contributions to the CRP. These institutes and/or programs have their own source of funding to support infrastructure, salaries and operational expenses. Through better coordination of efforts under the CRP, these opportunities will be tapped to greatly enhance the progress towards the goals of the CRP. We will also work with each partner to help identify additional funding resources to support the work of partners in the CRP.

Table 25. Budget by Partner (US$ '000s).

Partner	Year 1	Year 2	Year 3	Total	
CIAT	6,499	10,229	11,860	**28,588**	**21%**
ICARDA	5,055	4,786	4,980	**14,821**	**11%**
ICRISAT	11,145	15,122	16,920	**43,187**	**31%**
IITA	8,411	9,163	9,522	**27,096**	**19%**
GCP Partners	1,020	1,029	691	**2,740**	**2%**
Center Partners	5,249	6,132	6,676	**18,057**	**13%**
CRP Management	1,474	1,547	1,625	**4,646**	**3%**
Total Budget	**38,853**	**48,008**	**52,274**	**139,135**	**100%**

Personnel costs (scientific and technical salaries and supporting costs) represent the largest percentage of the budget (37%). Institutional management has been kept at 15%, while the CRP management is only 3% of total CRP costs (Table 26).

Table 26. Budget by Category (US$ '000s).

Research	Year 1	Year 2	Year 3	Total	
Personnel Costs	14,186	17,717	19,345	**51,248**	**37%**
Supplies and Services	6,594	9,066	10,020	**25,680**	**19%**
Travel	2,567	3,012	3,273	**8,852**	**6%**
Workshops/Conferences/Training	796	886	1,194	**2,876**	**2%**
Capital Expenditures	1,107	1,308	1,420	**3,835**	**3%**
Partners	6,269	7,161	7,367	**20,797**	**15%**
Institutional Management	5,860	7,311	8,030	**21,201**	**15%**
CRP Management	1,474	1,547	1,625	**4,646**	**3%**
Total Budget	**38,853**	**48,008**	**52,274**	**139,135**	**100%**

Costs for gender research and analysis are budgeted separately and include scientists' time and operating expenses across the partners (Table 27). Approximately 4% (US$ 5.3 million) of the total three-year budget has been specifically allocated for gender-related research. CIAT, ICRISAT and ICARDA have gender specialists who will devote approximately 35% time to the CRP researching gender aspects of targeting, planning, design and implementation.

Table 27. Gender Research & Analysis Budget (US$ '000s).

Partner	Year 1	Year 2	Year 3	Total
CIAT	367	460	488	**1,315**
ICARDA	156	164	172	**492**
ICRISAT	449	611	682	**1,742**
IITA	489	532	553	**1,574**
GCP	51	51	35	**137**
Total Gender Research Budget	**1,512**	**1,818**	**1,930**	**5,260**

Given the need to effectively manage the CRP across all partners, including a number of non-CGIAR partners, a specific budget for CRP management is proposed (Table 28). The budget includes costs (salaries, travel and operations) for the CRP Director (1.0 FTE), eight Product Line Coordinators (0.5 FTE each), the Program Management Unit (1.0 FTE administrative, 1.0 FTE communications, 0.5 FTE financial and 0.5 FTE HR managers), Research Management Committee meetings twice each year, and travel and honoraria costs for the Independent Advisory Committee members to meet twice each year. The total management budget is 3% of the total CRP budget for the three-year period.

Table 28. CRP Management Budget (US$ '000s).

Category	Year 1	Year 2	Year 3	Total	
CRP Director (salary, travel, operations)	280	294	309	**883**	**19%**
Product Line Coordinators (salaries, travel, operations)	768	806	847	**2,421**	**52%**
Program Management Unit (salaries, operations)	208	218	229	**655**	**14%**
Research Management Committee (travel, operations)	128	134	141	**403**	**9%**
Independent Advisory Committee (honorarium, travel, operations)	90	95	99	**284**	**6%**
Total CRP Management Budget	**1,474**	**1,547**	**1,625**	**4,646**	**100%**

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Appendices

Appendix 1. Profiles of targeted grain legumes

Chickpea (*Cicer arietinum* L.) is the world's second-largest cultivated food legume, with developing countries accounting for over 95% of its production and consumption (Gaur et al. 2008). Chickpea grain is an excellent source of high-quality protein, with a wide range of essential amino acids (Wood and Grusak 2007) and the crop has a high ability to fix atmospheric nitrogen. Since major consumers such as India do not produce sufficient chickpeas domestically, there are opportunities especially for East African countries to sell into this important market. In fact, chickpea area in ESA has doubled over the past 30 years and exports accounted for about 30% of total production, indicating that farmers are using chickpea for both food and to earn extra income. The area under chickpea in West Asia has also increased dramatically in the past 30 years (from 378,000 ha to 1,526,000 ha) leading to the export of chickpea from countries such as Turkey, Syria and Iran. Drought stress commonly affects chickpea because it is largely grown under rainfed conditions during the post-rainy season on residual soil moisture (Gaur et al. 2008). Research on drought tolerance has paid dividends in recent years with the improved drought tolerant chickpea cultivars. Collar rot, *Fusarium* wilt, dry root rot and *Ascochyta* blight are the more important diseases in the Indian subcontinent, whereas *Ascochyta* blight and *Fusarium* wilt are the most important worldwide (Chen et al. 2011). Chickpea in CWANA is traditionally grown during spring to avoid *Ascochyta* blight and cold/frost but then encounters drought, reducing potential yields (Malhotra et al. 2009).

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume for direct human consumption with 23 m ha grown worldwide (Broughton et al. 2003). Approximately 12 million metric tons are produced annually, of which about 8 million tons are from Latin America and Africa (FAO 2005). Over 200 million people in SSA depend on the crop as a primary staple, with beans contributing to the diets and incomes in over 24 countries in this region alone (Wortmann et al. 1998). In the developing world, beans are smallholder crops, and in Africa are cultivated largely by women. Consumption is as high as 66 kg/year/person, and in many areas, common bean is the second most important source of calories after maize. Typical bean yields, however, represent only 20 to 30% of the genetic potential of improved varieties due to major production risks such as insect pests, diseases and drought, which – due to climate change – is increasing in severity and frequency in the region (Funk et al. 2008). Drought affects production of common beans in most of Eastern Africa, but is especially severe in the mid-altitudes of Ethiopia, Kenya, Tanzania, Malawi and Zimbabwe, as well as in Southern Africa as a whole.

Cowpea (*Vigna unguiculata*) is the most important grain legume crop in sub-Saharan Africa (Timko et al. 2007), grown by tens of millions of smallholders. It is estimated that 200 million children, women, and men in West Africa rely on cowpea, consuming the grain daily whenever available. It is mostly grown in the hot drought-prone savannas and very arid Sahelian agro-ecologies, where it is often intercropped with pearl millet and sorghum (Hall 2004). Cowpea is a protein-rich grain that complements staple cereal and starchy tuber crops, but also provides fodder for livestock, soil improvement benefits through nitrogen fixation, and household benefits in the form of cash and income diversity. Cowpea is highly drought tolerant with deep roots that help stabilize the soil and dense foliage that shades the soil surface preserving moisture. Cowpea on-farm grain yields in SSA reach only 10–30% of their biological yield potential, due primarily to insect and disease attacks and drought (Ehlers and Hall 1997).

Faba bean (*Vicia faba* L.) also called fava bean, broad bean, field bean, horse bean and bell bean is an erect leafy winter or summer annual. It is one of the oldest crops domesticated in the Fertile Crescent of the Near East. It expanded around the world during Neolithic period – from Antalya (Turkey) towards Europe (Germany, Greece, France, Italy and Spain); from Egypt across North Africa and eastwards to Afghanistan and onwards to China, India and in more recent times to Latin America and North America (Canada and USA) (Cubero 1974). In WANA, faba bean is cultivated in coastal Mediterranean areas with 300 mm and above annual rainfall. In China, there are two major production areas, one sown in winter (mainly in the southern province of Yunnan) and the other sown in spring (in highlands stretching from Mongolia to Tibet). Faba bean is grown in northern India (Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Jharkhand, Orissa, West Bengal). In Latin America, it is mainly grown in Argentina and Chile. Cultivated faba bean is used as human food in developing countries, and as animal feed (mainly for pigs, horses, poultry and pigeons) in developed countries and in North Africa. In addition to boiled grains, it is consumed as vegetable green seeds/pods, dried or canned. It is a staple breakfast food in the Middle East, Mediterranean region, China and Ethiopia (Bond et al. 1985). Faba bean has a protein content of 24-30 percent. Although the global average grain yield of faba bean has almost doubled during the past 50 years, the total area sown to the crop has declined by 56% over the same period due to the cheap availability of fertilizers (devaluing some of the short-term economic benefits of BNF) and competition with policy-favored cereal and high-value urban cash crops. The most important diseases of faba bean are chocolate spot (*Botrytis fabae* and *B. cinerea*), rust (*Uromyces viciae fabae*), Ascochyta blight (*Ascochyta fabae*), black root rot (*Thielaviopsis basicola*), stem rots (*Sclerotina trifoliorum*, *S. sclerotiorum*), root rots/damping-off (*Rhizoctonia* spp.), pre-emergence damping-off (*Pythium* spp.), bean yellow mosaic virus, bean true mosaic virus, bean leaf roll virus and bean yellow necrotic virus (van Emden et al. 1988). Among the insect pests, bruchids and aphids are important.

Groundnut (*Arachis hypogaea*), is known by many local names including peanut, earthnut, monkey nut and poor man’s nut. Though groundnut is native to South America, it is successfully grown in other parts of the world and became an important oil seed and food crop. From a nutritional point of view, groundnuts are very important in the lives of poor as they are very rich source of protein (26%) and monounsaturated fat. In addition to protein, groundnuts are a good source of calcium, phosphorus, iron, zinc and boron. While China and India are the leading producers worldwide, millions of smallholder farmers in sub-Saharan Africa grow groundnut as a food and cash crop, which accounts for 9 m ha of cultivated farmland (2007 datum). While this area is 40% of the world total, this percentage represents only 25% of the total production due to low yield (950 kg/ha, versus 1.8 t/ha in Asia). The main constraints hampering higher yields and quality in Africa are intermittent drought due to erratic rainfall patterns and terminal drought during maturation. Yield losses from drought run to millions of dollars each year (Sharma and Lavanya 2002). A drought-related quality issue is pre-harvest contamination of seeds with aflatoxin, a carcinogenic mycotoxin produced primarily by the fungus *Aspergillus flavus*, which consequently shuts out SSA groundnuts from export markets. In addition, major foliar fungus diseases like early leaf spots, late leaf spots and rust; and virus diseases like rosette, peanut clump and bud necrosis causes devastating yield losses (Waliyar et al. 1991; Grichar et al. 1998; Yayock et al. 1976.; Olorunju et al. 1992).

Lentil (*Lens culinaris* Medikus), one of the world’s oldest cultivated plants, originating in the Middle East and spread east through Western Asia to the Indian subcontinent. Lentil is currently grown in South America, Europe, Australia and Asia (Bangladesh, India, Jordan, Lebanon, Syria and Turkey). Lentil has a variety of different names in different countries and languages including *Masoor* (India), *Adas* (Arabic), *Mercimek* (Turkey), *Messer* (Ethiopia) and *Heramame* (Japanese) giving some indication of the breadth of its importance (Erskine et al. 2009). It is a short-statured, annual, self-pollinated, high valued crop species. The crop has great significance in cereal-based cropping systems because of its nitrogen fixing ability, its high protein seeds for human diet and its straw for animal feed. Protein content ranges from 22 to 35% and like other grain legumes its amino acid profile is complementary to that of cereals. Lentil is currently grown on 3.8 m ha worldwide (though much of this is in developed countries) with production of over 3.5 m metric tons (FAOSTAT 2008). The major reason for its low productivity in developing countries is because the crop produced on marginal lands in semi-arid environments without irrigation, weeding or pest control. The major producers of lentil are the countries in Southern and Western Asia, Northern Africa, Canada, Australia and USA (Chen et al. 2011). The most economically important fungal diseases of lentil worldwide are *Ascochyta* blight and *Fusarium* wilt; however other diseases such as anthracnose, *Stemphylium* blight and *Botrytis* blight are also economically significant. Major pests include aphids, bud weevils, cutworms, leaf weevils, pod borer, stink bugs and thrips (Chen et al. 2011).

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a staple grain legume in South Asian diets and is also widely grown and consumed in household gardens in Africa – and rapidly expanding as an export crop from Eastern and Southern Africa to South Asia. Household production is not well documented in the FAO database, which indicates total global area of 4.8 m ha (FAO 2008) in 22 countries. India is by far the largest producer with 3.6 m ha although this is insufficient to meet its consumption needs; it imports from Myanmar (560,000 ha) and other countries, notably ESA. In Africa, smallholders are most intensified for dual consumption and export in Kenya (196,000 ha), Malawi (123,000 ha), Uganda (86,000 ha), Mozambique (85,000 ha), and Tanzania

(68,000 ha) (Saxena et al. 2010). With protein content totaling more than 20%, almost three times that of cereals, pigeonpea plays an important role in nutrient-balancing the cereal-heavy diets of the poor. Pigeonpea is also important in some Caribbean islands and some areas of South America associated where populations of Asian and African heritage have settled (Saxena et al. 2010). In addition to being an important source of human food and animal feed, pigeonpea also plays an important role in sustaining soil fertility by improving physical properties of soil and fixing atmospheric nitrogen. Traditional long-duration pigeonpea expresses a perennial tall bush-like growth habit that conveys additional soil protection and deep-rooted nutrient recycling ability. Pigeonpea is generally relay or intercropped with sorghum, cotton, maize and groundnut and thus has to compete with that associated crop for water, nutrients, sunlight and other resources. Recently, hybrid pigeonpea cultivars that produce 35% higher yields are currently being multiplied through the private sector for dissemination to farmers. Major biotic stresses include diseases especially sterility mosaic, *Fusarium* wilt, and *Phythophthora* blight in the Indian subcontinent; wilt and *Cercospora* leaf spot in eastern Africa; and witches' broom in the Caribbean and Central America (Reddy et al. 1990). The major insect pests are pod fly *(Melanagramyza* sp), pod borers *(Helicoverpa armigera* and *Maruca vitrata),* and pod sucker *(Clavigralla* sp) (Joshi et al. 2001). Major abiotic constraints are drought and in some areas intermittent waterlogging.

Soybean (*Glycine max* L. Merr.) cultivation originated in China around 1700-1100 B.C. Soybean is now cultivated throughout East and Southeast Asia, North America, Brazil and Africa where people depend on it for food, animal feed and medicine. It is highly industrialized in developed countries, providing more than a quarter of world's food and animal feed requirement in addition to protein (Graham and Vance 2003). It grows well in tropical, subtropical, and temperate climates during warm, moist periods. Postharvest technologies such as oil processing have led to many new applications of this useful plant. Soybean has great potential as an exceptionally nutritive and rich protein food. It contains more than 40% protein of superior quality and all the essential amino acids, particularly glycine, tryptophan and lysine, similar to cow's milk and meat protein. Soybean also contains about 20% oil including healthy fatty acids, lecithin and vitamins A and D. Soybean also contains secondary metabolites such as isoflavones (Sakai and kogiso 2008), saponins, phytic acid, oligosaccharides, goitrogens and phytoestrogens (Liener 1994; Ososki and Kennelly 2003). Soybean oil is also used as a source of biodiesel (Pimentel and Patzek 2008). Some of the major biotic constraints include Asian soybean rust, frogeye leaf spot, bacterial pustule, bacterial blight and soybean mosaic virus. Nematodes and insects such as pod feeders (stink bugs), foliage feeders, and bean flies feed on soybean plants. These wounds provide entry points for pathogens, and the plant frequently becomes susceptible to pathogenic organisms. Breeders at IITA are currently developing dual-purpose varieties that are tolerant to phosphorus-deficient soils and have enhanced capacity to kill seeds of the parasitic weed *Striga hermonthica* that attacks cereals.

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Malhotra RS. 2009. The CWANA countries have two well defined seasons, namely winter and spring, and chickpea is traditionally grown in the spring season (on conserved soil moisture) as most of the local land races grown in these countries are highly susceptible to Ascochyta blight and cold/frost which are the main constraints in the winter (Malhotra et al. 2009).

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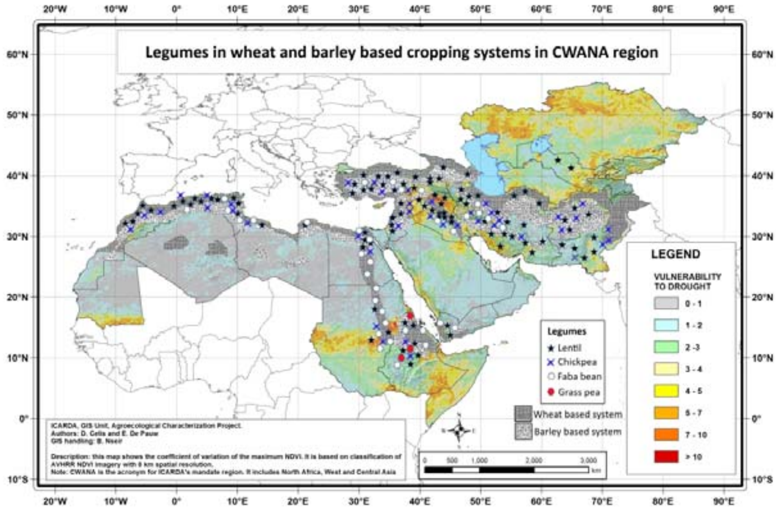
Appendix 2. Profiles of Grain Legumes focus regions

Central and West Asia and North Africa (CWANA)



Faba bean, chickpea and lentil are the most important grain legumes in CWANA. In general faba bean is grown in the low coastal areas, chickpea in the continental areas and lentil in the high altitude areas. Faba bean and lentil are grown during the cool rainy winters and chickpea in the late winter/early spring as the rains end and temperatures rise. These crops are usually rotated with wheat or barley.

Over the past 30 years, the chickpea and lentil area has been increasing in West Asia while faba bean and other grain legumes are declining in other parts of CWANA. Although yields are low in West Asia (0.5-1 t/ha) the sown area quadrupled from 1976 to 2008 (from 378,000 ha to 1,526,000 ha - FAO 2008). The increase in West Asia is mainly due to growing awareness of the benefits of food legumes in cereal-dominated cropping systems. It is also partly due to the adoption of new cultivars suitable for machine harvesting, and winter-chickpea technology (Ascochyta blight-resistant, cold-tolerant cultivars of kabuli chickpea).

The biotic stresses of major importance for chickpea are *Ascochyta* blight and *Fusarium* wilt while abiotic stresses are drought, cold and heat. For high-altitude areas R4D emphasizes *Fusarium* wilt and plant type for lentil. R4D on faba-bean is focused on yield potential, combining early maturity with heat tolerance, and resistance to biotic stresses such as chocolate spot and rust, and to parasitic weeds especially Orobanche.

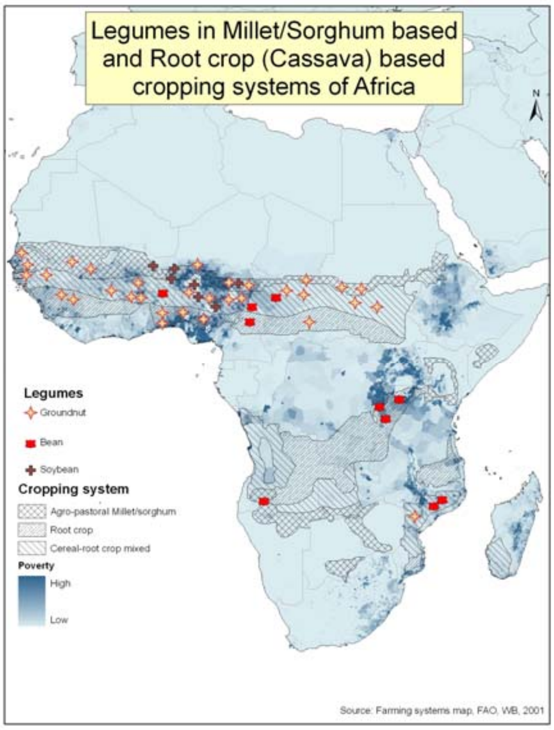
Livestock are very important components of CWANA farming systems, and lentil is well integrated as an important legume for food and feed. Lentil straw has good feed value and sometimes is as valuable as the grain per unit weight. Thus high biomass productivity is an important consideration for lentil.

There have been many reasons for the decline in grain legumes in North Africa including Orobanche infestation, non-availability of improved seed, lack of suitable varieties for mechanical harvesting, low prices, high production costs and climatic stress, especially severe droughts. Losses of human capacity to conduct R4D have also taken a toll. Morocco and Tunisia were formerly exporters of food legumes but have now become importers. Faba bean in North Africa is grown on 274,000 ha, mainly in Morocco. A large component of the faba bean production is in the form of green pods, but FAO production data do not report this form of the crop. Egypt (78,000 ha) and Sudan (68,000 ha) are the other large faba bean producers (FAO 2008).

During the Soviet era food legumes were important components of farming systems in Central Asia and the Caucasus, but have since become forgotten crops. Among the grain legumes, chickpea is still grown on a modest area of about 100,000 ha followed by lentil on about 10,000 ha. Chickpea is mainly grown in Uzbekistan and Azerbaijan, and lentil in Azerbaijan, Tajikistan, Armenia, and Uzbekistan. An organized marketing chain for these crops is lacking in this sub-region, so observations of grain legume trade within the region may give a false impression of production estimates. The main R4D effort on grain legumes takes place in Azerbaijan and Uzbekistan where few cultivars had been developed during the Soviet era.

Eastern and Southern Africa (ESA)

Bean, groundnut, cowpea, pigeonpea and soybean are the most important legumes in the ESA region, with lesser amounts of bambara groundnut, chickpea, lentil and faba bean. Largely grown as subsistence foodstuffs, these crops are especially cultivated by women for feeding the household. Annual per capita consumption is approximately 9 kg. A limited number of commercial farmers grow soybean in South Africa, Zimbabwe and Zambia.



Source: Farming systems map, FAO, WB, 2001

Continuous maize cultivation is widespread in ESA. This monoculture has led to the mining of soil nutrients and soil degradation. Drought and low soil fertility are the main constraints. Where landholdings are small, grain legumes (primarily bean, cowpea, and pigeonpea) are intercropped or rotated with maize to diversify food supplies, hedge against drought risk, generate income and combat declining soil fertility. Sole crops of groundnut and soybean are grown in rotation with maize where sufficient land and labor or machinery are available.

The area devoted to chickpea and soybean production, though small has been steadily increasing over the years in the region. Chickpea doubled in sown area over the past 30 years (from 210,000 to 420,000 ha between 1979 and 2008) to meet increasing demand in domestic and international markets.

West and Central Africa (WCA)

The main legumes grown in WCA are: groundnut, cowpea, soybean, common bean and bambara nut. Pigeonpea and African yam bean are also grown as home garden intercrops. According to FAO data, average annual production and areas under the main legume crops in WCA are: groundnut (6.4 million tons on 5. 3 million ha), cowpea (4.5 million tons on 10.1 million ha), soybean (610,000 tons on 660,000 ha), common bean (230,000 tons on 390,000 ha) and bambara nuts (58,300 tons on 71,000 ha).

Across WCA, both the production and land area under legumes has been increasing by 2- 6% per year over the past five years. This trend is expected to continue. Grain yield in these crops have remained static and low when compared with world averages.

Apart from soybean and groundnut to lesser extent, the other legumes are grown in mixed cropping including intercropping and relay cropping with cereals (sorghum, millet, maize), other legumes and root crops such as cassava, yam and sweet potato, cotton (cowpea mainly), sugarcane, and plantation tree crops. With their increased role as cash crops, mono-cropping of the legumes is expanding in the different countries.

Women are the main producers of homestead legumes in mixed and intercropping systems. Where legumes are grown as field cash crops, men are more likely to be involved. Few large scale commercial farmers growing these crops in this region. Grain legume processing and retailing are carried out almost exclusively by women.

Cowpea and bambara nut are cultivated mainly in the drier Sudan savanna and the Sahel regions, while groundnut is better adapted to the less harsh northern guinea savanna zone. Soybean is grown in the still moister savanna regions (southern guinea) and extending to the forest/savanna transition agro-ecology. The legume crops often occupy marginal poor farmlands. Farmers use no or little fertilizer on them and do not inoculate with rhizobium. The only input that is often used is insecticide on cowpeas in some situations in Nigeria where such inputs could be obtained, often through cotton input supply systems. Most crop management activities are done by hand in this region, although animal traction is used is some areas.

Latin America and the Caribbean (LAC)

In Latin America and the Caribbean two grain legumes are of major importance: common bean (*Phaseolus vulgaris*) and soybean (*Glycine max*). Other legume species including another four species of cultivated *Phaseolus* as well as groundnut are also cultivated but on relatively small areas in niches of extreme heat, drought or high rainfall, rendering some of them as interesting potential components to help adapt farming systems to climate change. Several introduced legume species are important locally: cowpea in northeast Brazil, the northern coast of South America and eastern Cuba; pigeonpea in Haiti; chickpea in the Pacific coast of Mexico; and faba bean in the high Andes. For human consumption common bean is by far the most important in area and tonnage.

Source: Farming systems map, FAO, WB, 2001

In general the grain legumes are cultivated by small farmers for home consumption and for sale through local and regional markets. Traditionally a large proportion of common bean area was planted with climbing or semi-climbing types in association or relay with maize; in highland areas of southern Mexico, Guatemala, Ecuador, and Peru some association with maize persists. However rising labor costs have led farmers to prefer upright bush habits that facilitate harvest. In Central America the small-seeded types of the Mesoamerican gene pool predominate, with most production in the range of 400 to 1200 m above sea level. Yields typically average around 700 kg/ha, although El Salvador now registers a national yield average of about 1000 kg/ha. In the low to mid-altitude regions Gemini viruses became the primary production limitation in the decade of the 1970s, and now are effectively controlled through genetic means. While vegetable production offers significant income for farmers with good market access, among field crops beans continue to be the best income option for small farmers.

In the Caribbean, Cuba, the Dominican Republic and Haiti are the most important producers and consumers of legumes. Here the altitudinal gradient, soil and climate determine which legumes are produced, although common bean is the legume of preference. In the Caribbean and in the Andean zone, as well as in parts of Brazil the large-seeded types that originated in the Andes are preferred.

Mexico and Brazil present extremes of production systems. In Brazil the irrigated winter planting represents about 5% of total area, while the northeast of Brazil remains one of the strongholds of poverty in the western hemisphere with more than a million hectares of bean and cowpea, out of more than 4 million ha nationwide. Mexico presents even wider variability in production, from irrigated high input agriculture on the Pacific coast, to mechanized dryland agriculture in the central plateau, to totally traditional systems in the south.

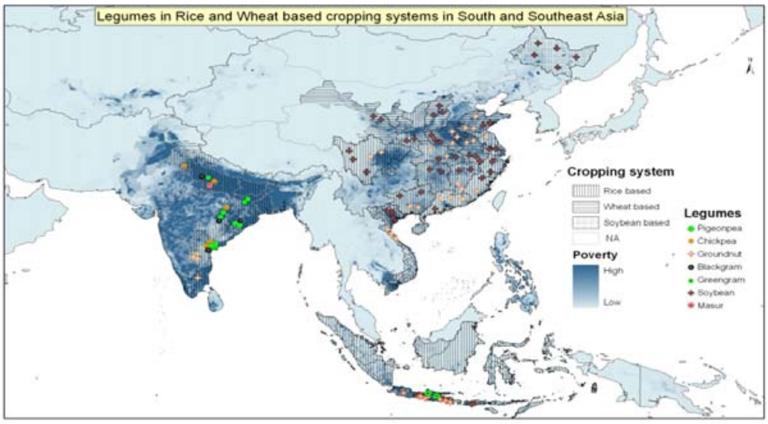
In Latin America urbanization has led to lower per capita consumption and in some cases more diet-related illnesses such as cardio-vascular disease and diabetes. Common bean area has been steady or has declined slightly, but production has increased due to gradually improving yields. However, erratic weather in Central America in recent years has led to serious production shortages, with grain buyers looking far afield to meet local demand.

Soybean production is concentrated in Brazil and Argentina and is principally in the hands of large mechanized farmers, although some technology (for example, BNF) could be of utility to other regions of the world.

South and Southeast Asia (SSEA)

South and Southeast Asia contains more than half of the world's population living on less than one-third of its arable land while producing more than half of the developing world's grain legume crop. Population pressures on land are particularly high in SEA, where grain legumes have traditionally provided a major source of food and nutritional security.

Asia is the center of origin of many important grain legumes. Asia dominates world production of several grain legumes including pigeonpea (95%), mung bean (90%) and chickpea (85%). India alone accounts for around 80% of SEA chickpea and pigeonpea production, about half of its lentils and about one third of its soybeans, groundnuts, dry peas and dry beans (mainly mung bean and urn bean). A ban on the trade of grasspea in India and Nepal due to neurotoxin concerns has been the main reason behind the drastic decline in this crop's cultivation. In Bangladesh, grasspea still occupies first position among the pulse crops.



The sustainable legume-cereal system began to break down with the Green Revolution in the 1960s that heavily promoted increasing cereal production, as well as the rise of other cash crops responding to industrial development. Traditional legume components in crop rotations were relegated to marginal land areas. For example wheat, rapeseed, and mustard have largely replaced chickpea and lentil in the middle and northern temperate regions of India, forcing those crops southward into hotter, drier areas. Competition from maize and cotton has contributed to declines in the area of groundnut in the Philippines, Thailand and India.

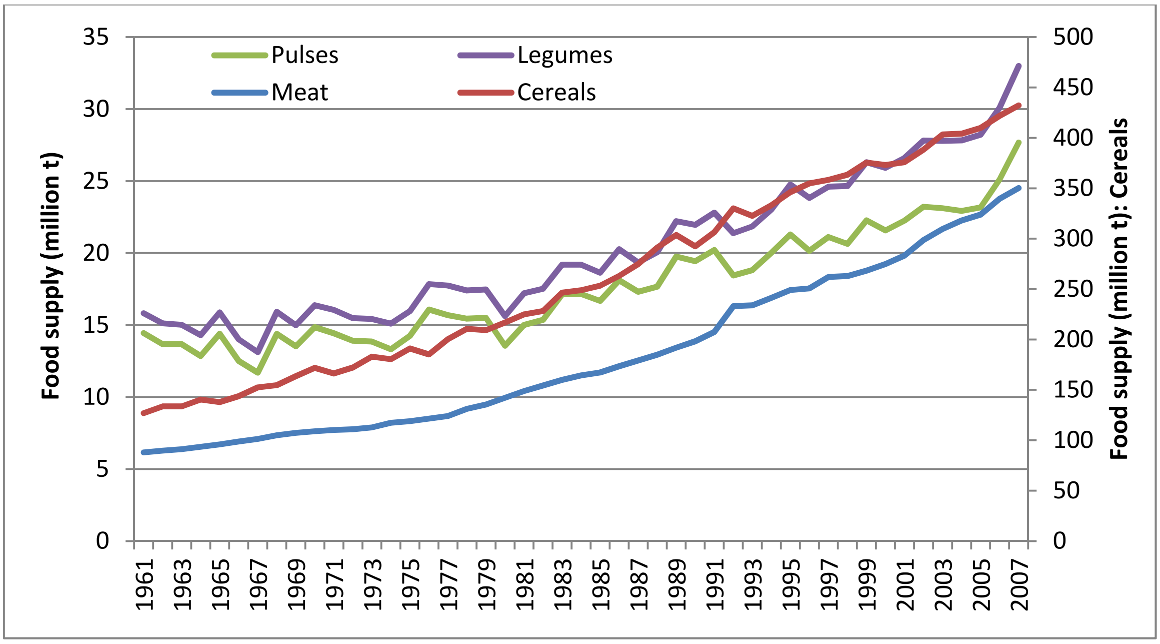
The deleterious consequences of policy bias against grain legumes on national economies as well as on farming systems are being increasingly recognized in the region. India, Pakistan and Sri Lanka have become major legume importers from China, Myanmar, Thailand, Australia and Canada, creating an outflow of hard currency from the region. Efforts to cope have resulted in the breeding of high-yielding short-duration grain legume varieties tolerant to heat and drought, so that these crops could better fit into the marginal niches available in cereal rotations, often maturing on residual moisture. But this progress has not been sufficient to meet growing food demand for legumes.

Rising prosperity is also changing the legume market in economically emergent parts of Asia. Increasing urbanization and changing food habits including growing demand for healthy convenience foods however is creating new kinds of demand that could benefit poor farmers. There is a need to diversify food products made from legumes to satisfy growing demands for such foods.

Reference

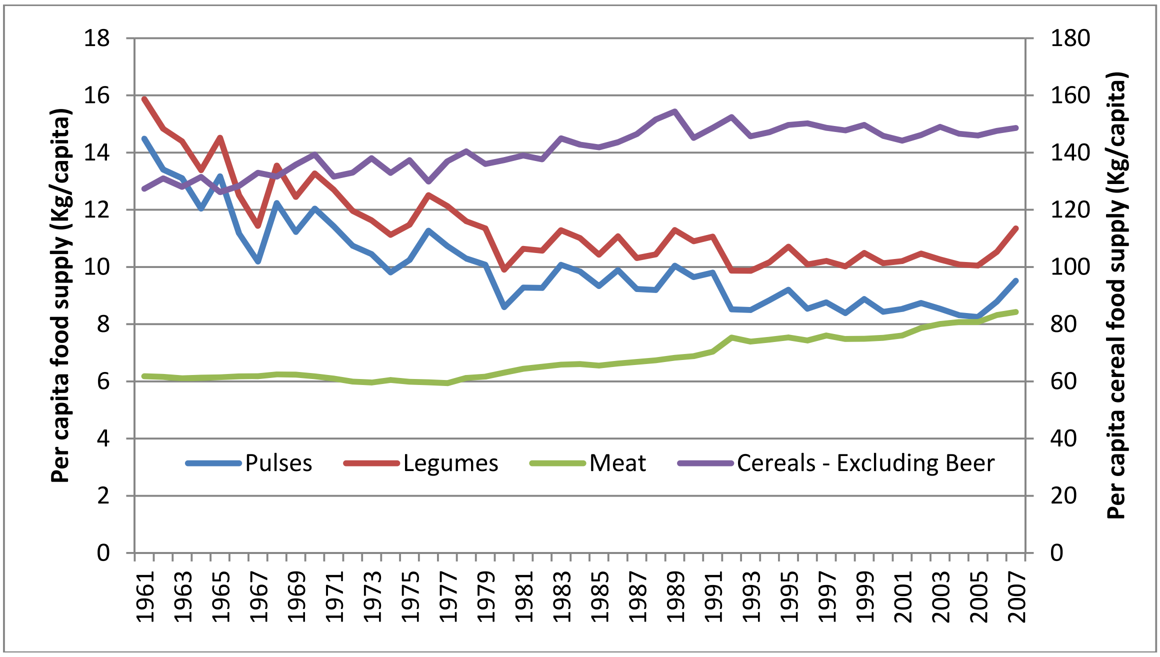
FAO. 2008. State of food insecurity in the world. High food prices and food security – threats and opportunities.

Appendix 3. Global trends in grain legume productivity, area, production and consumption



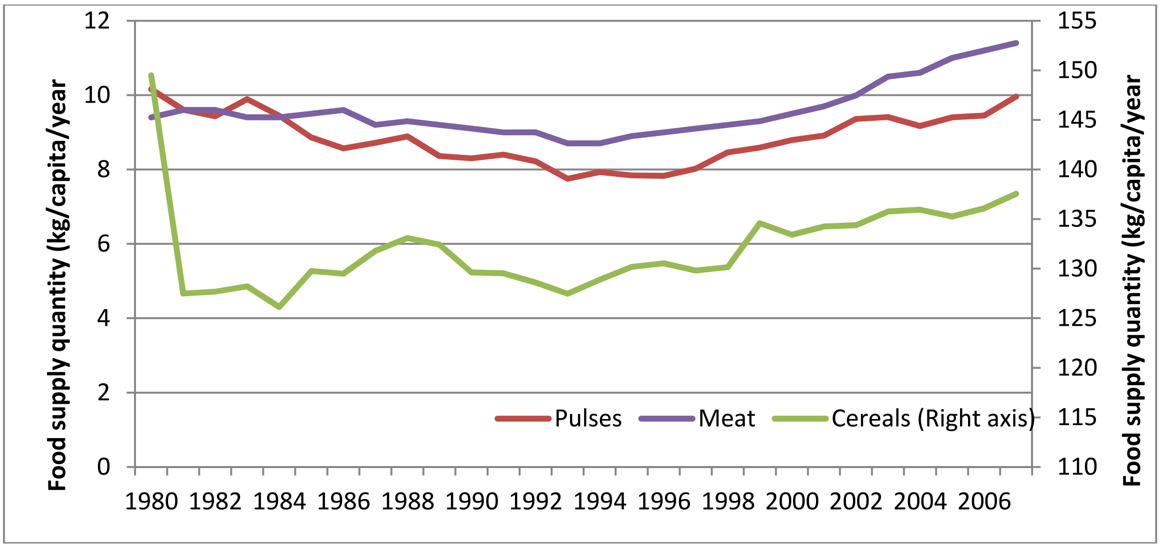
Source: FAOSTAT; LIFDC as per FAOSTAT Special Group classification but excluding China; Legumes = Pulses+Groundnut+Soybean

Figure 1: Trends in LIFDC (excluding China) food supply for LIFDC countries



Source: FAOSTAT; LIFDC as per FAOSTAT Special Group classification but excluding China; Legumes = Pulses+Groundnut+Soybean

Figure 2. Trends in LIFDC (excluding China) per capita food supply



Source: FAOSTAT

Figure 3. Trends in least developed country per capita food supply

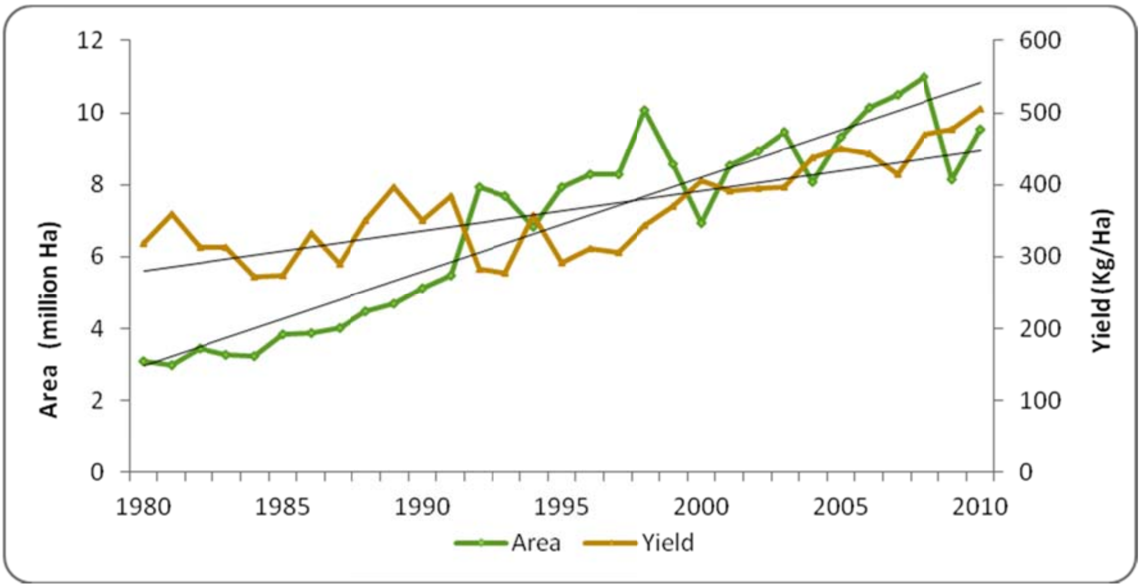
Sub Saharan Africa (SSA)

The production trends overall for grain legumes in ESA and WCA have been increasing since the 1980s. The degree of increase has varied among the targeted crops, with some crops starting from a very low base (soybean and pigeonpea) and with other established crops also increasing their acreage (groundnut). Beans and groundnut are the most significant grain legumes (by area) in both ESA and WCA. Chickpea area and production in ESA has also been increasing since the 1990s. Soybean is a relatively new entrant in ESA, however the growth has been spectacular with a number of countries exporting soybean. WCA is an important producer of cowpeas accounting for nearly 90% of the global cowpea acreage. Both area and yield have driven production increases in the region, however, area increases continues to be the dominant factor. Consumption of grain legumes in the region has more or less kept pace with the increased production. However, there are significant differences at a country level with some countries exporting most of their produce.

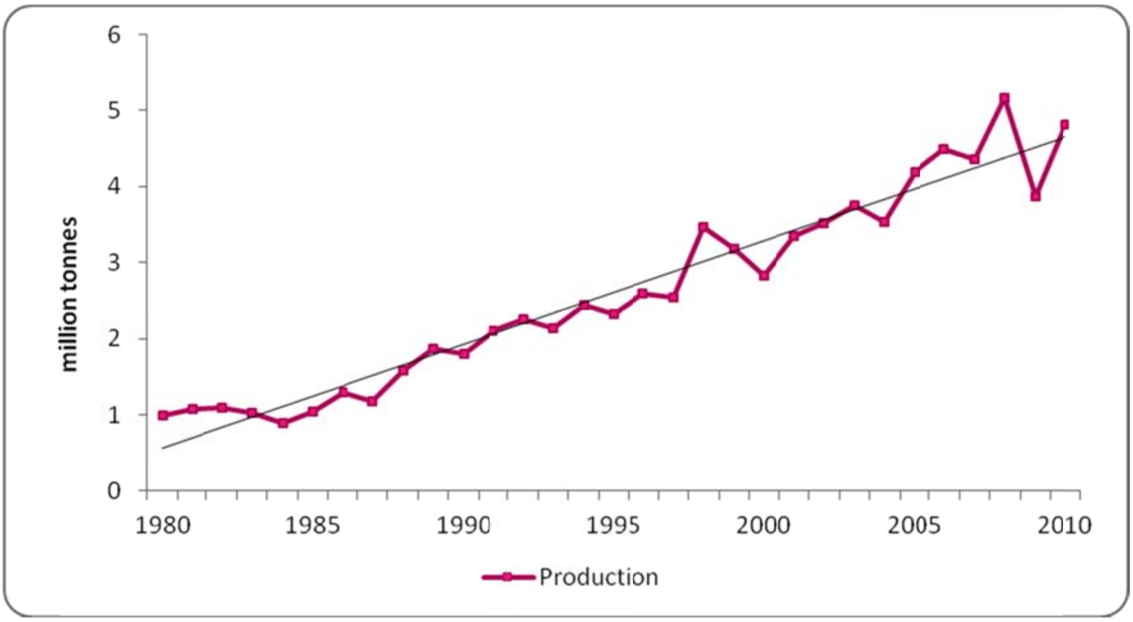
Table 1. Compound annual growth rates (%) for area and yield for selected grain legumes in SSA

Region/ Crop	**Area**				**Yield**			
	1980-90	**1991-00**	**2001-10**	**1980-10**	**1980-90**	**1991-00**	**2001-10**	**1980-10**
				WCA				
Cowpea	5.33	2.88	1.20	4.43	1.18	1.84	2.64	1.49
Groundnut	0.05	3.55	3.65	2.74	3.42	3.16	-1.19	1.47
Soybean	9.63	0.68	-1.22	3.04	3.44	12.91	3.06	5.47
				ESA				
Chickpea	1.01	7.75	1.71	2.10	-1.49	-1.41	4.44	1.56
Dry bean	2.14	3.65	1.87	2.76	2.07	-1.90	1.97	0.08
Faba bean	-3.77	3.70	2.71	2.19	-3.26	-0.92	1.03	0.10
Groundnut	-2.58	8.42	0.48	2.09	-0.96	0.97	0.18	0.63
Lentils	-1.80	4.32	3.83	3.02	-2.84	-4.09	8.29	0.54
Pigeonpea	5.80	2.02	1.52	3.26	-0.31	1.47	1.58	0.95
Soybean	7.54	3.10	6.25	7.05	0.53	2.63	0.77	-0.47

WCA: COWPEA



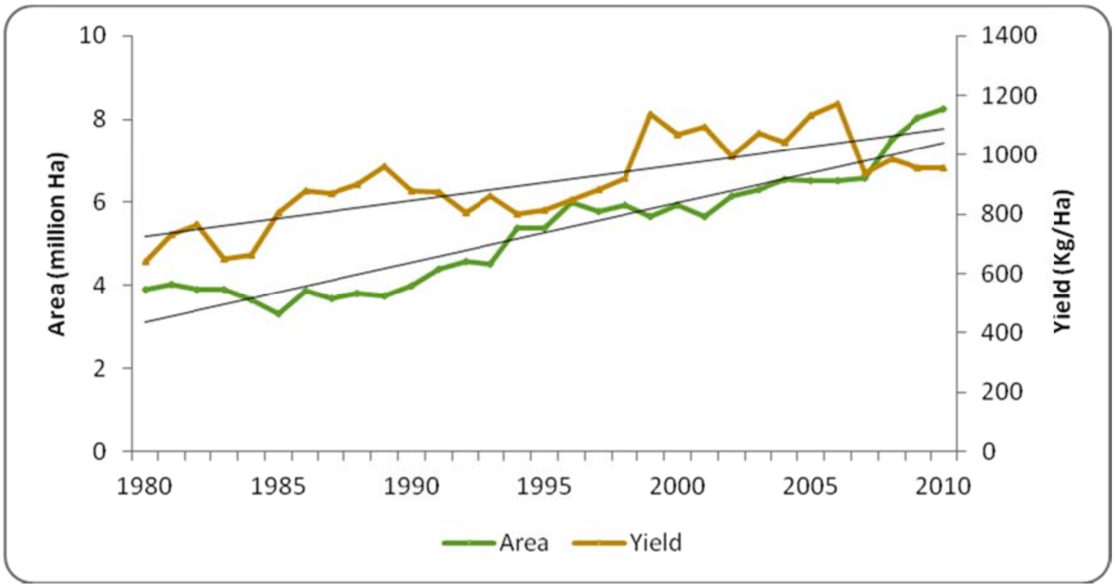
Area trend: t-value: 12.99 significant at 1% level;
Yield trend: t-value: 6.64 significant at 1% level



Production trend: t-value: 22.33 significant at 1% level

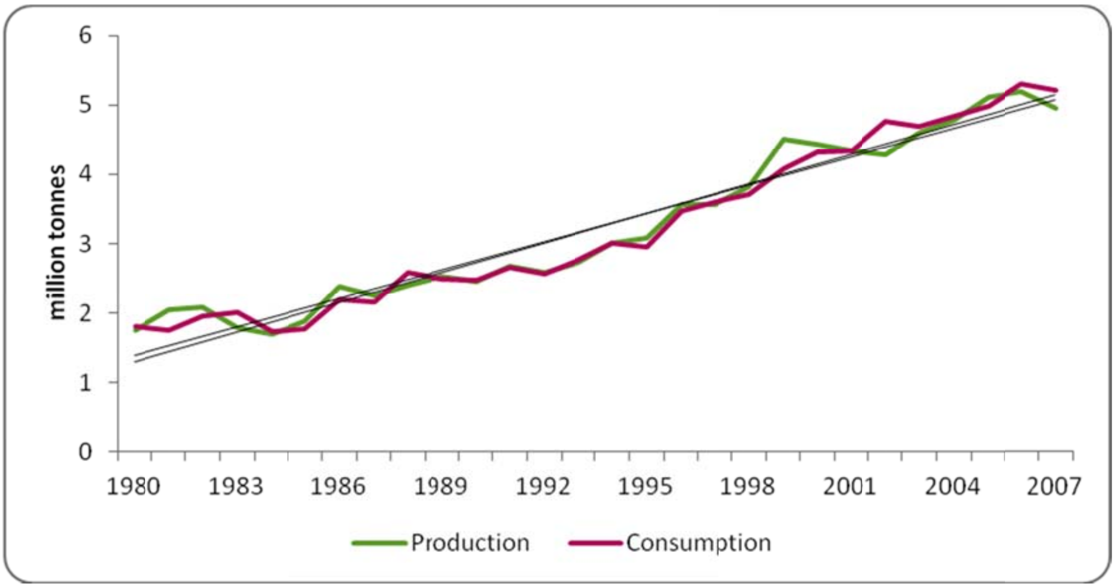
- WCA region contributes around 90% to the total cowpea acreage.
- In WCA region, area shows a significant upward movement with area increasing nearly four times from 1980 to 2010.

WCA: GROUNDNUT



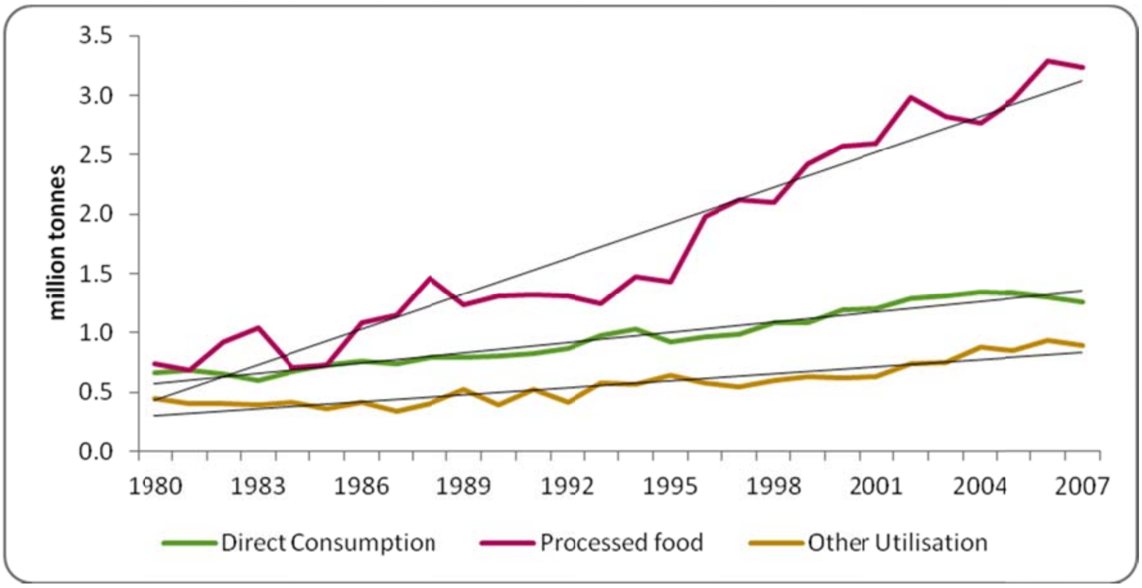
Area trend: t-value: 16.98 significant at 1% level;
Yield trend: t-value: 6.68 significant at 1% level

- WCA accounts for 22% of global groundnut area.
- Groundnut area has a positive growth rate of 2.78%
- Production registered an annual growth rate of 2.41%
- Yield trends have been positive, but in the last four years, declined from 1100 kg/ha to 950 kg/ha



Production trend: t-value: 21.5 significant at 1% level

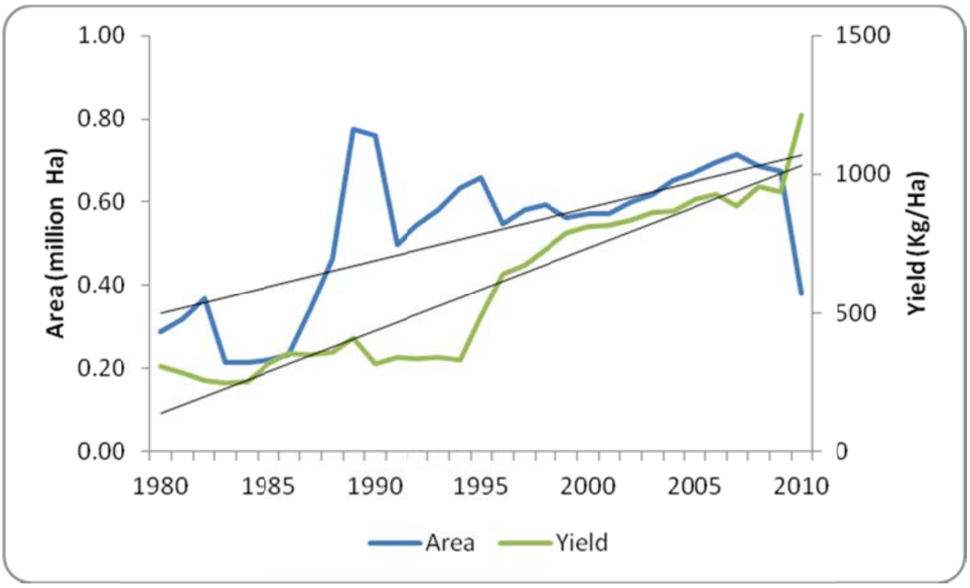
- Groundnut production and consumption closely follow a significant upward trend.



Direct consumption trend: t-value: 21.03 significant at 1% level;
Processed food trend: t-value: 17.99 significant at 1% level

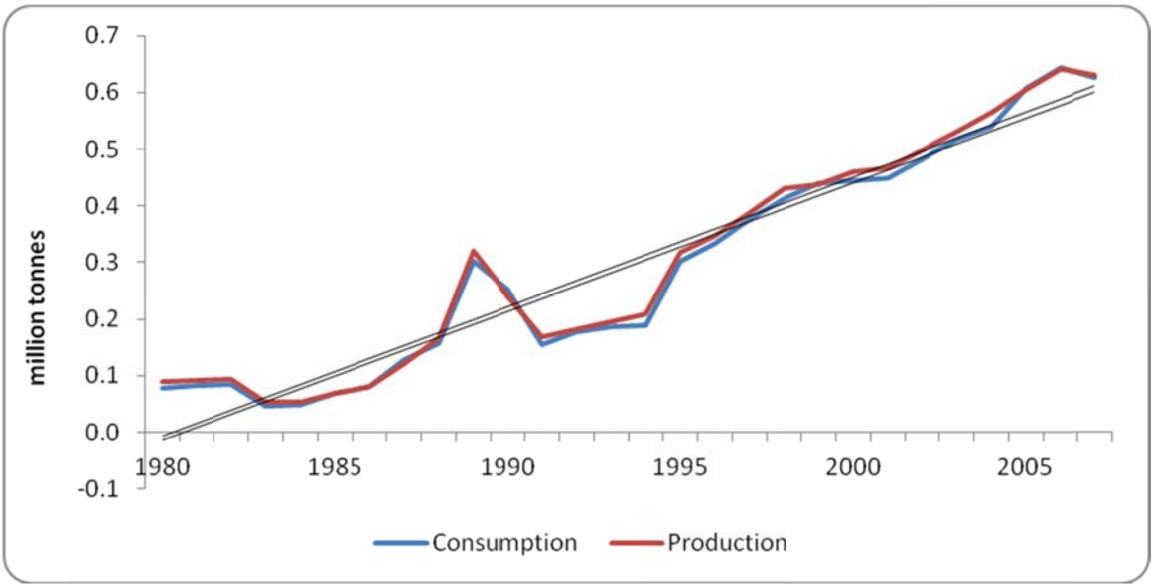
- A more disaggregated picture of the consumption shows that the share of groundnut used for processing is increasing.

WCA: SOYBEAN



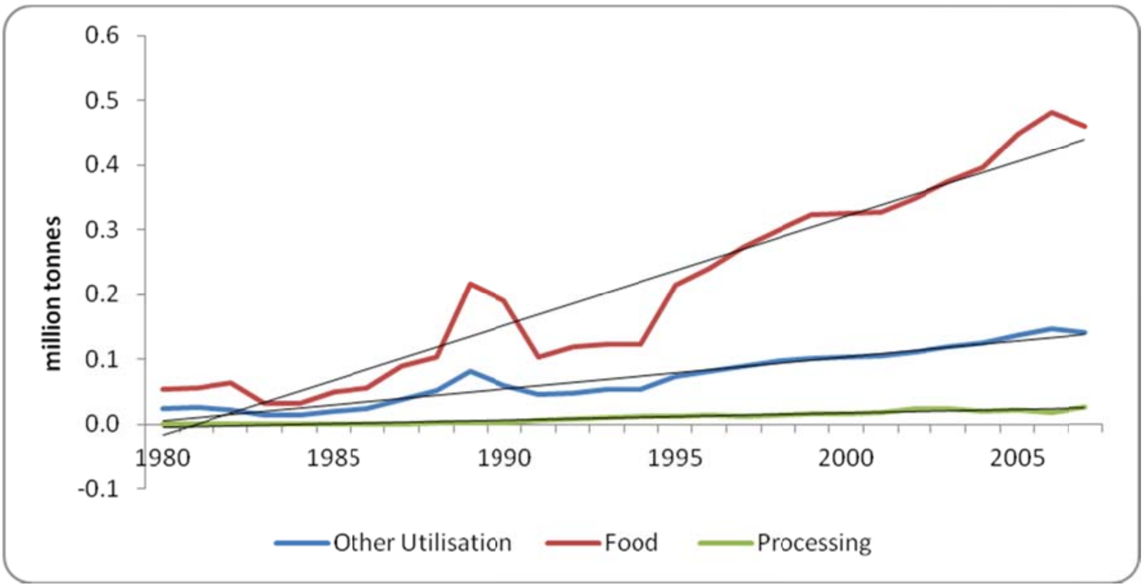
Area trend: t-value: 4.87 significant at 1% level;
Yield trend: t-value: 15.54 significant at 1% level

- Area and yield trends have been increasing in the region, although the rate of increase has decreased after the mid-nineties.



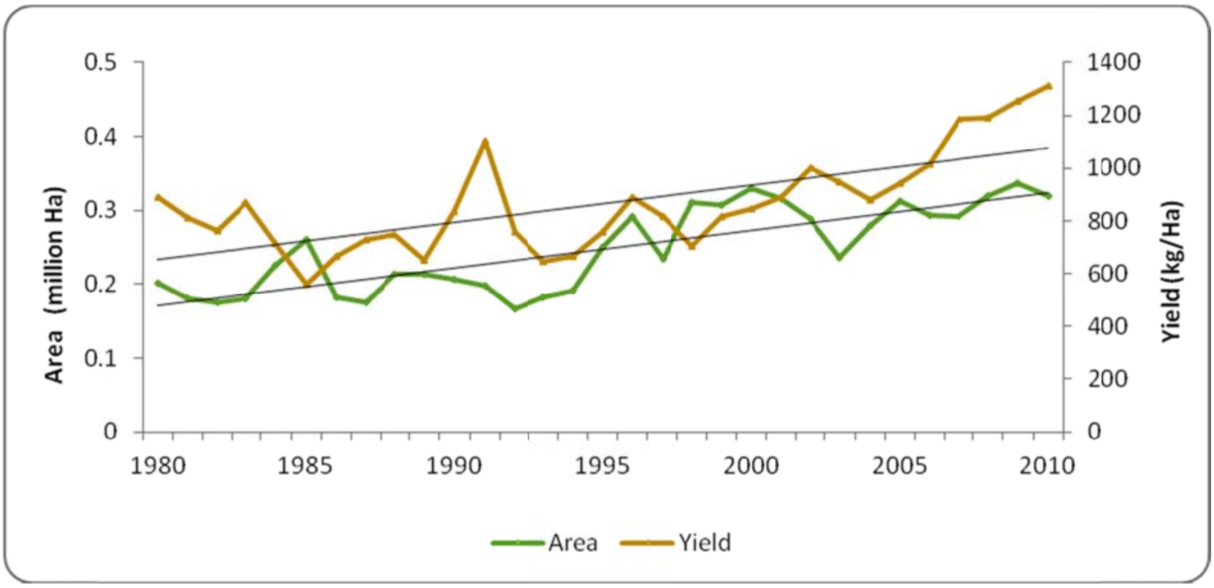
Production trend: t-value: 17.9 significant at 1% level;
Consumption trend: t-value: 17.53 significant at 1% level

- Production has been increasing from a very low base.

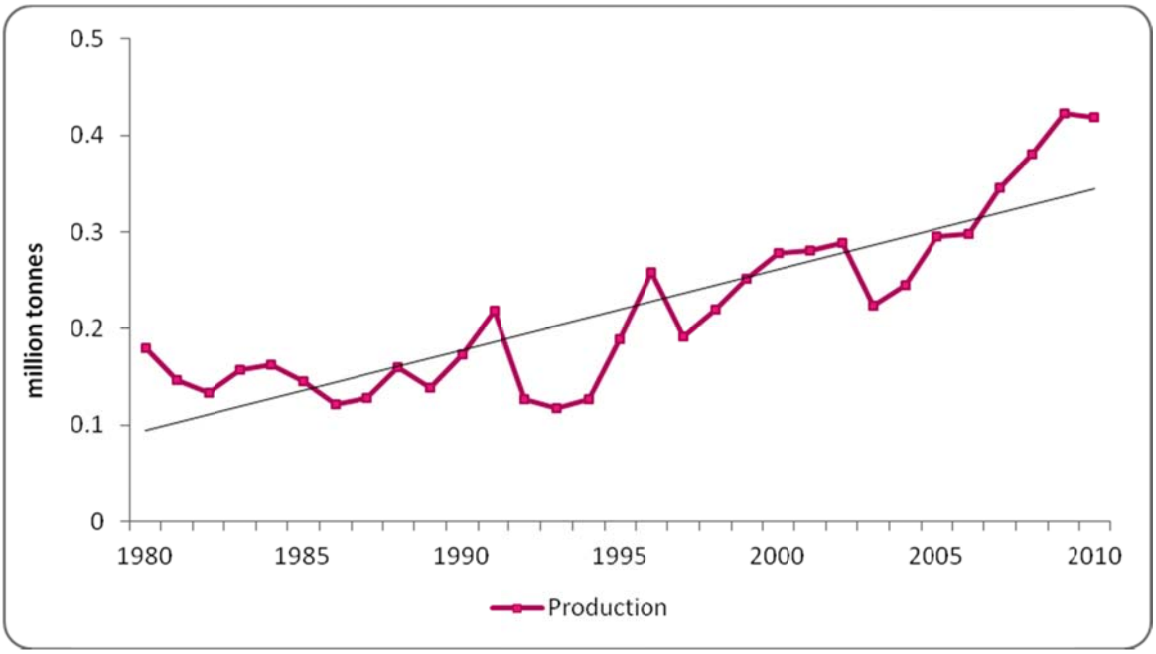


Food trend: t-value: 16.21 significant at 1% level;
Processed food trend: t-value: 17.9 significant at 1% level

ESA: CHICKPEA



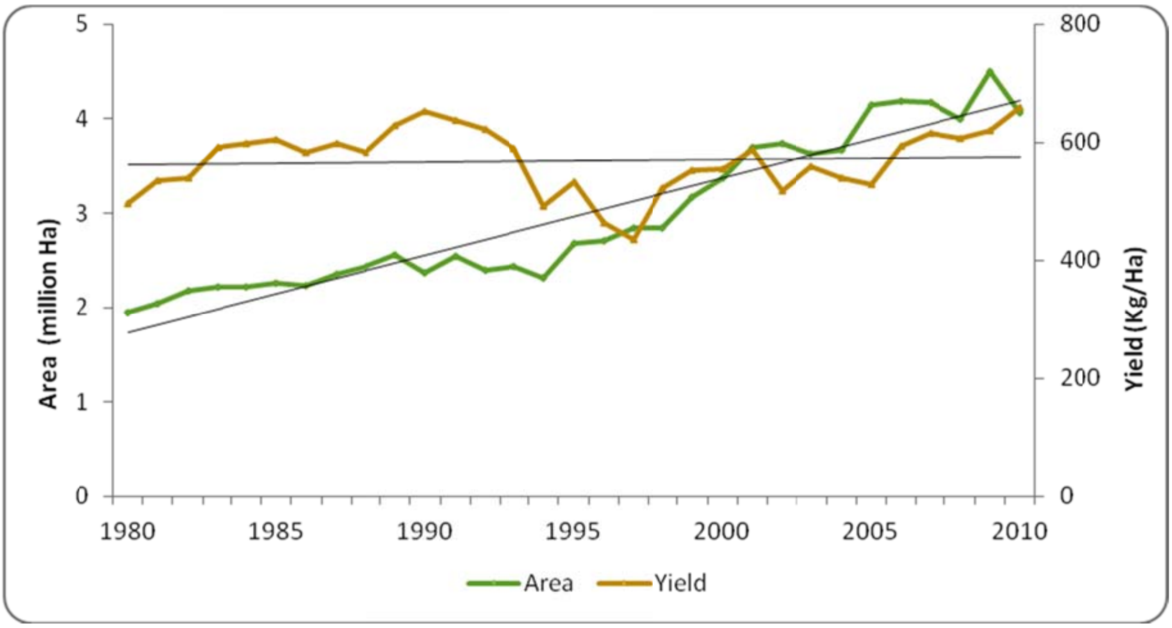
Area trend: t-value: 7.53 significant at 1% level; Yield trend: t-value: 3.39 significant at 1% level



Production trend: t-value: 9.06 significant at 1% level

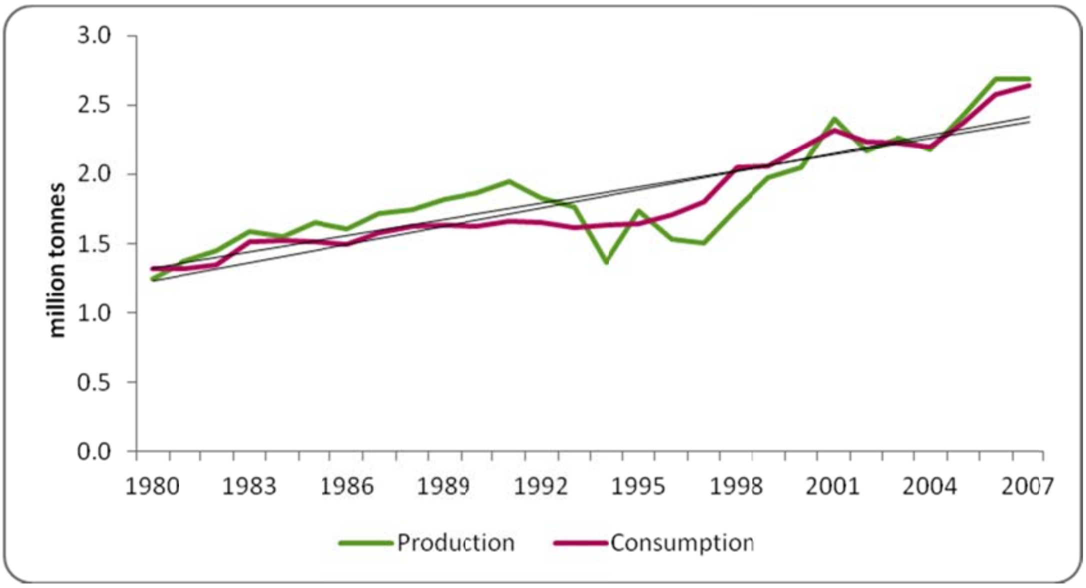
- This region's contribution is minimal around 2% to the total global acreage.
- Area and yield increased at around 2.19% and 1.14% respectively.
- In recent years, yield increases are more robust. Production increased from 0.17 to 0.38 mt in the 1980-2010 period

ESA: DRY BEAN



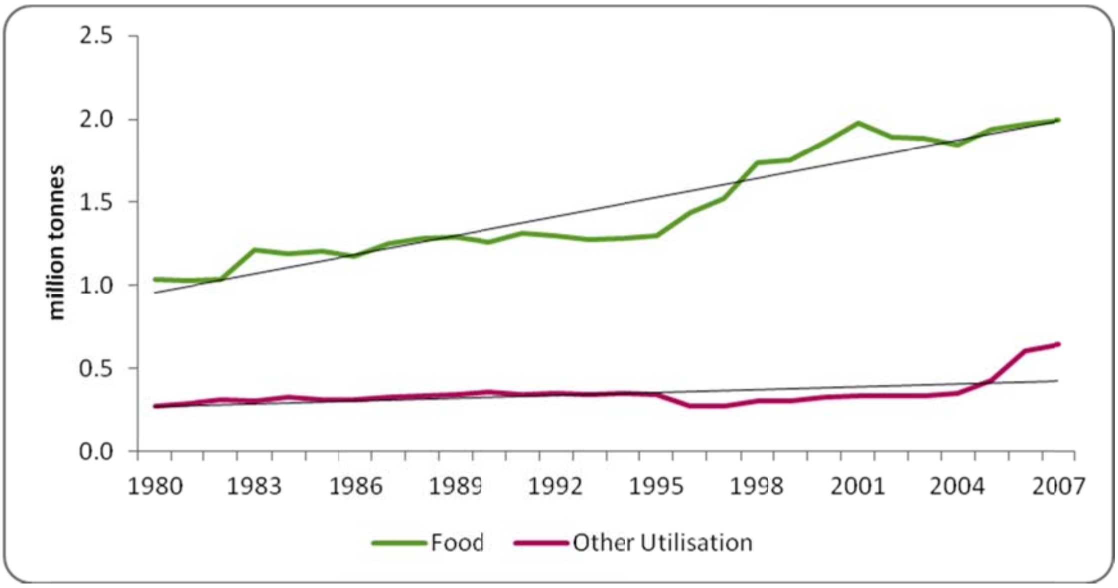
Area trend: t-value: 15.96 significant at 1% level; Yield trend: t-value: -2.65 significant at 5% level

- ESA region contributes around 10% (2.8-3.0 million ha) and 7-8% (1.74 mt) to the total global dry bean acreage and production respectively.
- From 1980's onwards the area increased at 2.44%



Production trend: t-value: 10.06 significant at 1% level

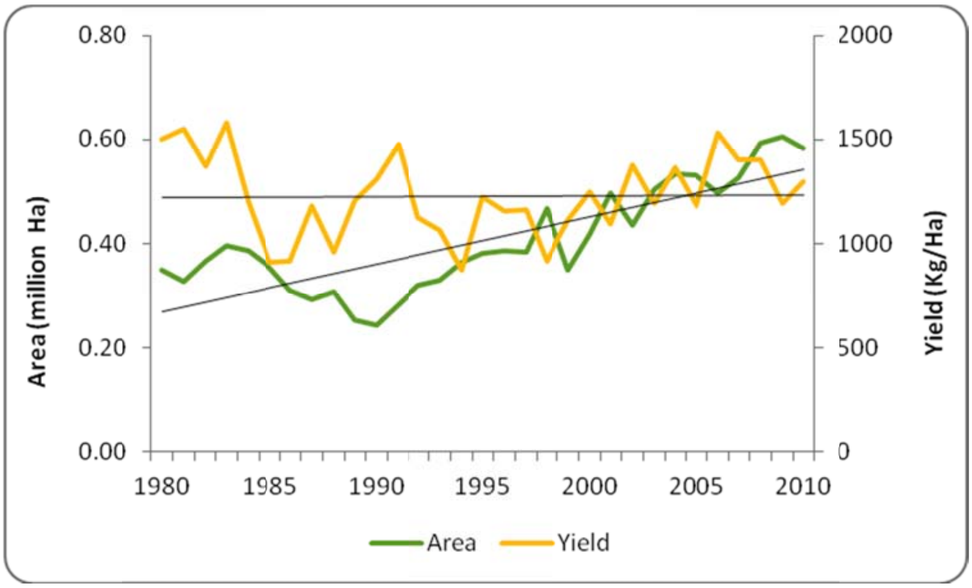
- In ESA region production and consumption are moving in positive direction, both highly significant.



Food consumption trend: t-value: 15.02 significant at 1% level;
other utilization trend: t-value: 3.45 significant at 1% level

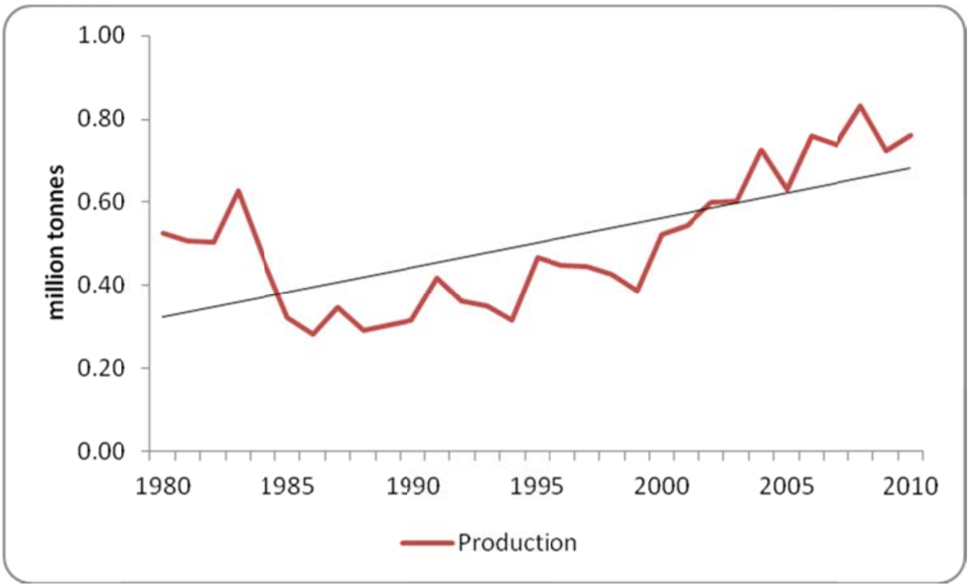
- Since 1995, a steep rise in food demand for bean is evident from the graph. This positive trend is significant at 1% level.
- Other utilization of bean has been increasing though at a slower rate (feed in Malawi and Tanzania).

ESA: FABA BEAN



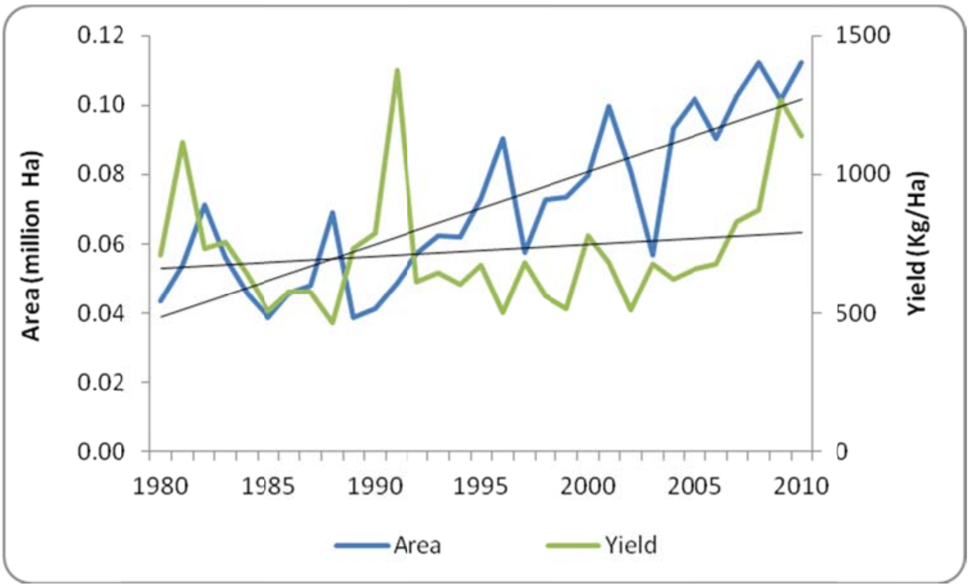
Area trend: t-value: 7.51 significant at 1% level;
Yield trend: t-value: 0.11 insignificant at 1% level

- Area trends have registered an increase since the early nineties
- Overall yields have been declining with considerable year to year fluctuations.
- Production trends are influenced by the area trends in the region.



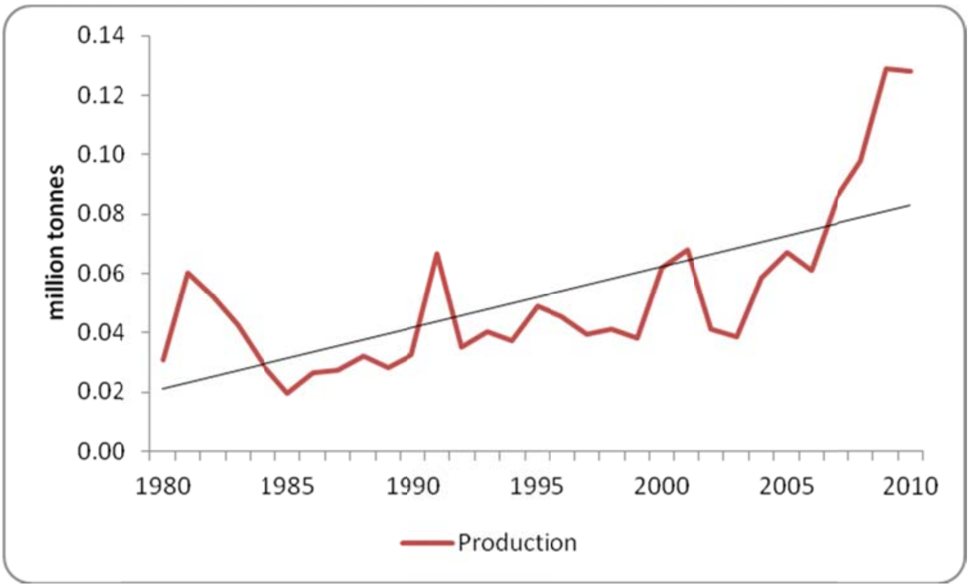
Production trend: t-value: 4.87 significant at 1% level

ESA: LENTILS



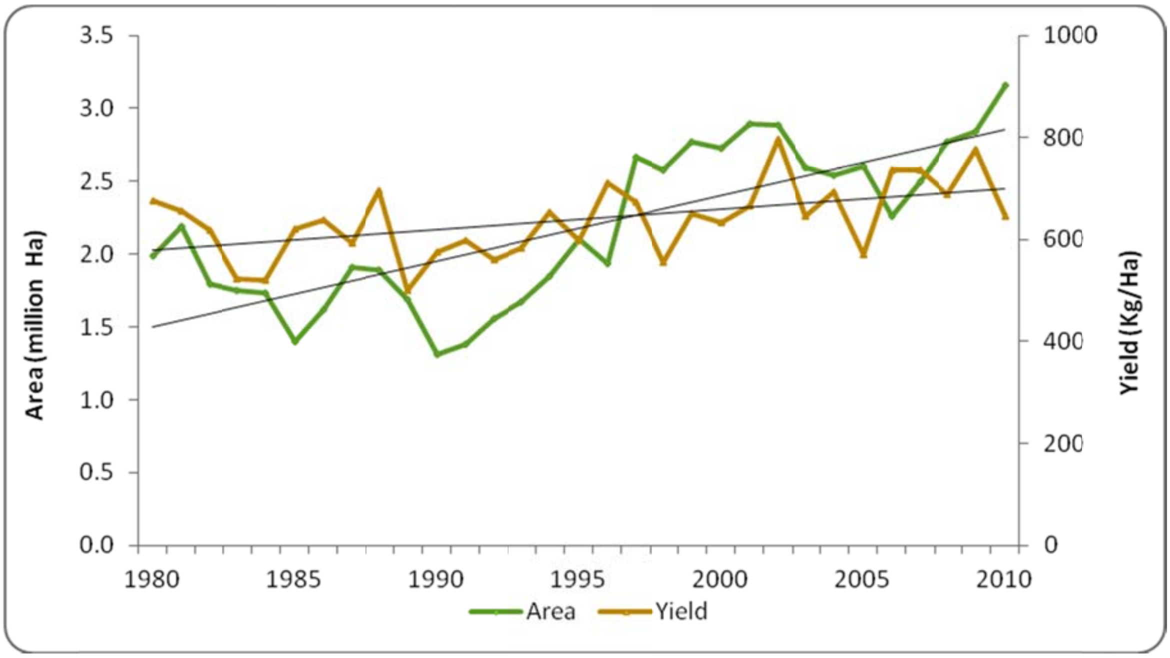
Area trend: t-value: 8.12 significant at 1% level; Yield trend: t-value: 0.98 insignificant at 1% level

- While area and yields in the region have been increasing, there are considerable yearly fluctuations.
- Yield trends have been relatively more stable, and have registered an increase post 2006.
- Production trends are positive overall, and in the recent years appear to follow yield trends more closely.



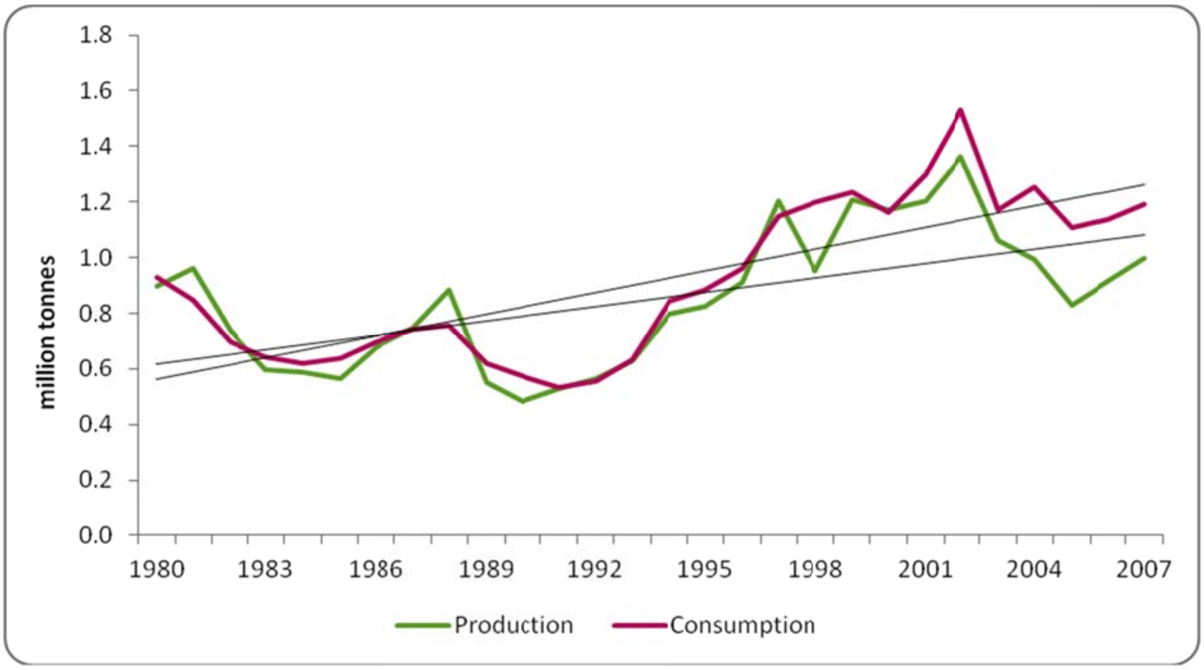
Production trend: t-value: 5.26 significant at 1% level

ESA: GROUNDNUT



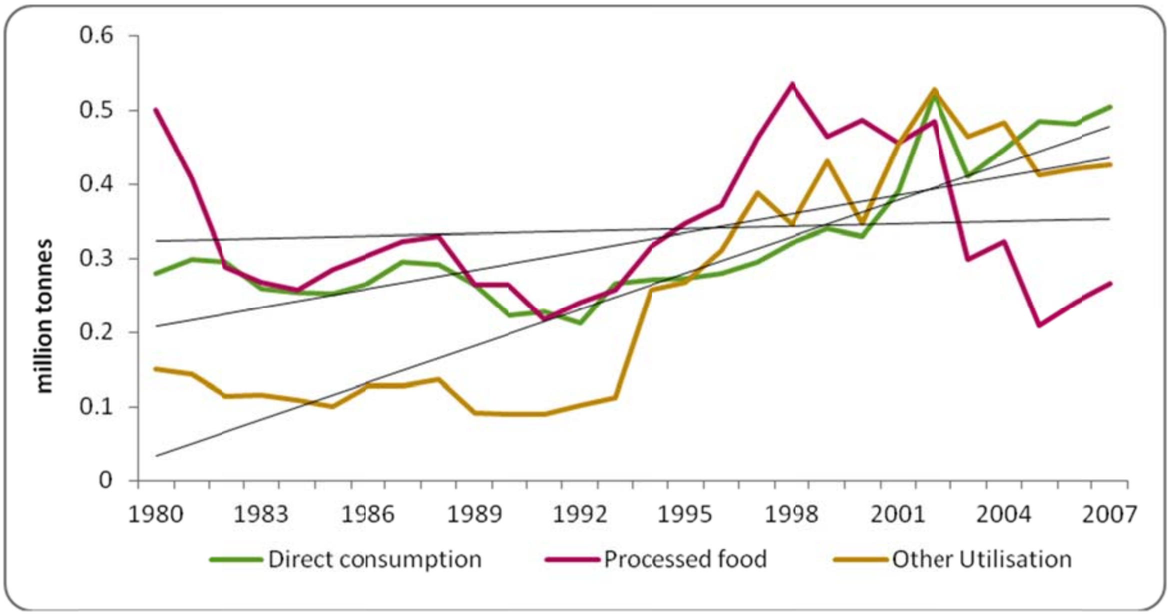
Area trend: t-value: 6.53 significant at 1% level; Yield trend: t-value: 3.12 significant at 1% level

- ESA contibutes around 9-11% to the total global groundnut acreage
- Area has followed a highly significant positive trend growing at 2.1%. Production grew at 2.73% in the same period although with considerable year-to-year variability.
- Yield levels are low and only marginally increased at 0.63%



Production trend: t-value: 6.56 significant at 1% level

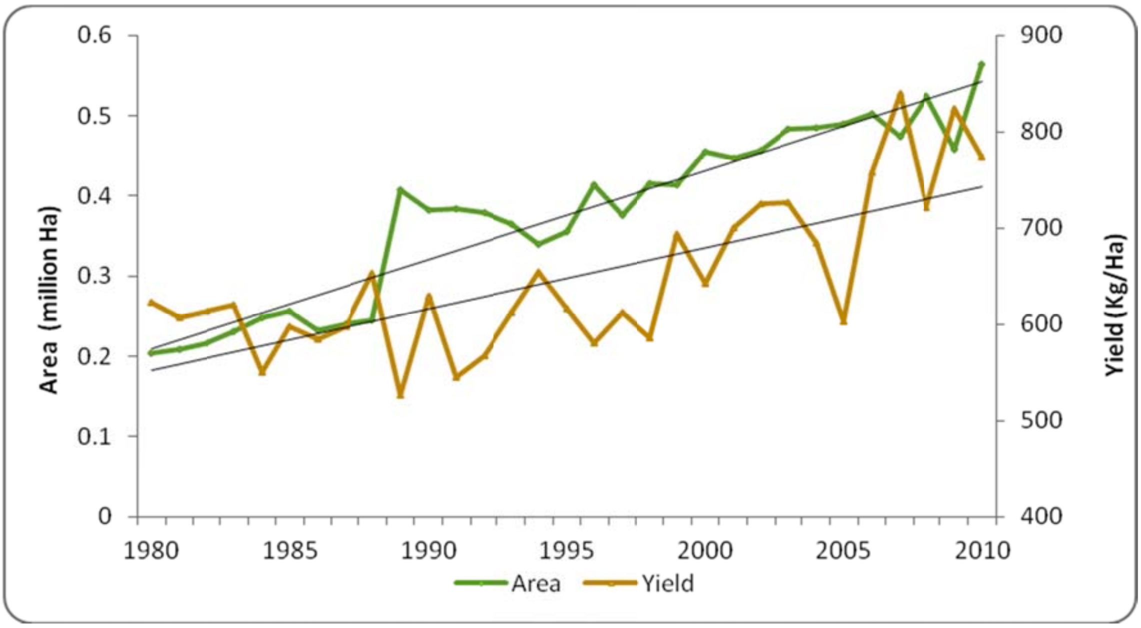
- Both production and consumption follow a significant upward trend.
- Consumption of groundnut is found to go up by about 25,000 tons every year while production increases by 17,000 tons on an average. In recent years (after 1999), the gap between production and consumption appears to be increasing.



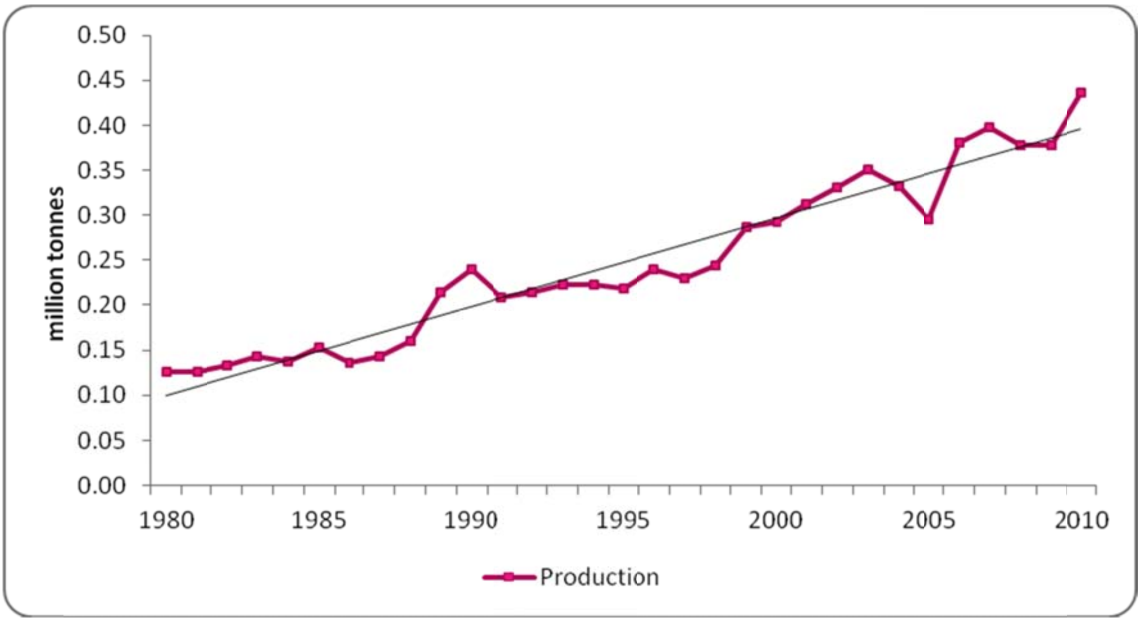
Direct consumption trend: t-value: 6.12 significant 1% at level;
Processed consumption trend: t-value: 0.46 insignificant 1% at level

- Both direct and processed consumption are equally found to be important in terms of their quantity consumed. Processed consumption is however showing a declining trend since 1998.
- From 2001 onwards, direct consumption seems to dominate the consumption pattern with an upward trend. Consumption increases by around 8,000 tons year after year.
- From 1993, use of groundnut for non-food purposes like oil for soap, pet food etc. has increased, which also follows an upward trend.

ESA: PIGEONPEA



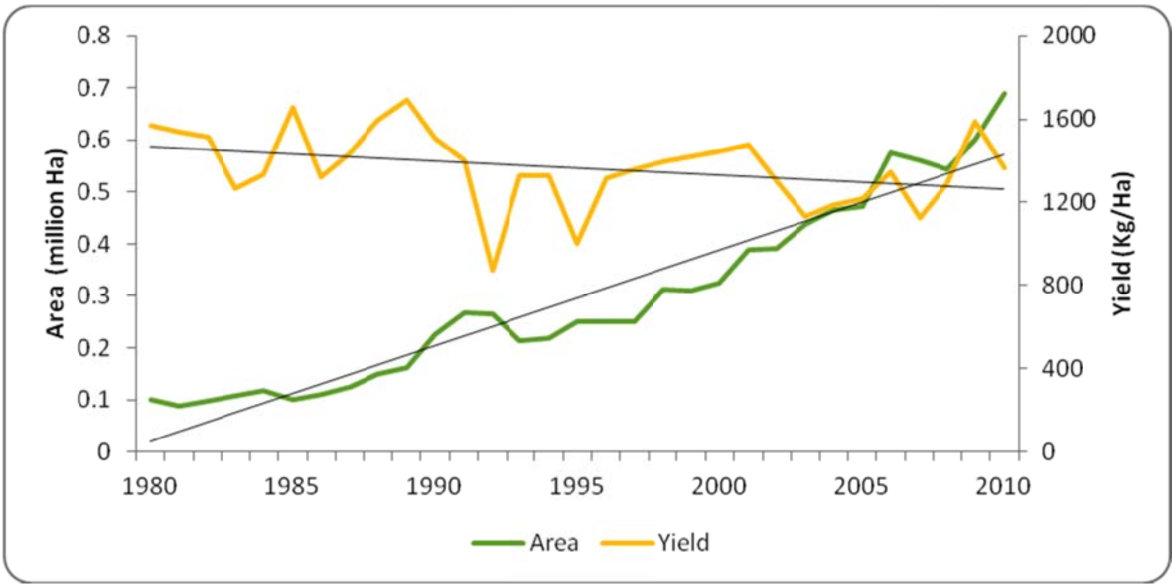
Area trend: t-value: 15.6 significant at 1% level; Yield trend: t-value: 5.76 significant at 1% level



Production trend: t-value: 20.07 significant at 1% level

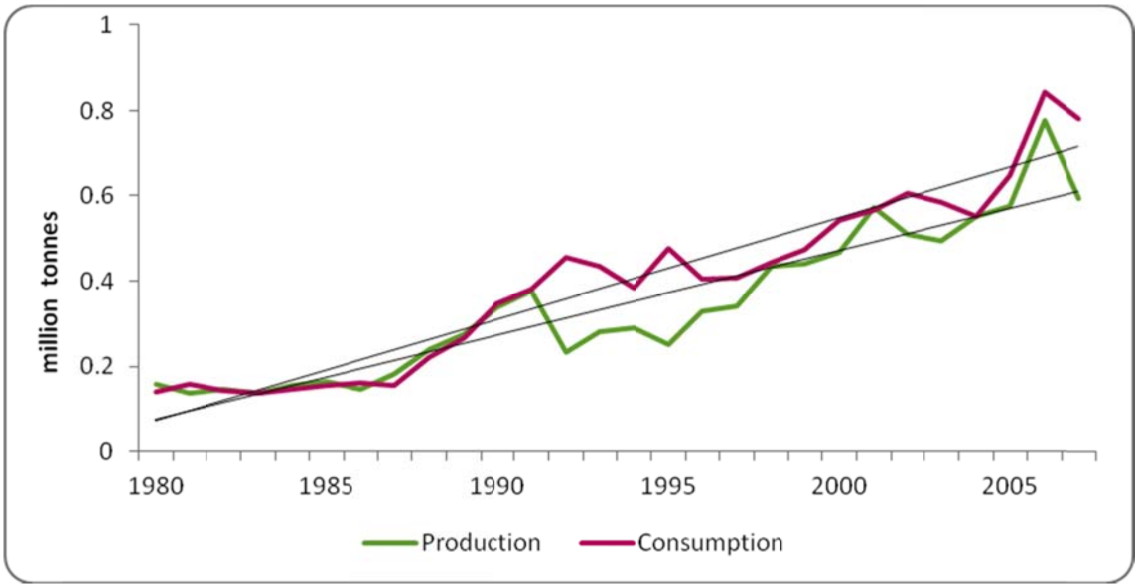
- ESA contributes is around 10% to total global pigeonpea production.
- Area, production and yield registered a continuous increasing trend in last three decades growing at 3.67%, 4.73% and 1.02%, respectively.
- Yield significantly increased in the same period on adoption of improved cultivars and technology.

ESA: SOYBEAN



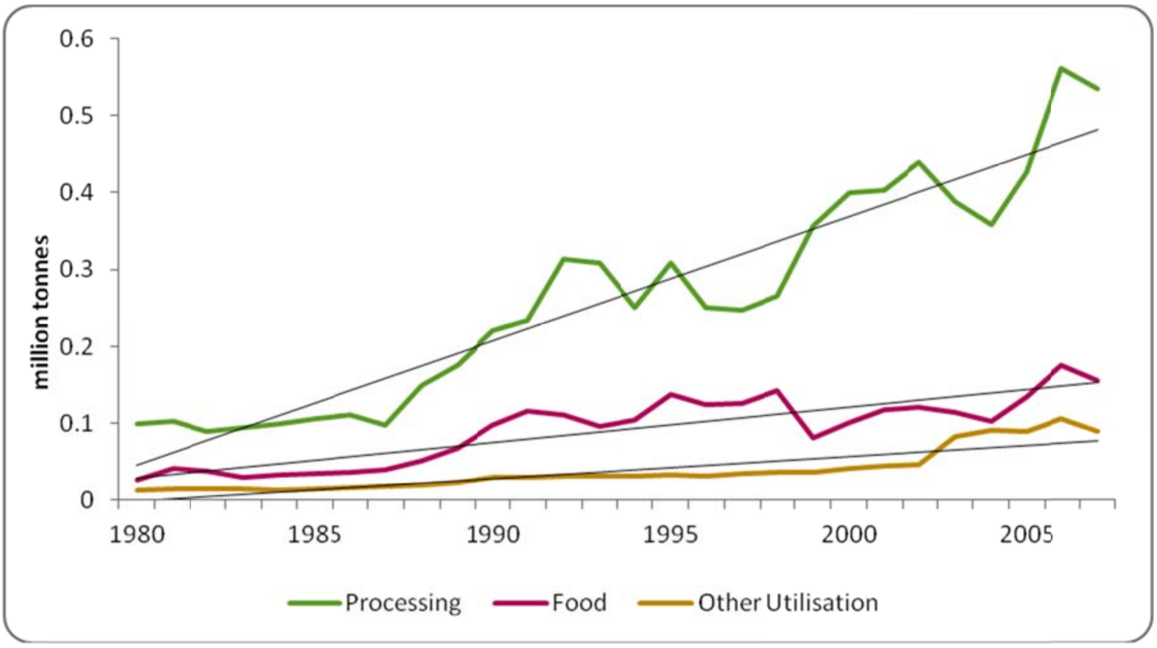
Area trend: t-value: 18.58 significant at 1% level; Yield trend: t-value: -1.9 insignificant at 1% level

- Area has been expanding at more than 1.06% year during the thirty year period ending 2010.
- Yield shows a declining trend. Zimbabwe is the major contributor of soybean in ESA whose production shows a constant trend.



Production trend: t-value: 13.34 significant at 1% level

- Production increases have been driven primarily by area increases.
- Consumption demand has been exceeding production since 1995.



Food trend: t-value: 5.07 significant at 1% level;
Processed food trend: t-value: 9.8 significant at 1% level

- In the ESA region much of the production goes for processing as tofu, bean curd and flour. Direct consumption as food is much less compared to processing usage of soybean.
- Some countries like Malawi, Uganda, Zambia and Zimbabwe export soybean.
- Lately use of soybean as feed has been found in Sudan and Malawi in the last decade.

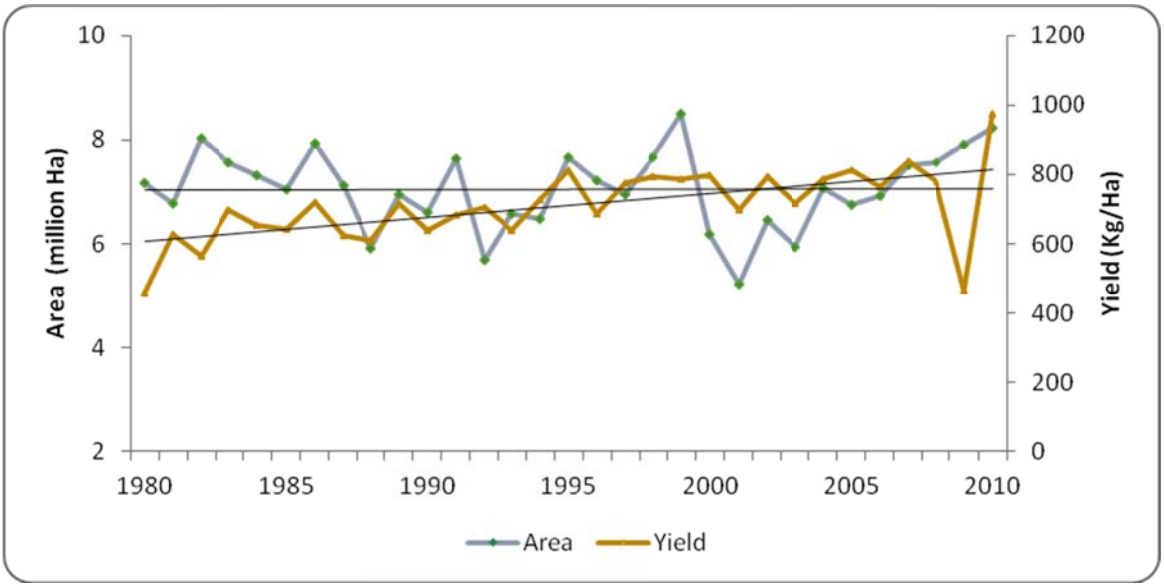
South and South East Asia (SSEA)

The overall grain legumes production trends in this region are mixed. While production and consumption have been increasing, area under grain legumes has been declining. Although yield levels have followed an increasing trend, the levels continue to be low compared to global yields. This region is a dominant force in the grain legumes market, both as an important producer and a major importer.

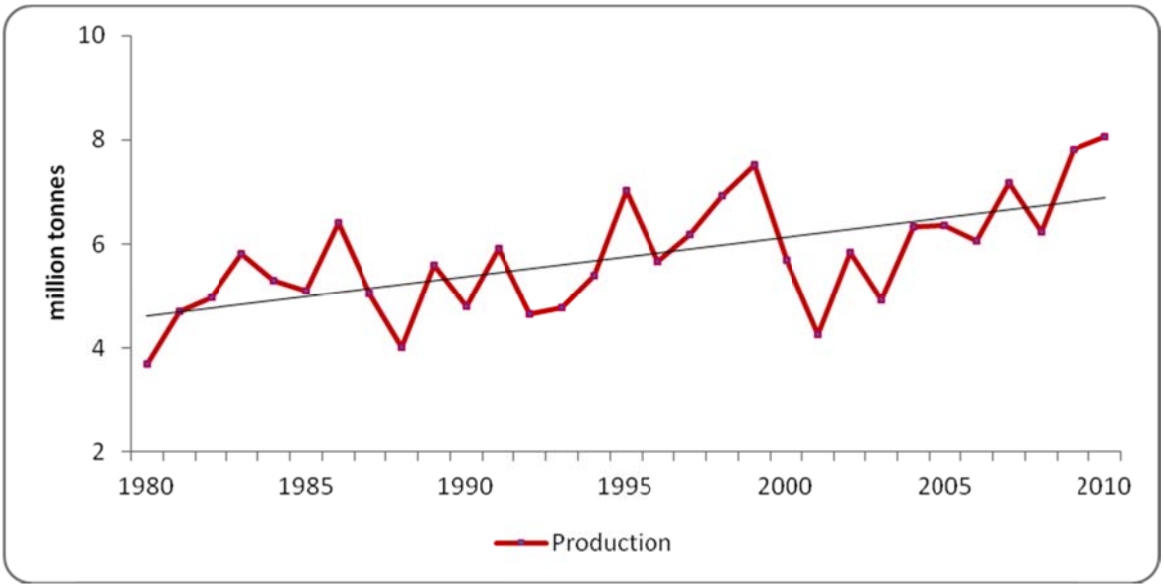
Table 2: Compound annual growth rates for area and yield for selected grain legumes in SSEA

Crop	Area				Yield			
	1980-90	1991-00	2001-10	1980-10	1980-90	1991-00	2001-10	1980-10
Chickpea	-1.12	1.02	4.36	0.04	2.35	1.98	1.60	1.34
Groundnut	1.87	-2.23	-0.96	-0.58	1.57	1.09	1.02	1.02
Lentils	1.16	1.84	-1.57	1.02	3.66	0.49	0.38	0.99
Pigeonpea	2.39	-0.05	0.72	1.15	1.09	1.52	2.21	0.19

SSEA: CHICKPEA



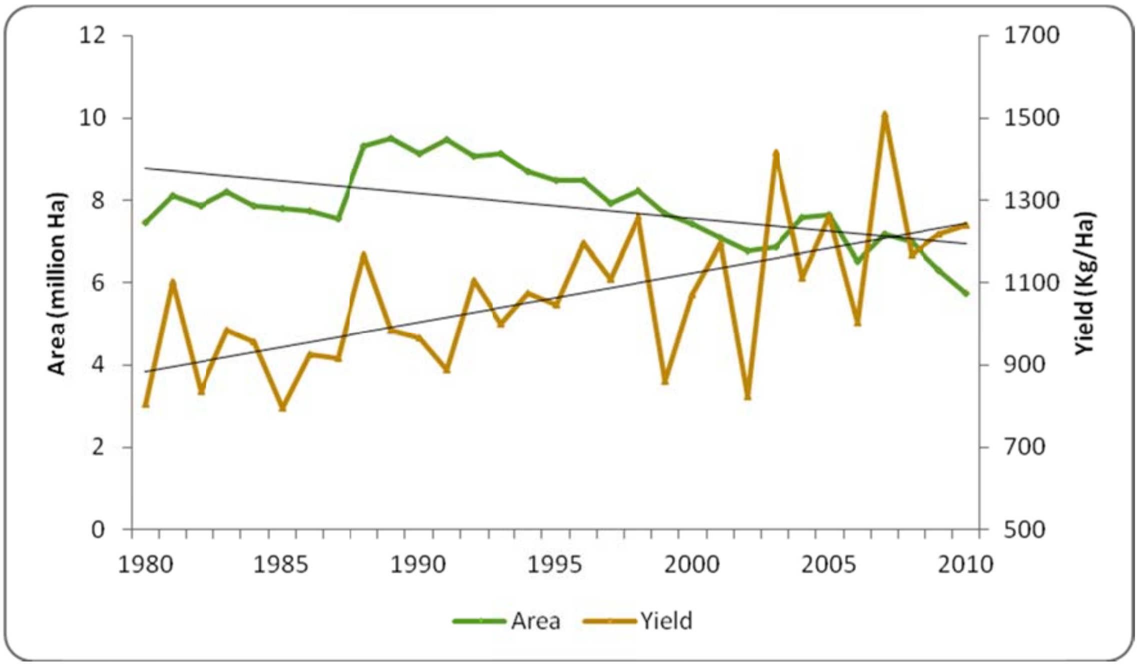
Area trend: t-value: 0.28 not significant at 1% level;
Yield trend: t-value: 8.94 significant at 1% level



Production trend: t-value: 4.67 significant at 1% level

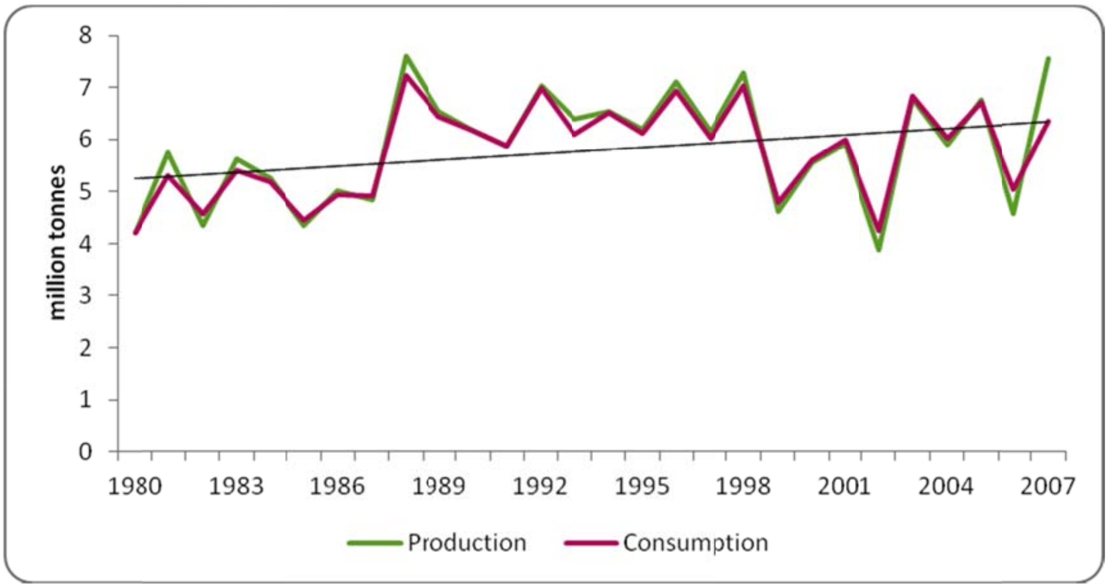
- SSEA region accounts for 70-75% of global chickpea acreage
- Production trends in the region are driven by yield trends as area levels have increased only marginally. Significant increase in area was observed only between 1990-2000.

SSEA: GROUNDNUT



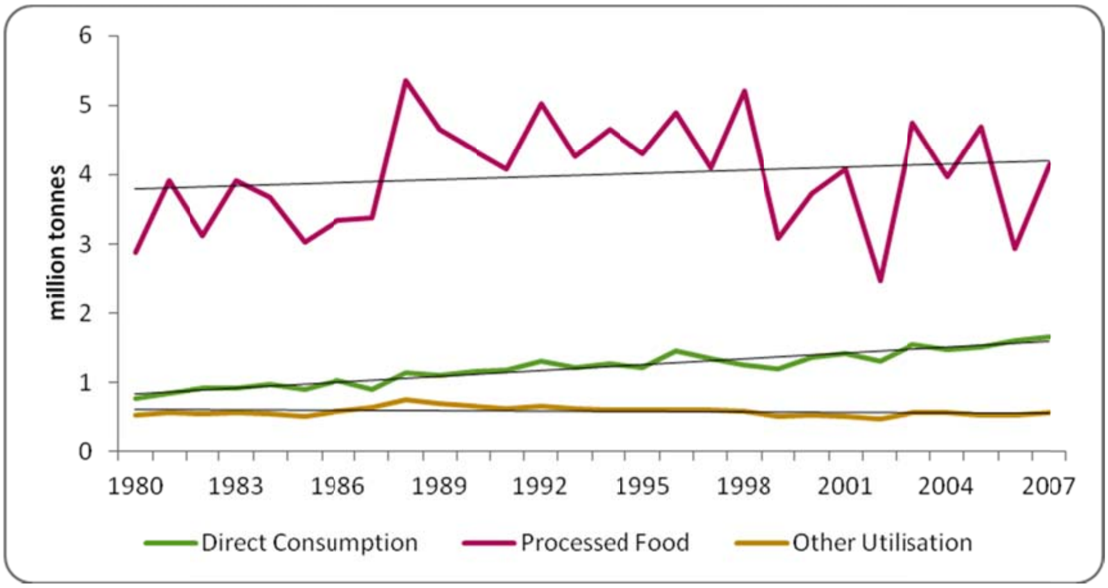
Area trend: t-value: -3.16 significant at 1% level; Yield trend: t-value: 5.16 significant at 1% level

- SSEA region accounts for 25-30% in global groundnut acreage.
- In this region groundnut area has followed continuous down trend from 1990s onwards
- Yield registered an annual growth rate of 1.7% but this increase is marked by large year-to-year variability



Production trend: t-value: 1.96 insignificant at 1% level

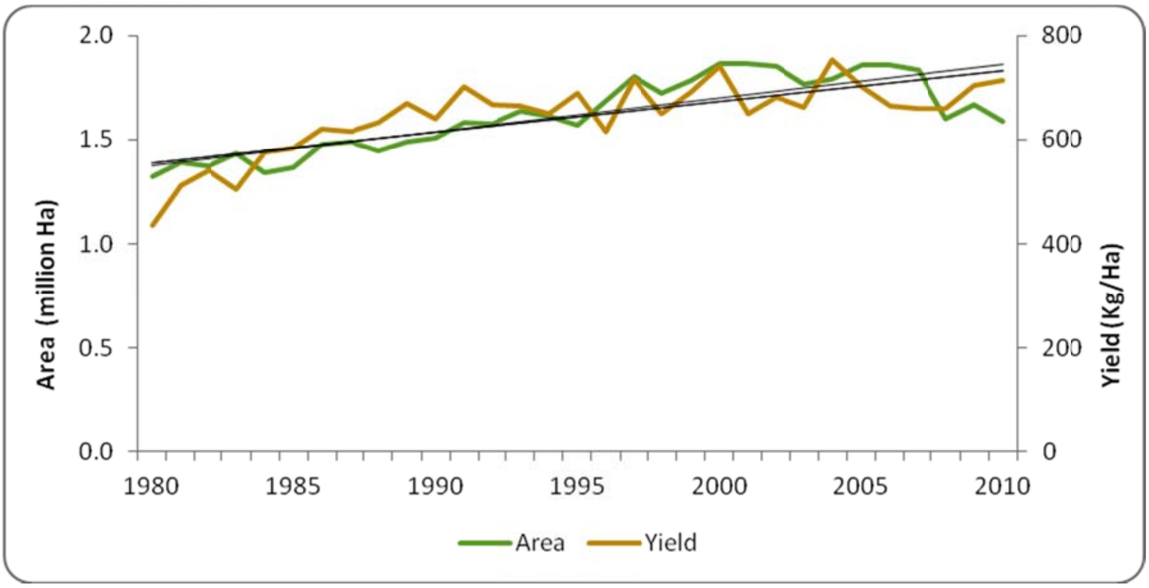
- Both production and consumption follow a significant upward trend.



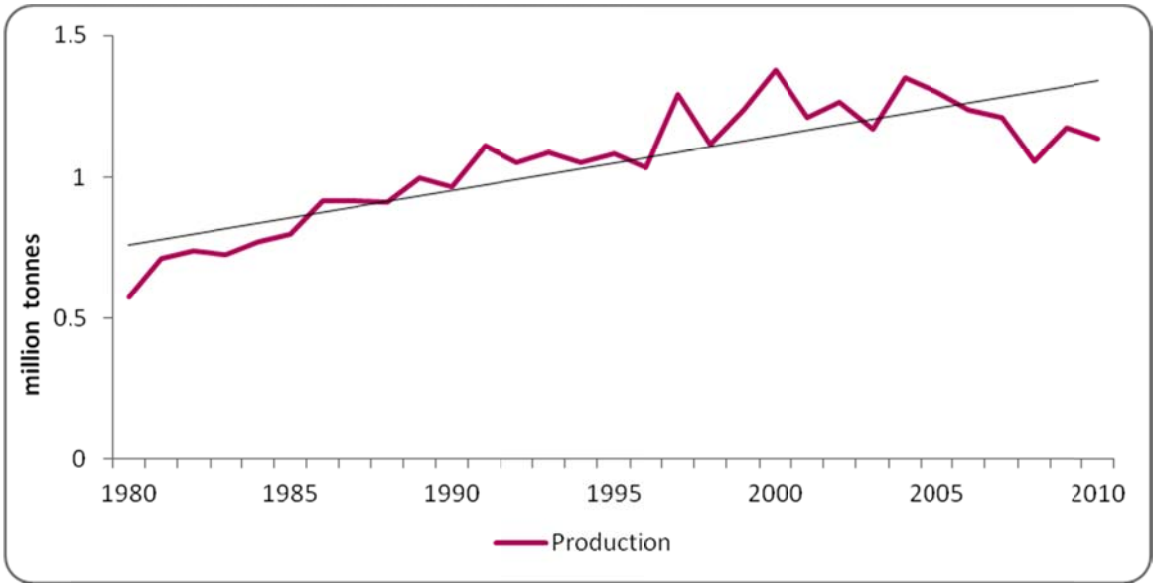
Direct consumption trend: t-value: 15.02 significant at 1% level;
Processed food trend: t-value: 0.82 insignificant at 1% level

- Processed consumption of groundnut is higher in SSEA region.
- Direct consumption has been increasing in recent years

SSEA: LENTIL



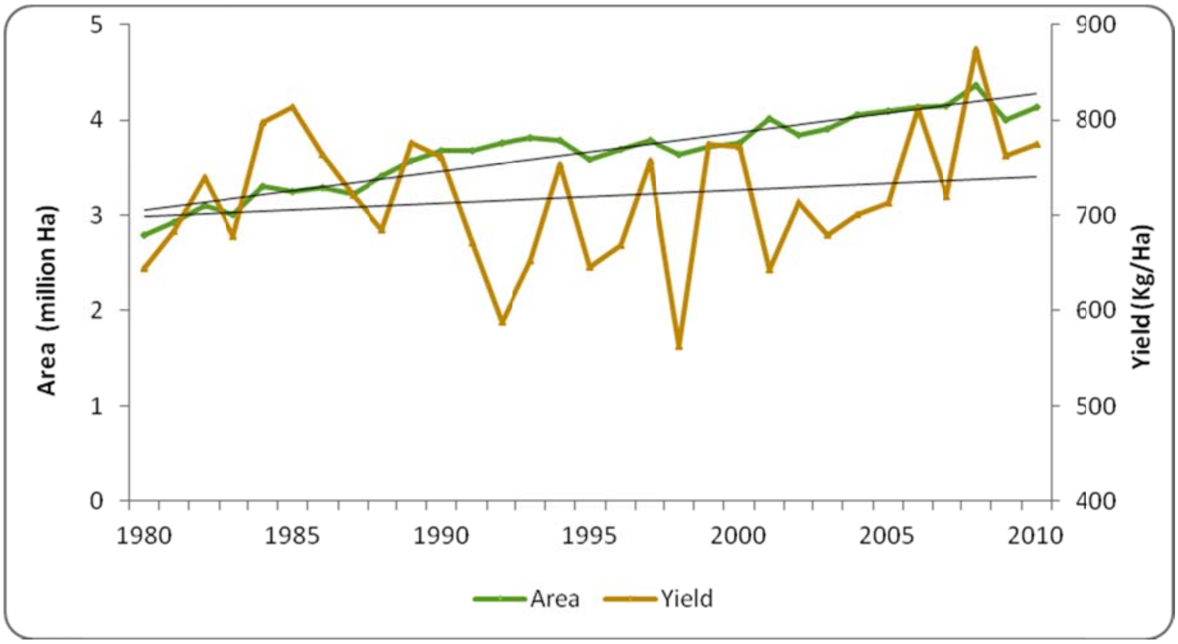
Area trend: t-value: 7.79 significant at 1% level;
Yield trend: t-value: 6.26 significant at 1% level



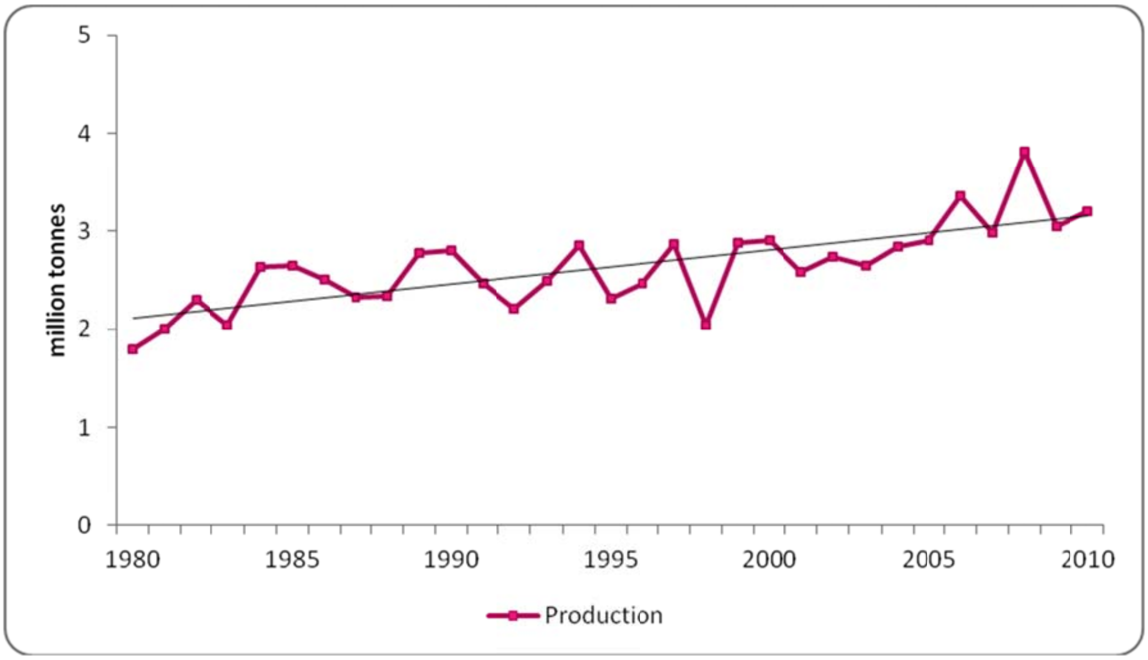
Production trend: t-value: 8.6 significant at 1% level

- Both area and yield are driving significant increase in production t

SSEA: PIGEONPEA



Area trend: t-value: 14.49 significant at 1% level;
Yield trend: t-value: 1.02 insignificant at 1% level



Production trend: t-value: 6.04 significant at 1% level

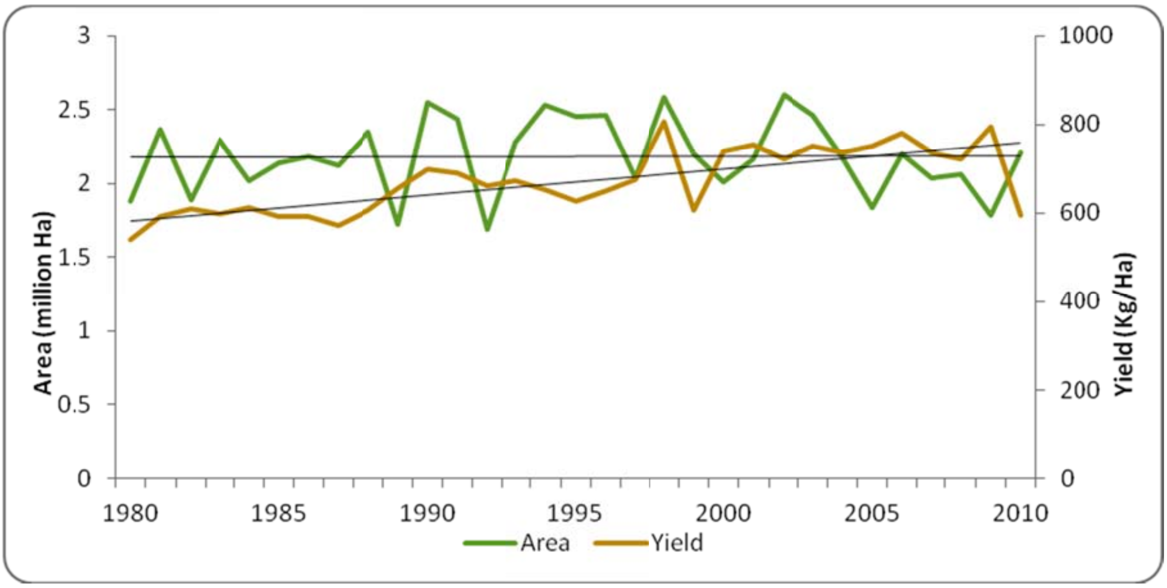
- SSEA region contributes around 75% to the global pigeonpea acreage
- In this region, area under pigeonpea shows a significant positive trend with annual growth rate of 0.59%.
- Production also registered annual growth rate of 0.45% in the same period
- Yield remained stagnant around 640-750 kg/ha albeit with large year-to-year fluctuations

Latin America and the Caribbean (LAC)

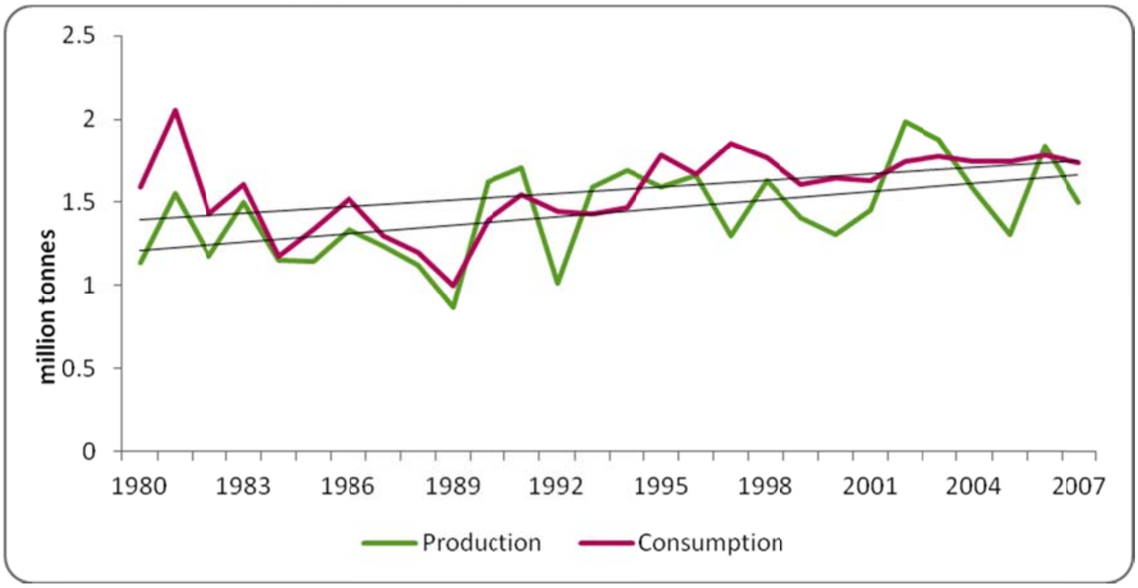
Table 3. Compound annual growth rates for area and yield for selected grain legumes in LAC

Crop	Area				Yield			
	1980-90	1991-00	2001-10	1980-10	1980-90	1991-00	2001-10	1980-10
Dry beans	0.77	0.05	-2.02	0.02	-1.58	-0.53	1.00	1.03

LAC: DRY BEAN

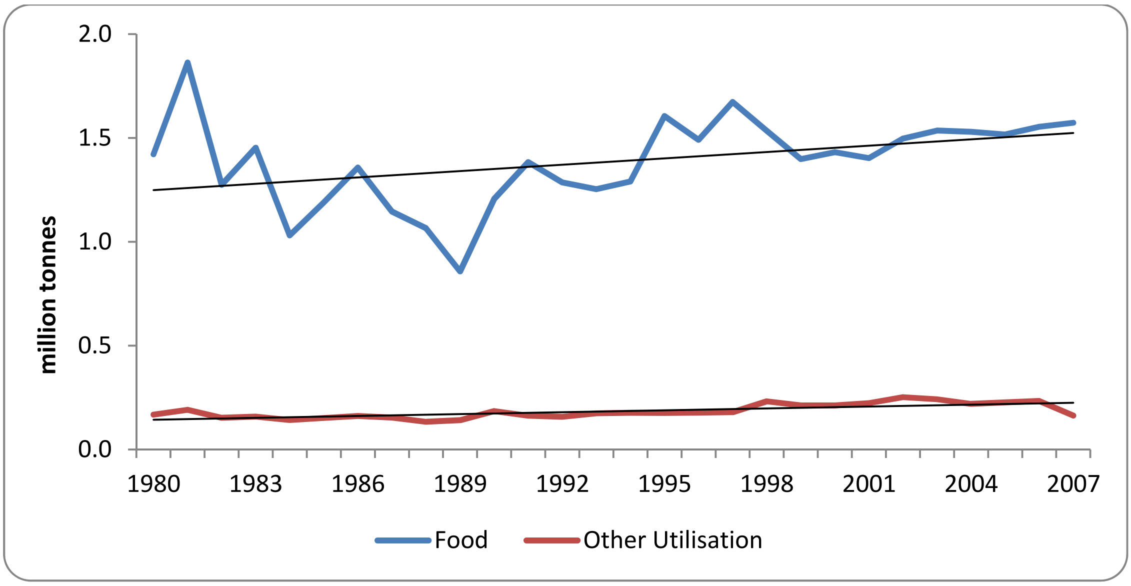


Area trend: t-value: 0.06 insignificant at 1% level; Yield trend: t-value: 5.74 significant at 1% level



Production trend: t-value: 3.09 significant at 1% level

- Between 1980 and 2010, area has increased at the rate of 0.02% year and yield has grown at an annual rate of 1.03%. Therefore, production has registered a growth rate of 1.05% mainly because of yield gains. Yield gains are mostly attributed to usage of disease resistant varieties.



Food trend: t-value: 9.67 significant at 1% level;
Other utilization: t-value: 7.02 significant at 1% level

- Food demand shows an upward trend, which is highly significant. Other uses of bean do not much influence the total consumption.
- The drop in consumption in late eighties is due to drop in consumption in Mexico due to the urbanisation, rising incomes and shift in consumption pattern away from traditional staples particularly among the young population. The consumption has however, recovered since then.

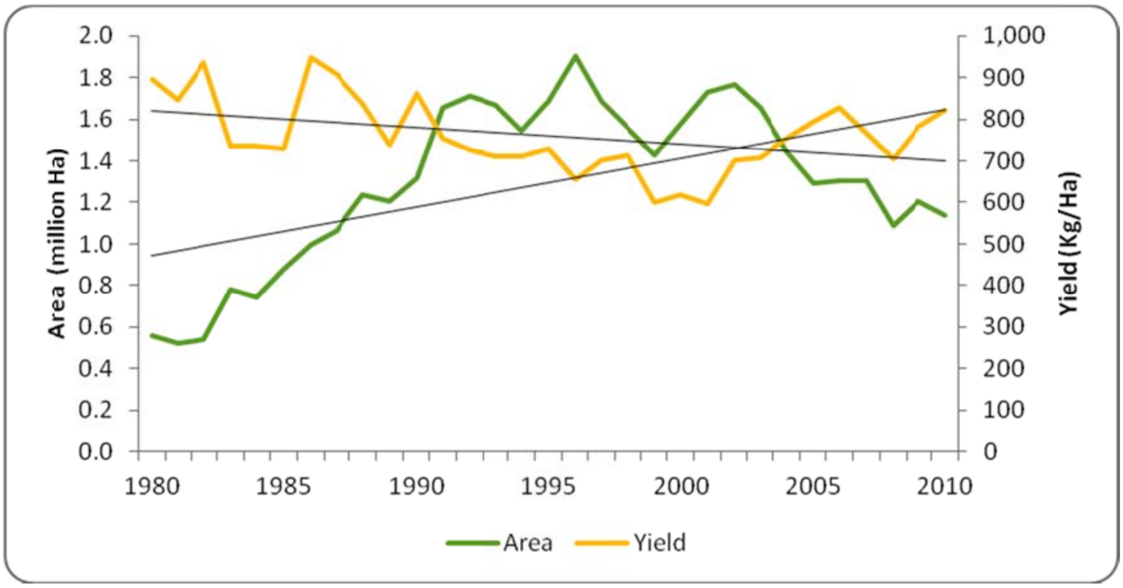
Central and Western Asia and Northern Africa (CWANA)

Grain legumes in the CWANA region occupy relatively low area compared to the global scenario. The most important legumes in the region are chickpea, lentil and dry beans. However, these crops are significant contributors to the incomes and food security of the people in the region. The region is a significant exporter of chickpea. Overall in the region, production trends are positive but mainly driven by area increase. Yields have declined significantly for faba bean and lentils during 2001-2010. Overall the yields of all three major legumes have remained stagnant during the last 30 years. In many of the major grain legume producing countries, production exceeds consumption. Turkey, Pakistan and Iran are the most important producers in the region. Egypt and Sudan in the Nile Valley and the Red Sea sub-region and Morocco in the North African sub region are also important producers.

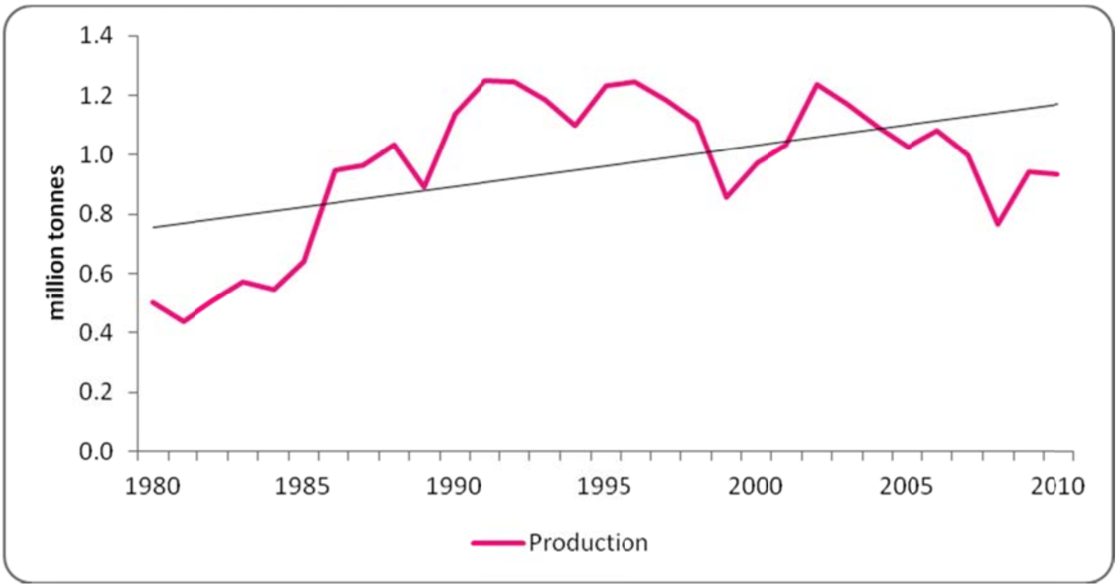
Table 4. Compound annual growth rates for area and yield for selected grain legumes in CWANA

Crop	**Area**				**Yield**			
	1980-90	**1991-00**	**2001-10**	**1980-10**	**1980-90**	**1991-00**	**2001-10**	**1980-10**
Chickpea	10.57	-1.03	-5.22	2.43	-0.37	-1.94	2.25	-0.51
Faba bean	4.74	-1.43	-0.13	-0.38	2.81	-0.54	-1.95	0.71
Lentils	6.82	1.14	-3.00	2.47	-1.62	-5.52	-3.92	-0.85

CWANA: CHICKPEA



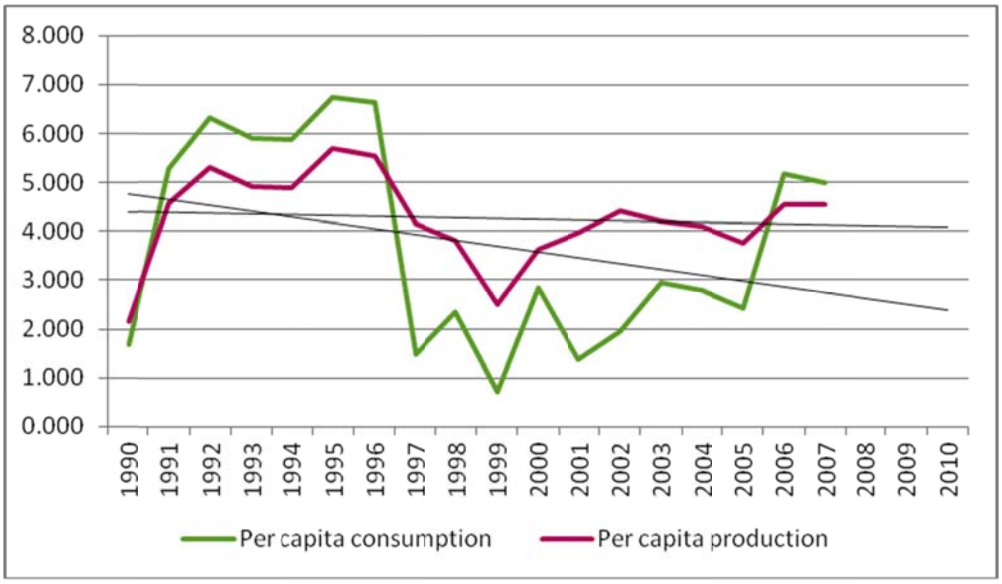
Area trend: t-value: 3.47 significant at 1% level; Yield trend: t-value: -2.4 insignificant at 5% level



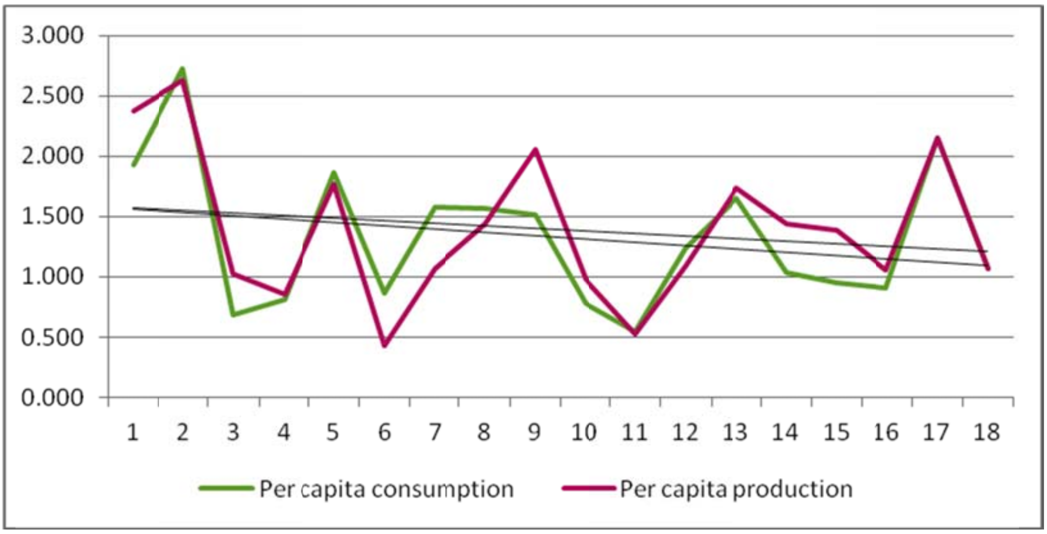
Production trend: t-value: 3.19 significant at 1% level

- In CWANA region, area was increasing until the mid 2000's, while yield was declining. However, since 2003-04, this trend has reversed
- CWANA region contributes only 2% to the global chickpea area.
- Production per capita trends are either increasing (Ethiopia) or steady with high annual variability in most countries but declining for Bangladesh and Turkey. This decline is mainly due to population growth rate, which is faster than production growth and does not necessarily mean that overall production and productivity were declining. In fact in most cases these were increasing trends of production and productivity.
- The consumption per capita was increasing in Ethiopia, and steady in other countries. The decline in per capita consumption was in countries with large populations and higher growth rates (Bangladesh) or countries where the populations were becoming more affluent and people are increasing animal sources as protein, for example in Turkey.

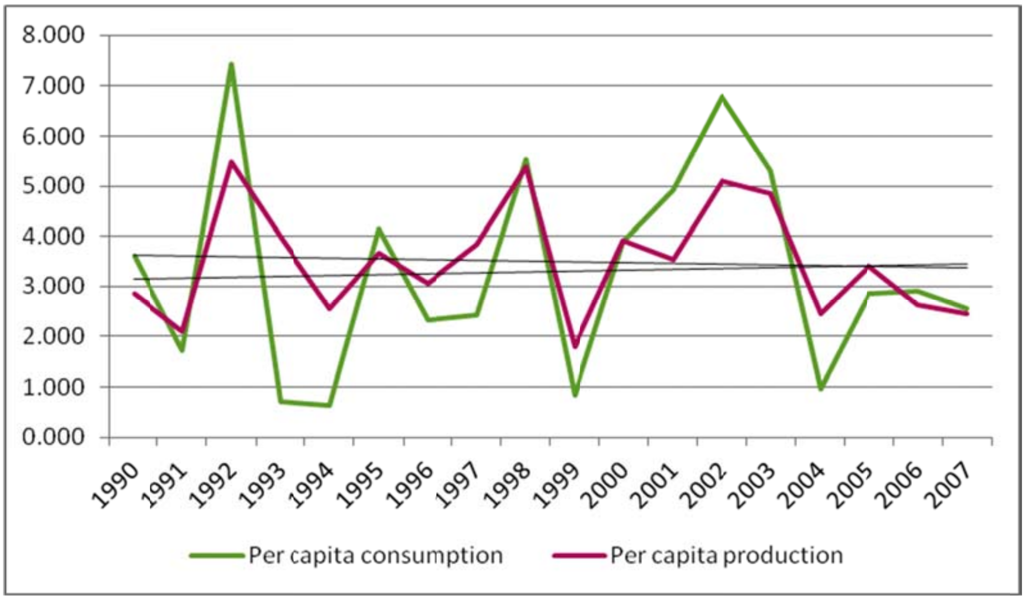
Iran



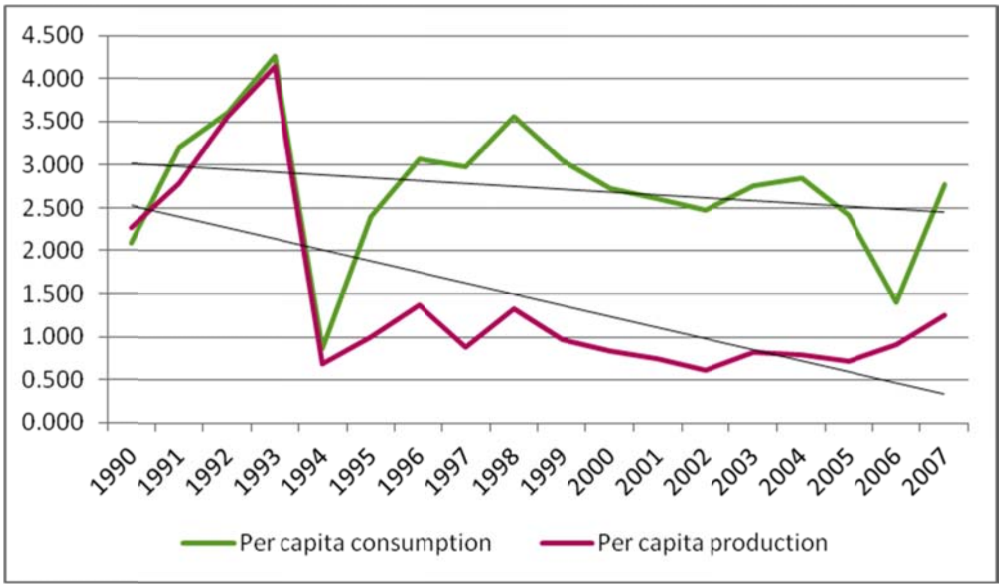
Morocco



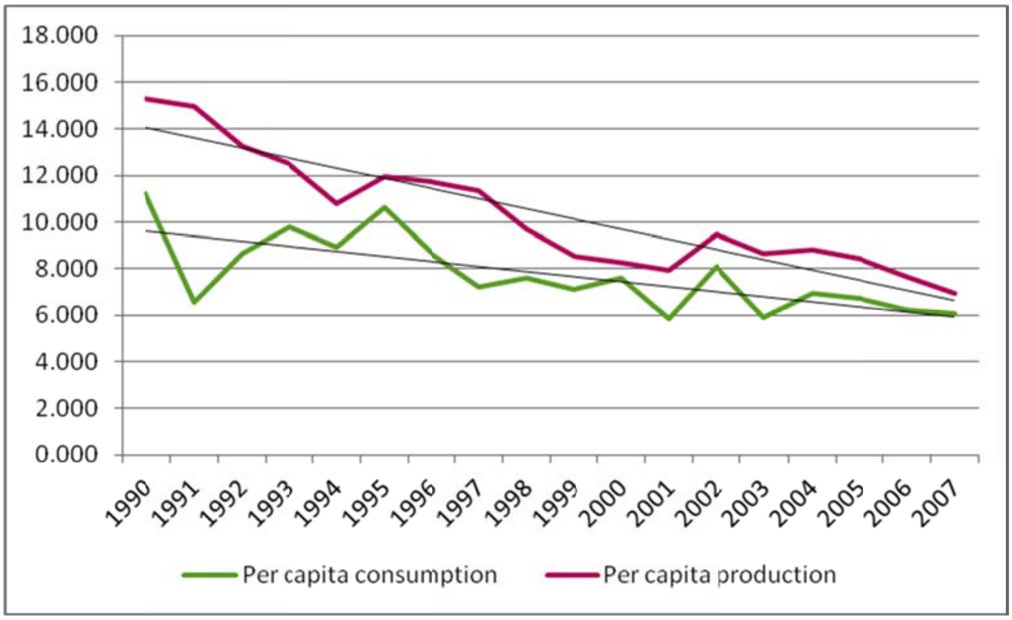
Syria



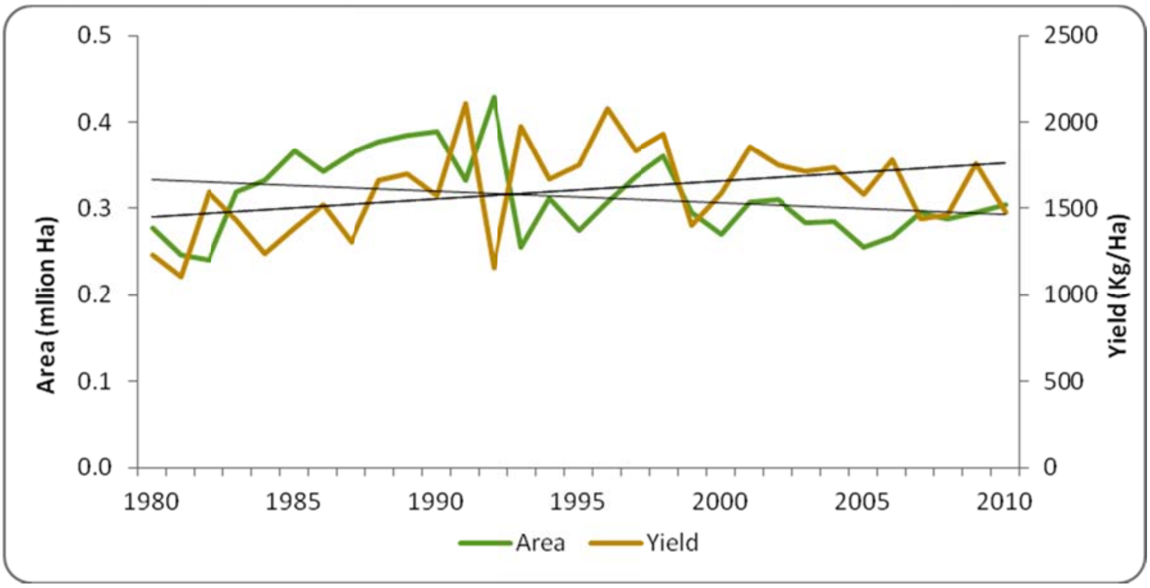
Tunisia



Turkey



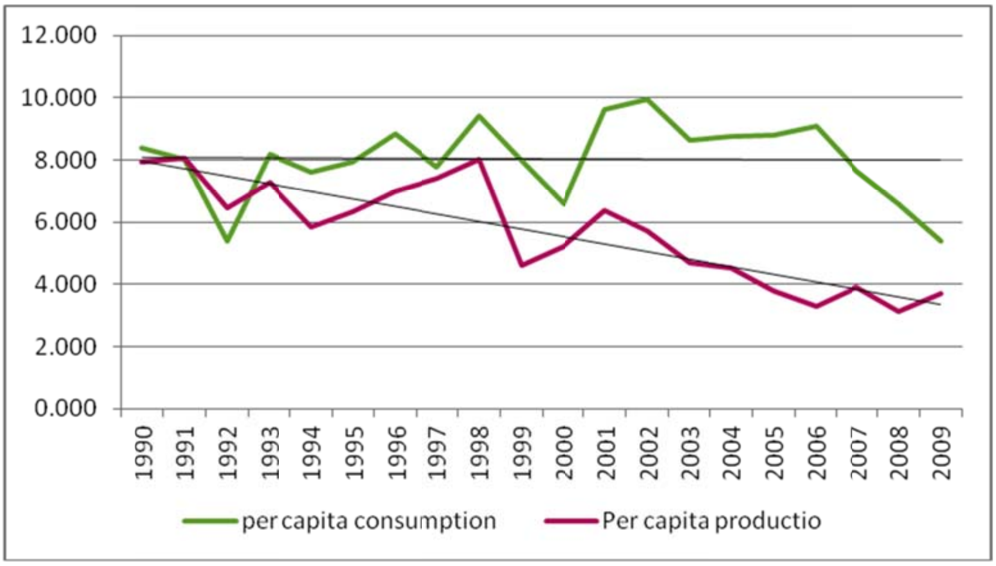
CWANA: FABA BEAN



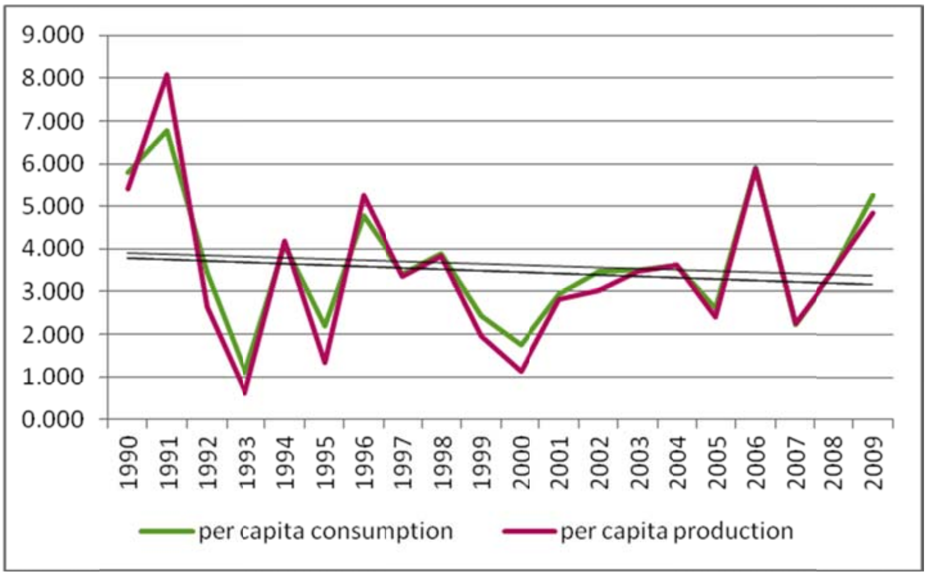
Area trend: t-value: -1.45 insignificant at 1% level; Yield trend: t-value: 2.1 significant at 5% level

- Area harvested with faba beans shows a decreasing trend overall, but it has risen from 250,000 Ha in 2005 to 300,000 Ha in 2007 after which it has remained stable.
- Yield also shows a declining trend but the year-to-year fluctuations have reduced largely after 2001.

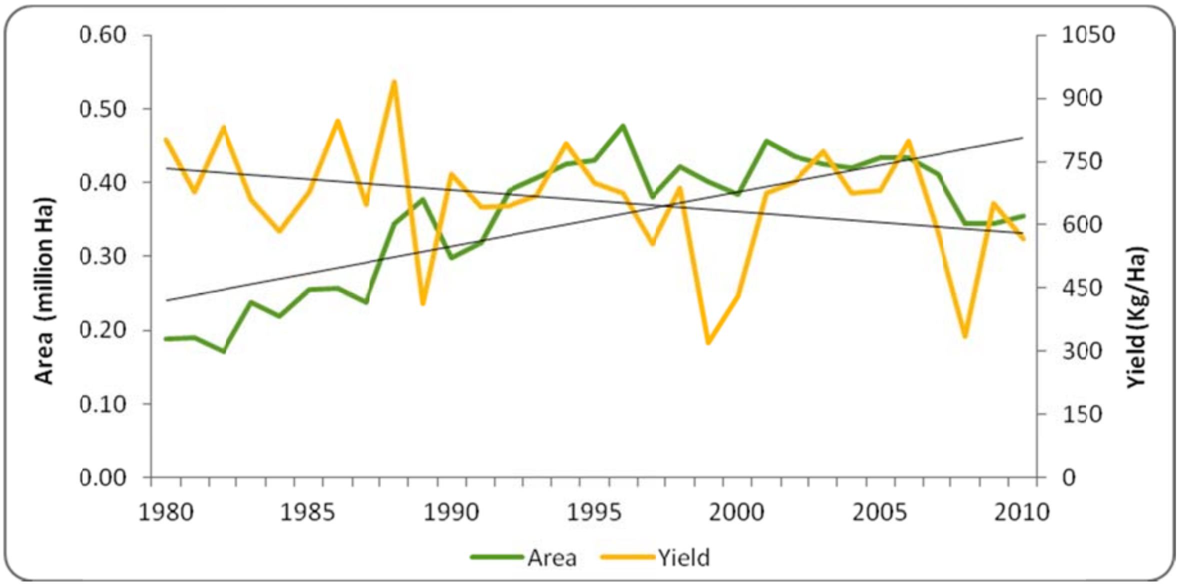
Egypt



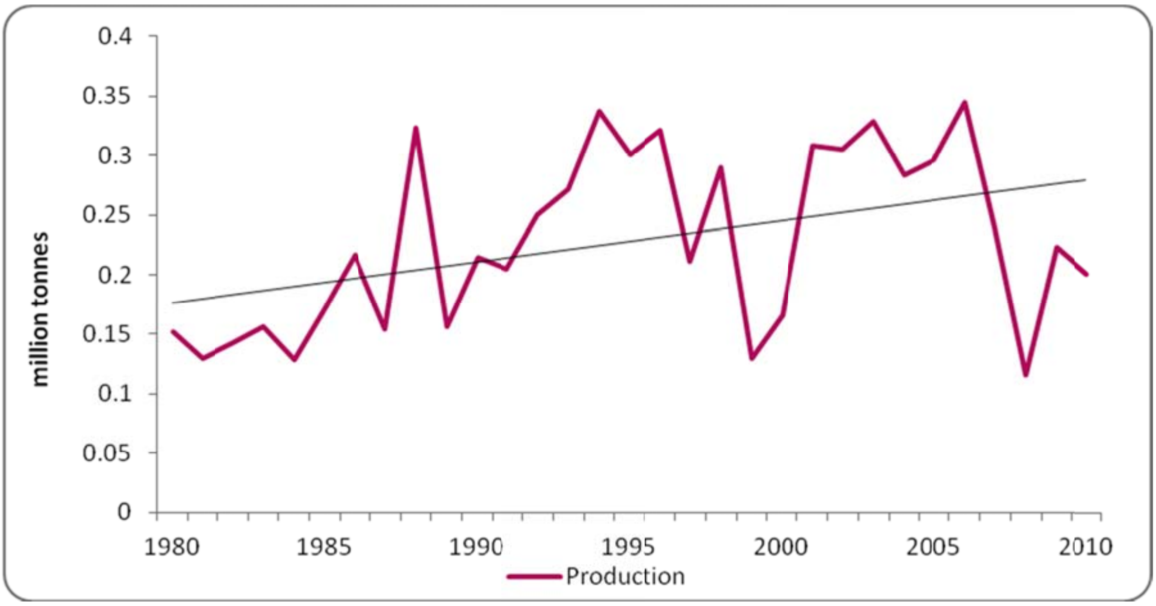
Morocco



CWANA: LENTILS

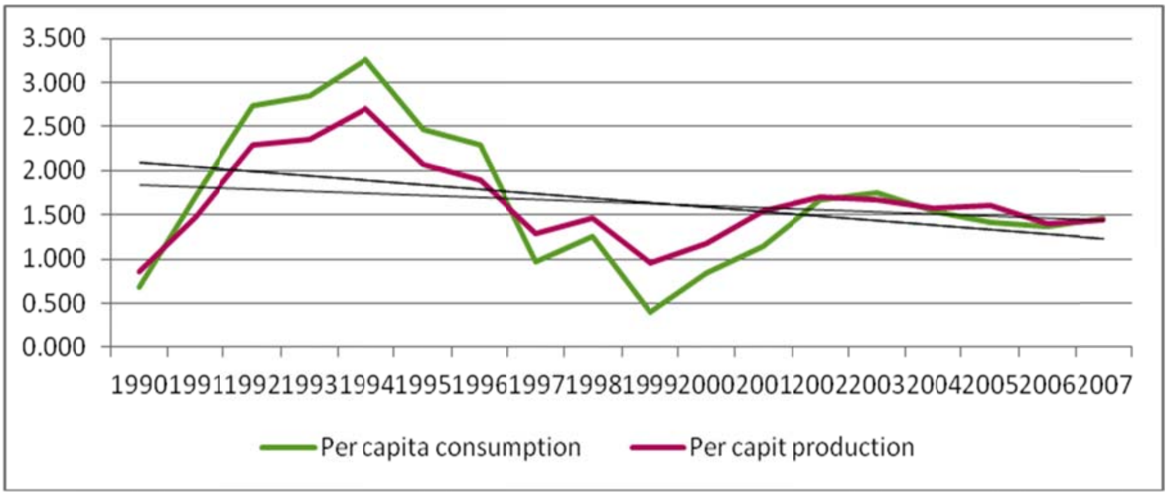


Area trend: t-value: 6 significant at 1% level; Yield trend: t-value: -1.87 insignificant at 1% level

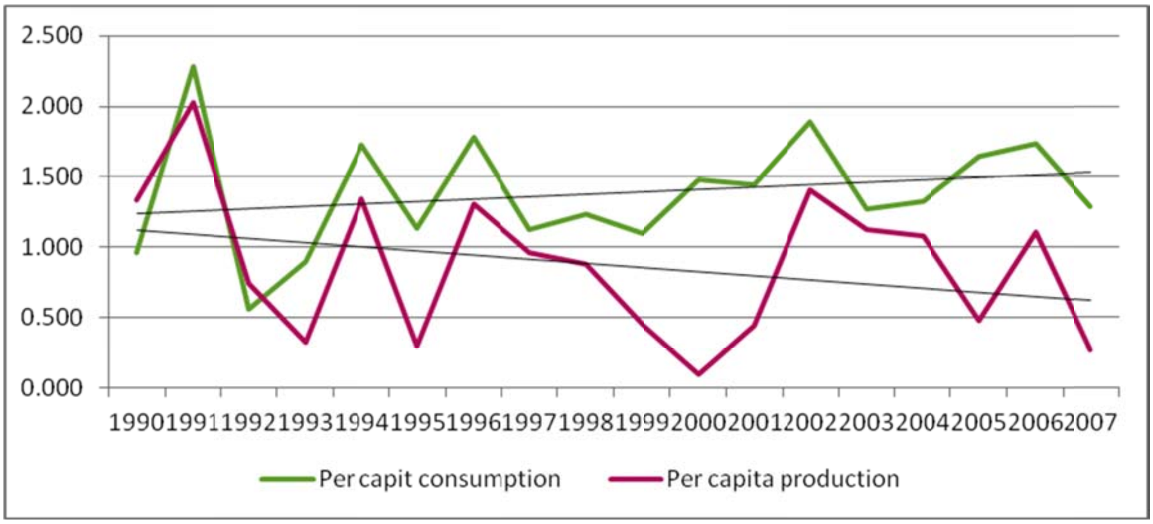


- Area harvested with Lentils shows an increasing trend between 1980 and 2010, with a growth rate of 0.98% in the last decade.
- Yield also shows an increasing trend, though at a lower rate than area. High variability in yields is leading to high variability in production.
- Both area and yields have declined sharply after 2006.
- The per capita consumption of lentils is fluctuating in the countries such as Morocco and declining marginally in Iran. However, in higher income countries such as Turkey the decline is sharper. The fluctuations in per capita consumption are a reflection of the fluctuations in supply (production and imports), which shows a serious food security concerns.

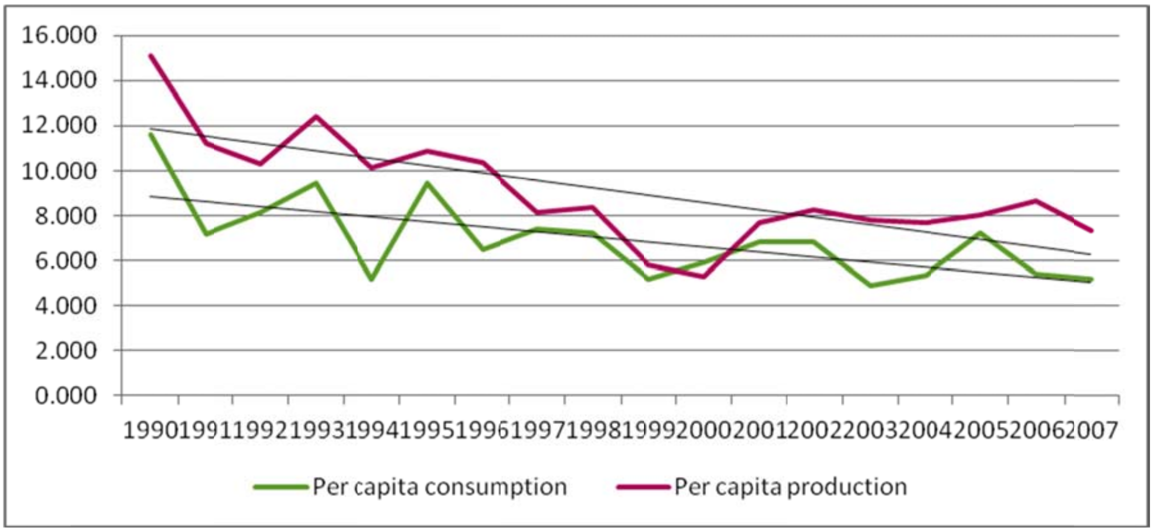
Iran



Morocco

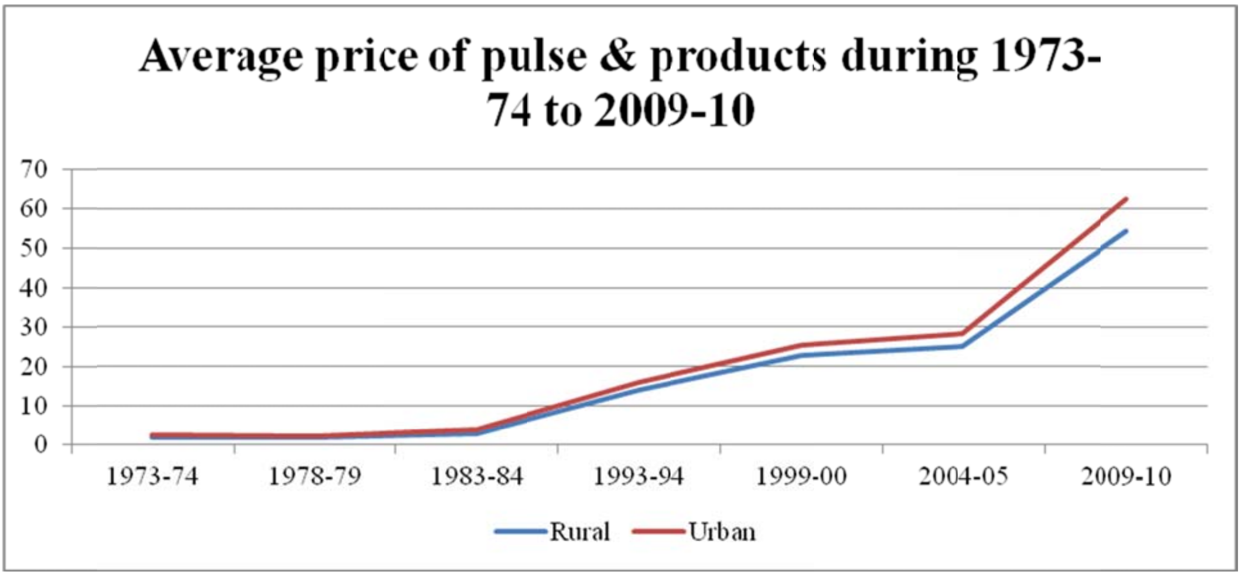


Turkey



Appendix 4. Consumption trends of grain legumes in India

India is the largest producer of pulses in the world but paradoxically also the largest importer. This is because domestic production could not keep pace with domestic demand for pulses. This is reflected in rising pulse prices, particularly since 1993-94 from Rs 14 / kg to Rs 54/kg in 2009-10 (Figure 1). Imports too rose sharply since 1999-2000 from 0.25 million t to 3.51 million t in 2010-11. Pulse imports included a basket of pulses like chickpea, pigeonpea, green gram and peas mainly from Myanmar, Canada, Australia, USA, Tanzania and other exporting countries. However, growth in total supply of pulses, domestic production plus imported quantity, could not keep pace with population growth. Thus, per capita availability of pulses in India declined over time.



Source: Compiled from various NSSO rounds

Figure 1. Average price of pulses & products during 1973-74 to 2009-10

In the situation of declining availability of pulses which resulted in rise in the price level of pulses, it would be pertinent to see what has happened to consumption of pulses & products for different income classes of rural and urban population in India as pulses are a vital source of protein and nutrition for all income classes and especially for the lower income group in India. In order to depict the decile wise pattern of consumption of pulses & products, we have analyzed the quinqennial rounds of NSSO (National Sample Survey Organization) data from 1973-74 to 2009-10 on 'Level & pattern of consumption expenditure' in India. The National Sample Survey Organization (NSSO) has been carrying out all-India household surveys on Consumer Expenditure and Employment & unemployment with a large sample usually once in every five years. Data are collected by the household interview method from a randomly selected sample of household spread over all States and Union Territories of India. NSS surveys not only provide average level of consumption but also distribution of households and persons over different ranges of consumption separately for rural and urban areas of each State and Union Territory of the country. Such distribution allows studies of inequality and poverty in different regions of the country, and is used in estimating the number of persons below poverty line. The first survey on consumer expenditure was conducted during October 1972-September 1973 and subsequently during July 1977-June 1978, December 1982-December 1983, July 1988- June 1989, July 2004-2005, and July 2009- June 2010. During July 2004-June 2005, for the central sample, data were collected from 1, 24,644 households spread over 7999 villages and 4602 urban blocks. In July 2009- June 2010 data were collected from 1, 00,855 households from all over India.

In order to make an income group wise comparison of consumption of pulses across NSSO rounds on **'Level and pattern of consumption of consumer expenditure'**, we have homogenized the income groups across various rounds. Since the number of income categories, which NSSO defines as decile, kept on varying across various rounds, for this analysis we have standardized it to categories or deciles. The first nine deciles in each round are kept unchanged. In case, the deciles extend beyond tenth decile, we have clubbed them and taken average consumption of pulses for that particular group and considered it as tenth decile. First decile in each round has been considered as **very poor category**. **Poor** category includes second and third deciles. **Lower middle** category includes fourth and fifth deciles. **Higher middle** category includes sixth and seventh deciles. **Rich** is represented by eighth and ninth declies and **Very rich** by tenth decile.

Table 1 and Figures 2 & 3 indicate that that consumption of pulses and products in the rural areas for the very poor and poor categories has risen from the level of 150 g/month and 250 g/month to 410 g/month and 510 g/month, respectively, during the periods 1973-74 to 2009-10. This is also true for the lower middle income group as their consumption level has gone up from 340 g/month to 570 g/month. The increase in consumption is despite the rising price of pulses. This could be due to the fact that even after price rise of pulses it remained the cheapest source of protein and nutrition for them. Very poor people appear not to be able to substitute pulses with other sources of protein such as milk, meat and eggs due to the higher prices of these food items in comparison with pulse and its products. This is endorsed by the fact that the cross price elasticity of demand for pulses with meat, fish and eggs is very low (0.12) indicating that there is no shift in consumption towards such commodities. However, for the higher middle, rich and very rich income group categories, we observe a totally different trend in the consumption of pulses with consumption declining for all categories and sharply for the very rich. The observed decline in per capita consumption among the higher expenditure groups could be due to three factors: a) the declining per capita availability of pulses; b) considerable increase in price levels; and c) their capacity to substitute pulses by other alternative protein rich food like milk, meat and eggs.

Empirical estimates of price and income elasticities support the deprivation in consumption hypothesis. Price elasticity of demand is high for the non-poor population living in rural (-0.76) and urban (-0.75) India. High levels of price elasticity of demand indicate that consumption levels will drastically fall with the rise in prices. As mentioned earlier, the price of pulses and pulse products as well as the general price level has gone up over time and rapidly during the last decade.

With the rise in prices, real income of the consumers erodes. Income erosion is likely to reduce consumption of commodities that have high income elasticity. It may be noted here that income elasticity of demand for pulses is also very high for both rural poor (0.91) and urban poor (0.79), and high for the non-poor population living in rural (0.53) and urban (0.51) India. Thus, the consumption level of pulses declined with rise in prices. Therefore, the decrease in per capita consumption of pulses is an indication of deprivation in consumption.

Table 1. Consumption of pulses and products (in kg) by income group in rural India

Years	Very poor	Poor	Lower Middle	Higher Middle	Rich	Very Rich
1973-74	0.15	0.25	0.34	0.69	0.94	2.56
1977-78	0.10	0.29	0.68	1.07	1.51	2.88
1983-84	0.10	0.83	1.20	1.33	1.63	2.88
1993-94	0.40	0.53	0.63	0.73	0.83	1.13
1999-00	0.38	0.55	0.67	0.77	0.90	1.19
2004-05	0.42	0.49	0.58	0.66	0.73	0.96
2009-10	0.41	0.51	0.57	0.63	0.74	0.91

Source: compiled from various NSSO rounds on 'Level and pattern of consumer expenditure'

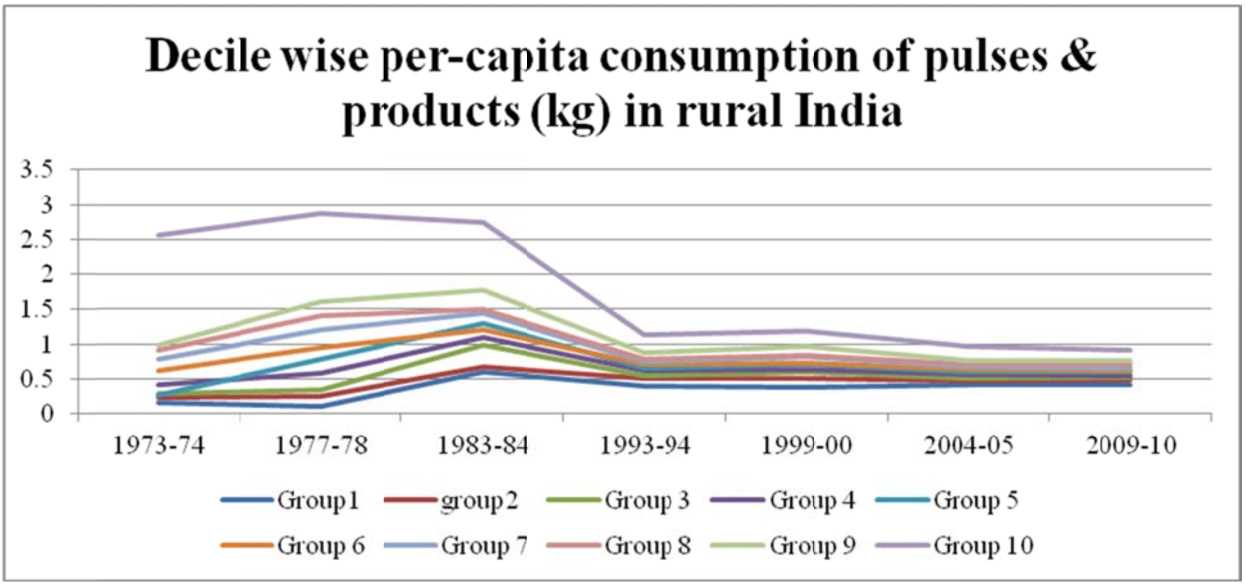


Figure 2: Per capita consumption (kg / month) of pulses & products by decile, 1973-74 to 2009-10

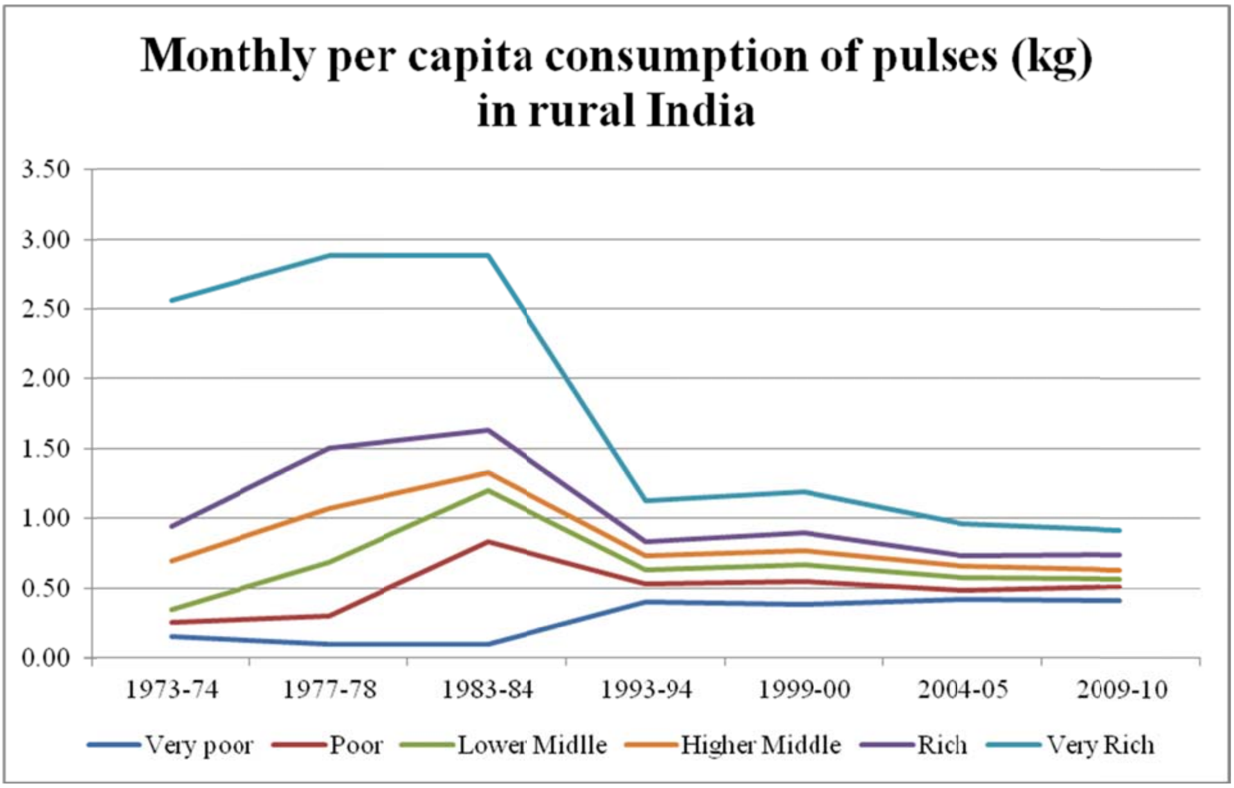


Figure 3: Per capita consumption (kg/ month) of pulse & products by income categories in rural India

A similar pattern is observed for urban India as shown in Table 2 and Figure 4. Consumption of pulses for the very poor, poor, and lower middle categories of urban population increased during the period of 1973-74 to 2009-10. It also increased for the other higher income group categories but there has been a general decline in their per capita consumption soon after the mid-1980s to 90s due to the substantial rise in the price of pulses during the period.

In view of the nutritional status and improvement in welfare of the poorer category of the population it is imperative to reduce the average level of pulses price. This can be made possible by measurably enhancing India's pulses productivity through research, technological innovations and development and effectively reducing per unit cost of production. Technological change through research is likely to reduce per unit cost of production and thereby prices. Very high levels of price elasticity for pulses among the poor population indicate that they will directly benefit if prices of pulses decline. Also, the higher income elasticity of pulses implies that India's economy grows and per capita incomes rise, future demand for pulses will grow with increase with economic growth and rise in in population.

Table 2. Consumption of pulses and products (in kg) per income group in urban India

Years	Very Poor	Poor	Lower Middle	Higher Middle	Rich	Very Rich
1973-74	0.10	0.18	0.22	0.42	0.73	1.39
1977-78	0.10	0.31	0.65	0.96	1.34	1.95
1983-84	0.16	0.40	0.90	1.02	1.40	1.87
1993-94	0.42	0.58	0.72	0.85	0.98	1.21
1999-00	0.49	0.62	0.83	0.99	1.05	1.31
2004-05	0.43	0.56	0.68	0.77	0.87	1.05
2009-10	0.46	0.57	0.69	0.81	0.91	0.89

Source: compiled from various NSSO rounds on 'Level and pattern of consumer expenditure'

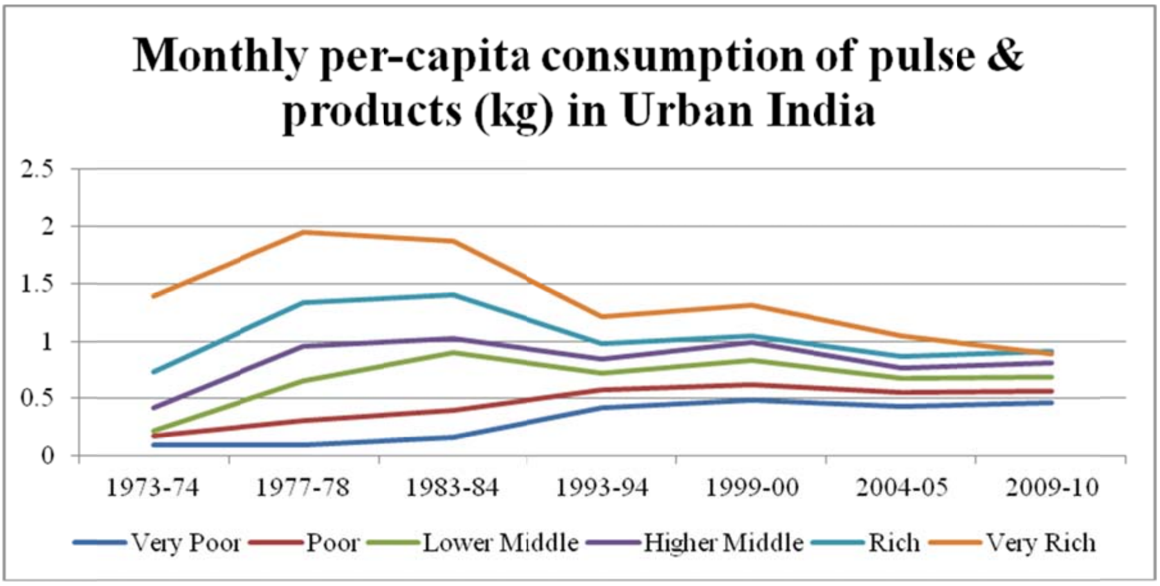


Figure 4. Monthly per capita consumption (kg) of pulse and products in urban India

Appendix 5. Relative importance and yield losses (%) due to abiotic and biotic stresses in grain legumes in different regions

Crop/constraint	Asia	ESA	WCA	CWANA	LA
Chickpea					
Abiotic:	34.0	30.0	-	40.0	-
Drought stress	25.0	25.0		25.0	
Heat/cold tolerance	9.0	5.0		15.0	
Diseases:	24.0	27.0	-	35.0	-
Fusarium wilt/root rot*	16.0	15.0		15.0	
Ascochyta/Botrytis*	8.0	12.0		20.0	
Insect pests:	26.0	20.0	-	22.0	-
Helicoverpa*	18.0	15.0		12.0	
Leaf miner/aphids/cut worm	8.0	5.0		10.0	
Soil Fertility/BNF:	16.0	23.0	-	3.0	-
Common bean					
Abiotic:	20.0	18.0	34.0	-	31.0
Drought/heat stress	20.0	18.0	34.0		31.0
Diseases:	30.0	23.0	23.0	-	21.0
Mosaics - Viruses	15.0	4.0	4.0		8.0
Angular leaf spot/Anthracnose	7.0	10.0	10.0		11.0
Root rots	8.0	9.0	9.0		2.0
Insect pests:	25.0	11.0	14.0	-	11.0
Bean fly/Apion	15.0	4.0	2.0		2.0
Leaf hoppers/aphids	10.0	7.0	12.0		9.0
Weeds		6.0	5.0		6.0
Soil Fertility/BNF:	25.0	42.0	24.0		31.0
Cowpea					
Abiotic:	20.0	20.0	22.0	-	20.0
Drought/heat stress	20.0	20.0	22.0		20.0
Diseases:	32.0	25.0	26.0	-	31.0
Mosaics - Viruses	15.0	10.0	10.0		15.0
Bacterium blight	10.0	8.0	8.0		10.0
Rust	7.0	7.0	8.0		6.0
Insect pests:	23.0	25.0	32.0	-	29.0
Flower thrips	5.0	5.0	7.0		8.0
Pod bugs	8.0	5.0	8.0		7.0
Maruca	7.0	10.0	14.0		10.0
Aphids	3.0	5.0	3.0		4.0
Weeds		5.0	7.0		
Soil Fertility/BNF:	25.0	25.0	13.0	-	20.0
Faba bean					
Abiotic:	30.0	14.0	-	15.0	-
Drought stress	10.0	7.0		10.0	
Heat/cold stress	10.0	7.0		5.0	
Salinity	10.0				
Diseases:	30.0	36.0	-	30.0	-
Ascochyta blight*	20.0	2.0		12.0	
Choclate spot/rust	10.0	34.0		20.0	
Viruses	-	-	-	8.0	-
Insect pests: Aphids	15.0	15.0	-	15.0	-
Parasitic weeds:	-	30.0	-	30.0	
Soil Fertility/BNF:	25.0	10.0	-	10.0	

Crop/constraint	Asia	ESA	WCA	CWANA	LA
Groundnut					
Abiotic:	23.0	17.0	17.0	-	-
Drought/heat stress	23.0	17.0	17.0		
Diseases:	36.0	50.0	50.0	-	-
Aflatoxin	10.0	12.0	15.0		
Foliar diseases	15.0	20.0	20.0		
Rosette/bud necrosis*	11.0	18.0	15.0		
Insect pests:	18.0	18.0	15.0	-	-
Defoliators/leaf miners	10.0	8.0	5.0		
White grubs/termites	8.0	10.0	10.0		
Soil Fertility/BNF:	23.0	15.0	18.0	-	-
Lentil					
Abiotic:	28.0	28.0	-	28.0	-
Drought stress	15.0	20.0		15.0	
Heat stress/low temperature	13.0	8.0		13.0	
Diseases	40.0	27.0	-	22.0	-
Wilt/root rots*	20.0	12.0		10.0	
Rust	10.0	8.0		7.0	
Ascochyta/Stemphylium/Botrytis	10.0	7.0		5.0	
Insect pests:	12.0	15.0	-	20.0	-
Sitona weevil	5.0	10.0		15.0	
Aphids	7.0	5.0		5.0	
Parasitic weeds:	0.0	0.0	-	10.0	
Soil Fertility/BNF:	20.0	30.0	-	20.0	
Pigeonpea					
Abiotic:	15.0	20.0	-	-	-
Drought stress	15.0	20.0			
Diseases:	32.0	30.0	-	-	-
Fusarium wilt*	15.0	20.0			
Sterility mosaic*	9.0	0.0			
Phytophthora*	8.0	10.0			
Insect pests:	33.0	35.0	-	-	-
Helicoverpa/Maruca	20.0	20.0			
Pod fly	13.0	15.0			
Soil Fertility/BNF:	20.0	20.0	-	-	-
Soybean					
Abiotic:	23.0	20.0	20.0	-	23.0
Drought/heat stress	23.0	20.0	20.0		23.0
Diseases:	40.0	35.0	40.0	-	37.0
Bacterial blight*	10.0	5.0	5.0		7.0
Mosaic virus*	10.0	10.0	10.0		10.0
Soybean rust	15.0	15.0	10.0		15.0
Frogeye leaf rust	5.0	5.0	15.0		5.0
Insect pests:	20.0	15.0	25.0	-	20.0
Pod sucking bugs	5.0	5.0	5.0		5.0
Bean fly	8.0	5.0	8.0		10.0
Leaf defoliators	7.0	5.0	12.0		5.0
Soil Fertility/BNF:	17.0	30.0	15.0	-	20.0

*Have the potential to cause complete loss during outbreaks, which are quite frequent in the tropics. Weeds and bruchids cause 10–15% loss across crops/regions.

Notes: Based on inputs received on percentage yield loss in different regions due to various biotic and abiotic production constraints, and the published information on various crops / constraints. Total yield loss due to various constraints in a region has been computed as a percentage of total loss.

Appendix 6. Outlook of grain legumes – IMPACT model projections

The IMPACT model developed by IFPRI (Rosegrant MW, Msangi, Ringler C, Sulser TB, Zhiu T and Cline SA. 2008. International Model for Policy Analysis of Agricultural Commodities and Trade: Model description. Washington DC, USA: International Food Policy Research Institute, 49 pp.) was used to estimate the future outlook in terms of likely changes in their cropped area, production and consumption in the medium and long term.

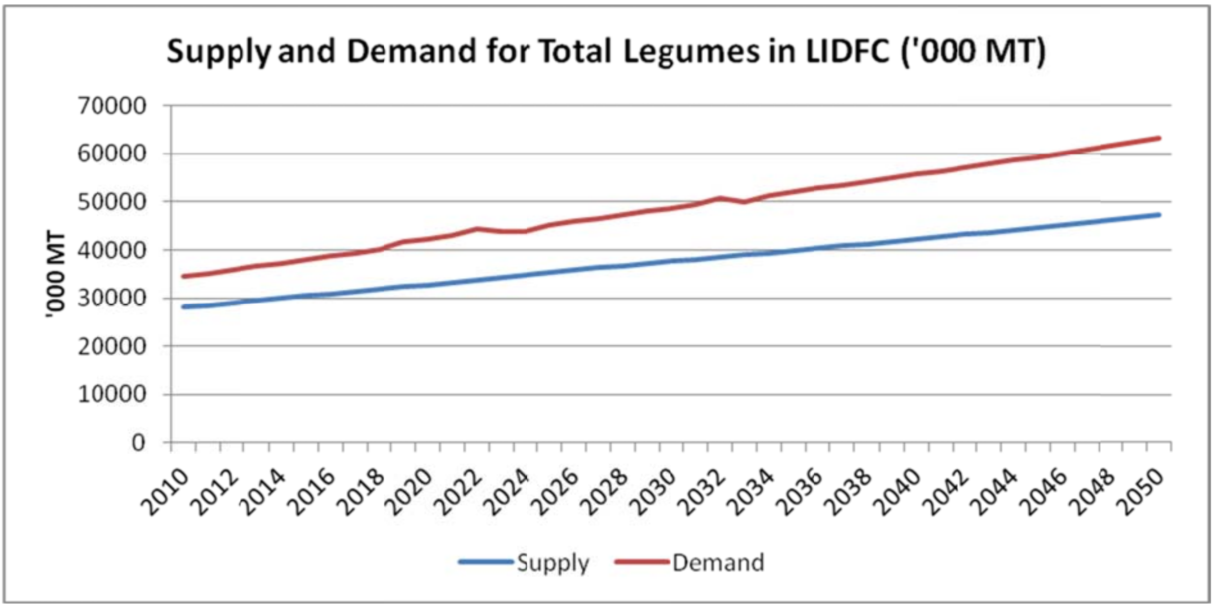
The IMPACT model simulates the behavior of a competitive world market for agricultural commodities. It is specified as a set of countries or regional sub-models, within each of which yearly supply, demand and market clearing prices for agricultural commodities are generated. The country and regional sub-models are linked through trade in a non-spatial way, such that the effects on country-level production, consumption and commodity prices are captured through net trade flows in global agricultural markets. Demand is a function of prices, income and population growth. Growth in production in each country is determined by farm harvest prices and the rate of productivity growth. World agricultural commodity prices are determined annually at levels that clear international markets. The model uses a system of linear and nonlinear equations to approximate the underlying production and demand relationships, and is parameterized with country-level elasticities of supply and demand (Rosegrant et al. 2008).

In the IMPACT-WATER model, there are several drivers that underlie the dynamics of agricultural production and consumption growth over time. The primary macroeconomic drivers are income growth and population growth, which jointly determine the dynamics of per capita income for each country, which is a major determinant of commodity consumption behavior. The principal drivers for agricultural growth are those which determine the expansion or contraction of available land for agriculture, and the productivity growth of irrigated and rainfed crops, which reflects the improvements in agricultural technology and growth potential that can be realized over time. Other important policy relevant variables to consider are those which affect market prices of the commodities directly, such as marketing margins of the crops within their respective regions, as well as the degree of subsidy/protection that is given to either consumers or producers.

The current version of the IMPACT is calibrated to generate projections for pulses as a group and groundnut, chickpea, pigeonpea and, soybean individually. The other grain legume crops like faba beans, lentils, peas and cowpeas have not been included separately in the model as yet.

Supply and demand projections of groundnut, chickpea, pigeonpea and soybeans

The aggregate supply and demand projections for four grain legumes (groundnuts, chickpea, pigeonpea and soybeans) in the LIFDC (Low Income Food Deficit Countries) follow an increasing trend. However, the aggregate supply of grain legumes in the LIFDC countries is lower than the demand. Furthermore, the supply-demand gaps for these countries will widen in the long term. To ensure food and nutritional security in these countries, the supply side constraints need to be addressed through development and diffusion of appropriate technologies for different production environments in the LIFDC countries.



Chickpea

Central and West Asia and Northern Africa (CWANA

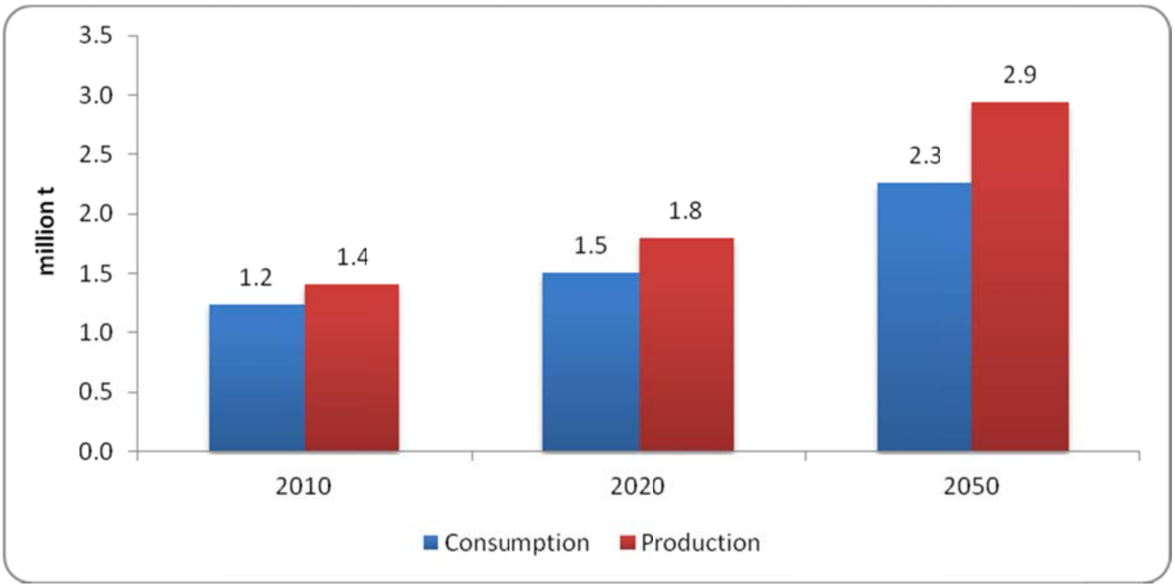


Figure 1: Production and consumption of chickpea in CWANA

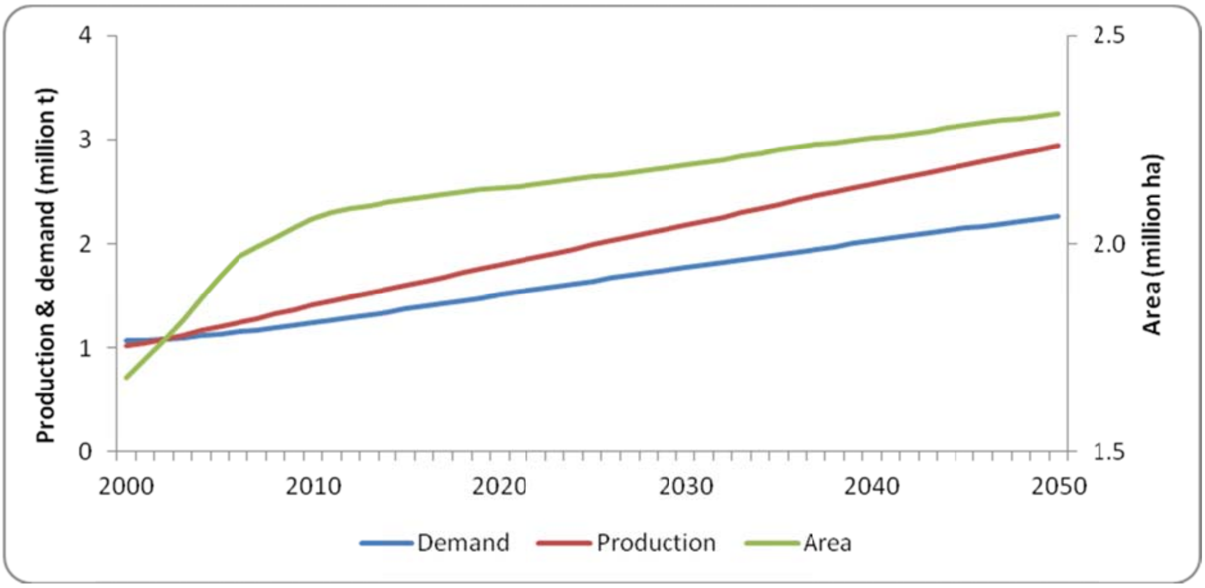


Figure 2: Area, demand and supply projections for chickpea in CWANA

- Production of chickpea in CWANA is estimated to exceed domestic demand between 2000 and 2050 by 30%.
- The surplus production of chickpea in the future is mainly due to increase in yield and to some extent, area expansion.

Eastern and Southern Africa (ESA)

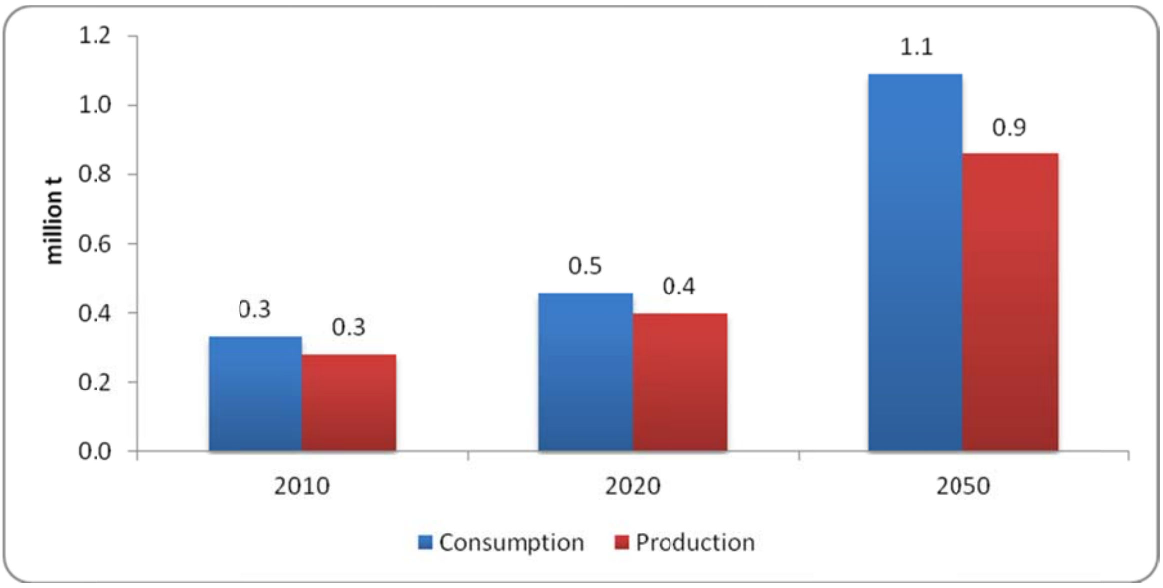


Figure 3: Production and consumption of chickpea in ESA

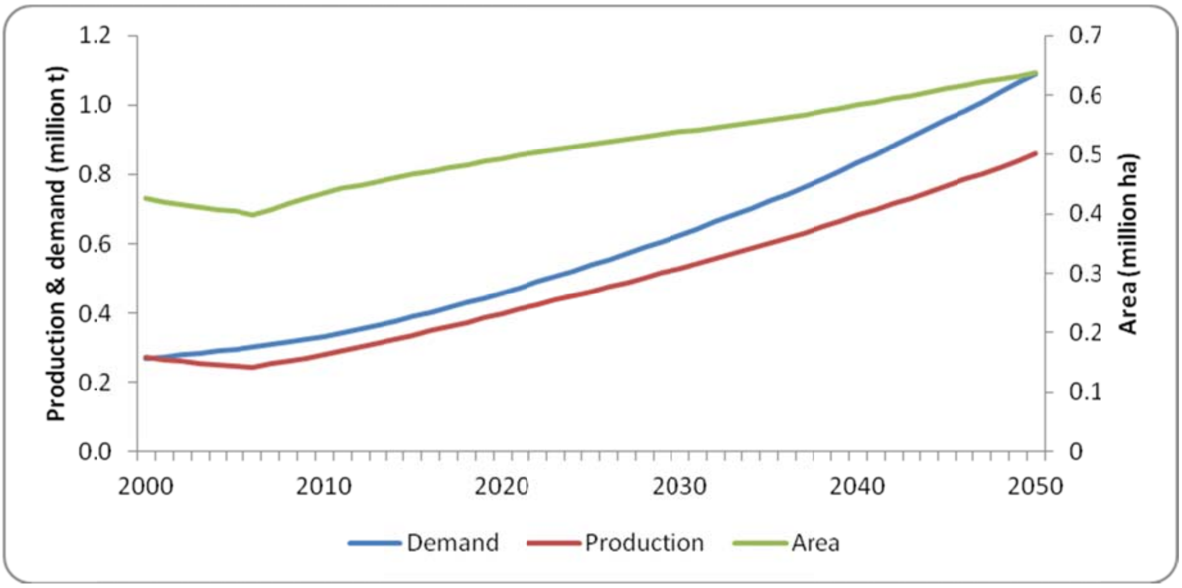


Figure 4: Area, demand and supply projections for chickpea in ESA

- Area and yield of chickpea in ESA are projected to increase between 2000 and 2050.
- Yield is estimated to grow at the rate of 1.7% year between 2000 and 2050 while area grows much slower.
- Production thus falls below demand and this shortfall grows larger and larger over the years

South and South East Asia (SSEA)

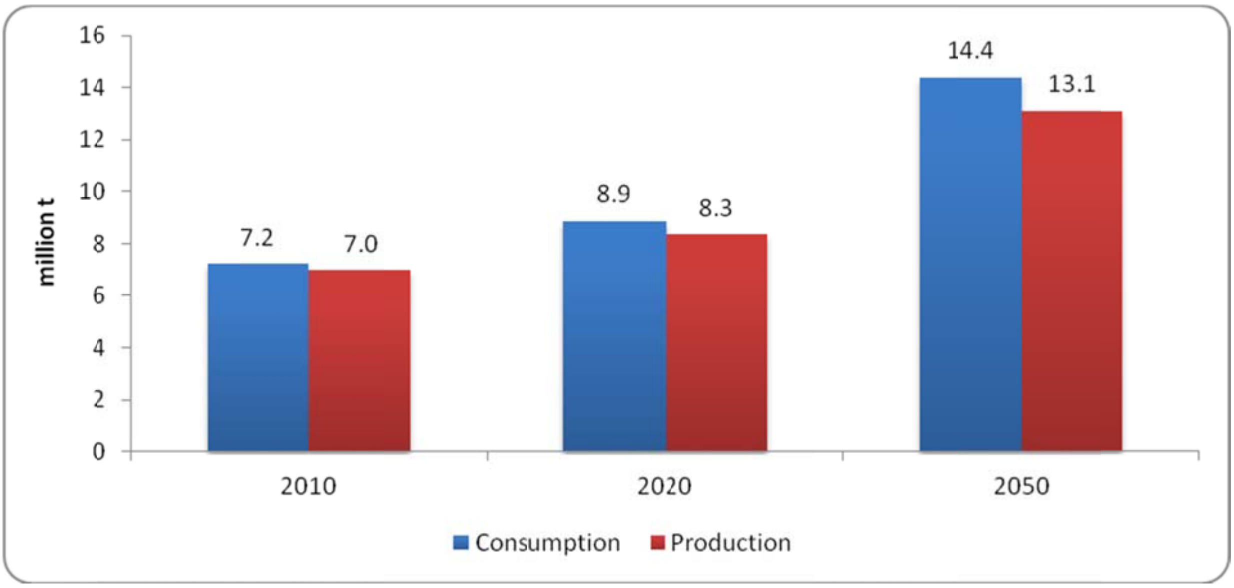


Figure 5: Production and consumption of chickpea in SSEA

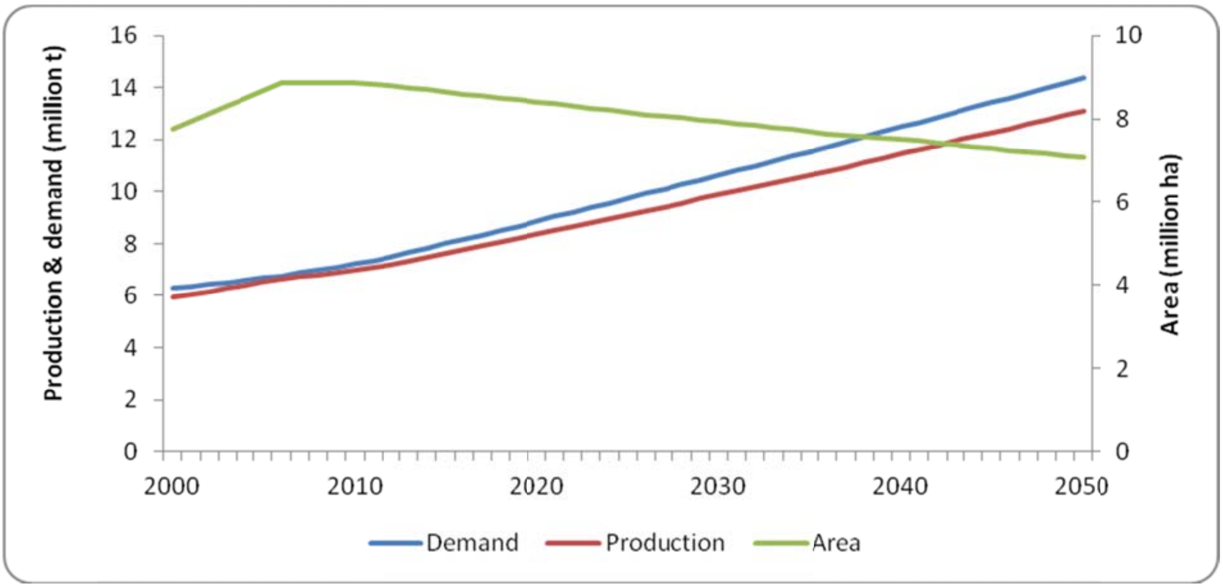


Figure 6: Area, demand and supply projections for chickpea in SSEA

- Demand grows much faster than production beyond 2010 and by 2050, production is about 8% less than that of demand.
- Yield grows at the rate of 2% year
- Area under chickpea is projected to fall in SSEA. Although yield increases compensate for much of the production forgone due to area contraction, it does not fully satisfy demand, leading to a deficit of chickpea production intensifying with time.

Groundnut

Eastern and Southern Africa (ESA)

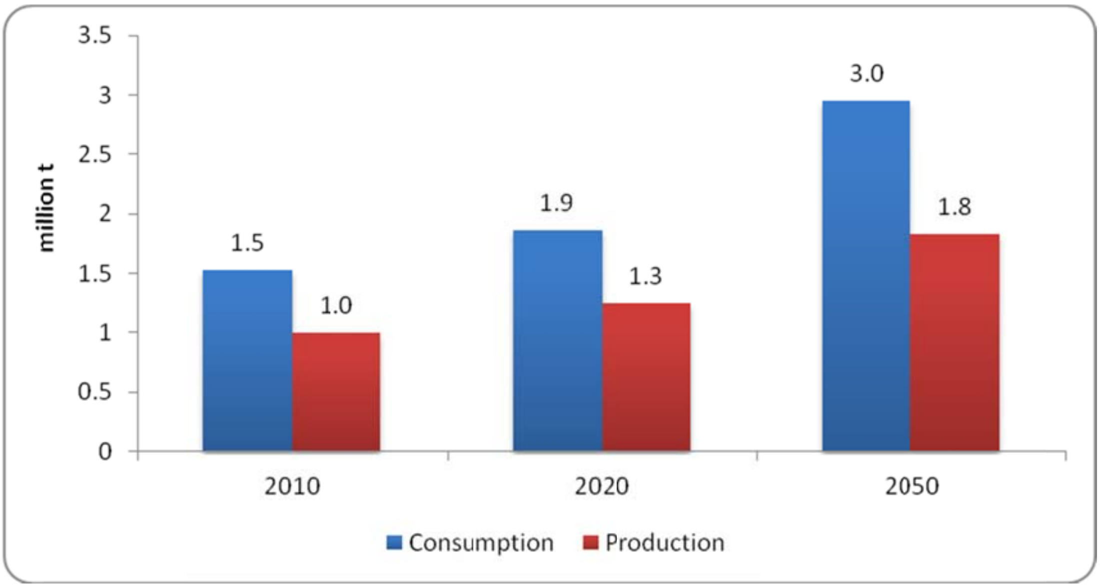


Figure 7: Production and consumption of groundnut in ESA

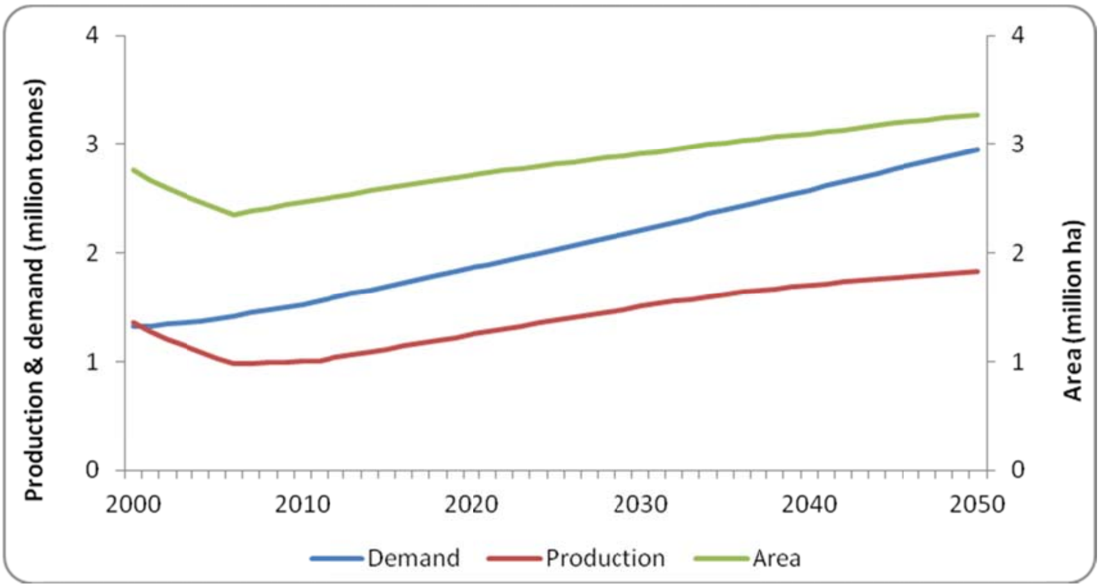


Figure 8: Area, demand and supply projections for groundnut in ESA

- Groundnut area and production continue along a positive trend
- From 2000 onwards, productions falls short of demand and this gap widens over the years which is evident from the Figure 7 and 8.
- Yield trends are however stagnant over the fifty year period
- Therefore by 2050, demand falls short of production by almost 40%

South and South East Asia (SSEA)

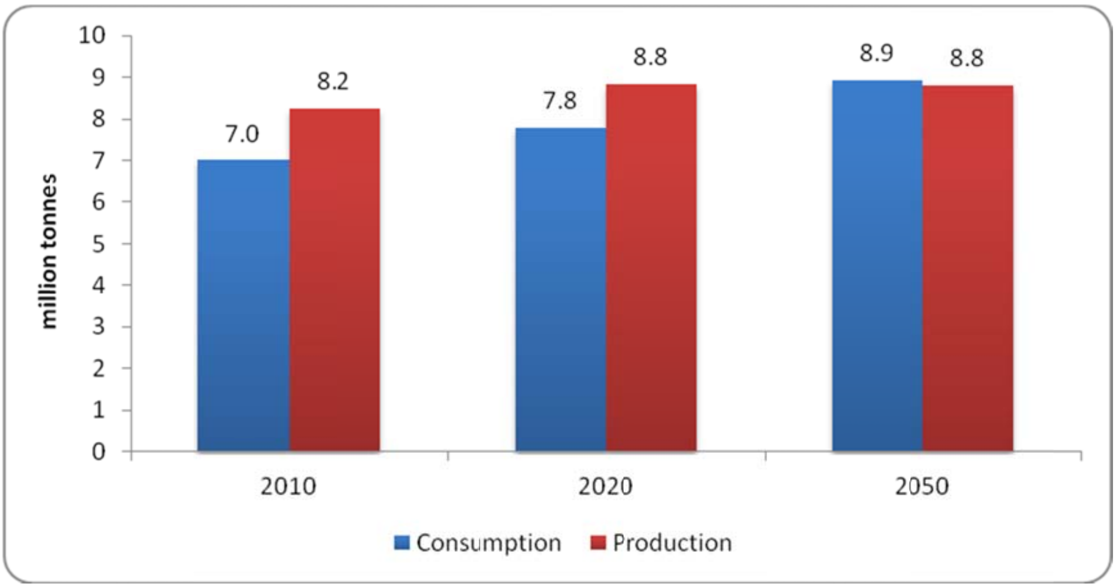


Figure 9: Production and consumption of groundnut in SSEA

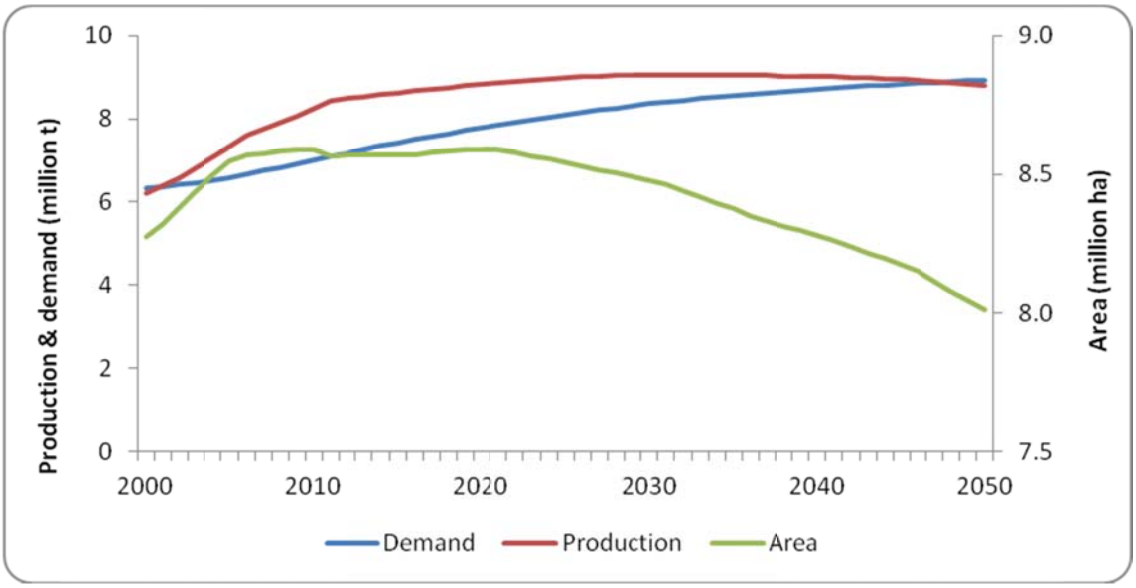


Figure 10: Area, demand and supply projections for groundnut in SSEA

- Demand for groundnut in SSEA follows a constant upward trend.
- Production and area trends decline overall after an initial increase in the years 2000-10. From 2010 onwards, production begins to stagnate and SSEA produces just enough groundnuts to satisfy demand by 2050.

Western and Central Africa (WCA)

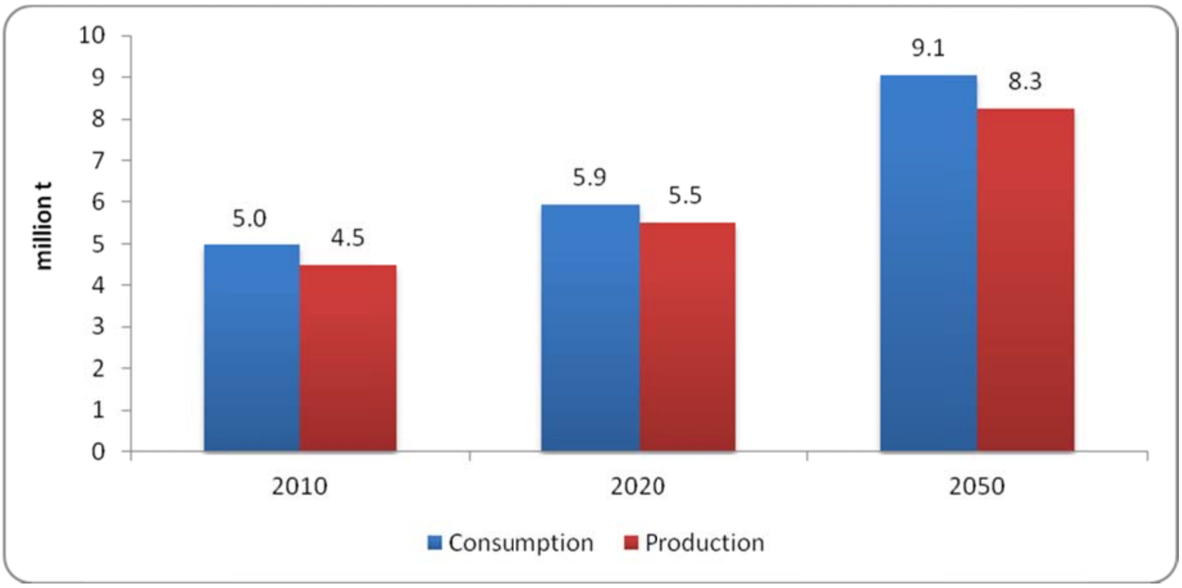


Figure 11: Production and consumption of groundnut in WCA

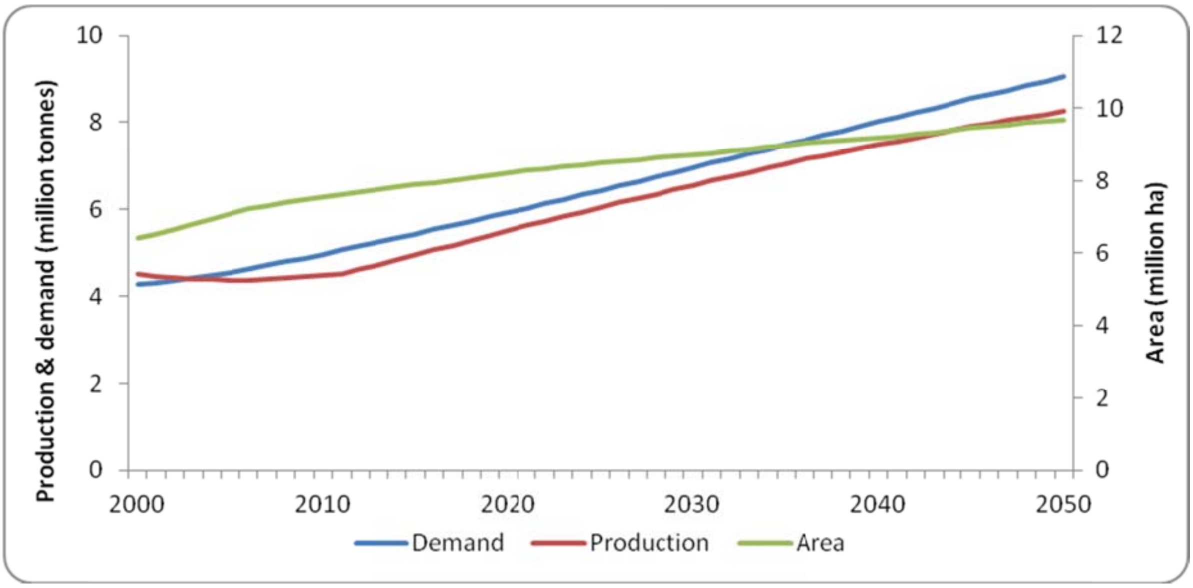


Figure 12: Area, demand and supply projections for groundnut in WCA

- The rate of growth of area and yield is below 1% annually
- By 2050, demand falls short of production by 8.8%

Pigeonpea

Eastern and Southern Africa (ESA)

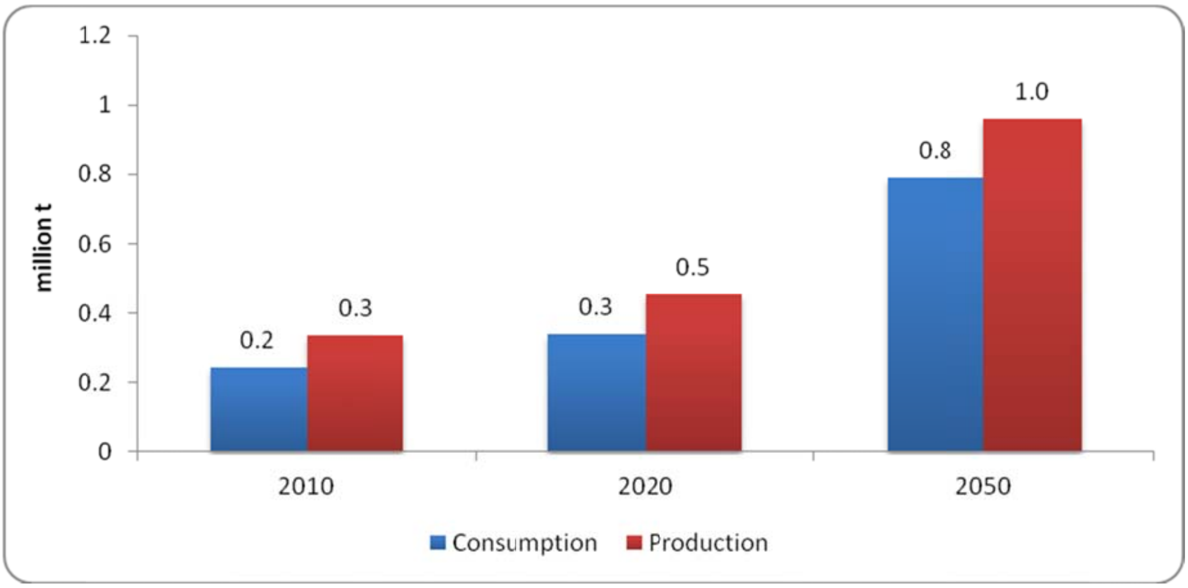


Figure 13: Production and consumption of pigeonpea in ESA

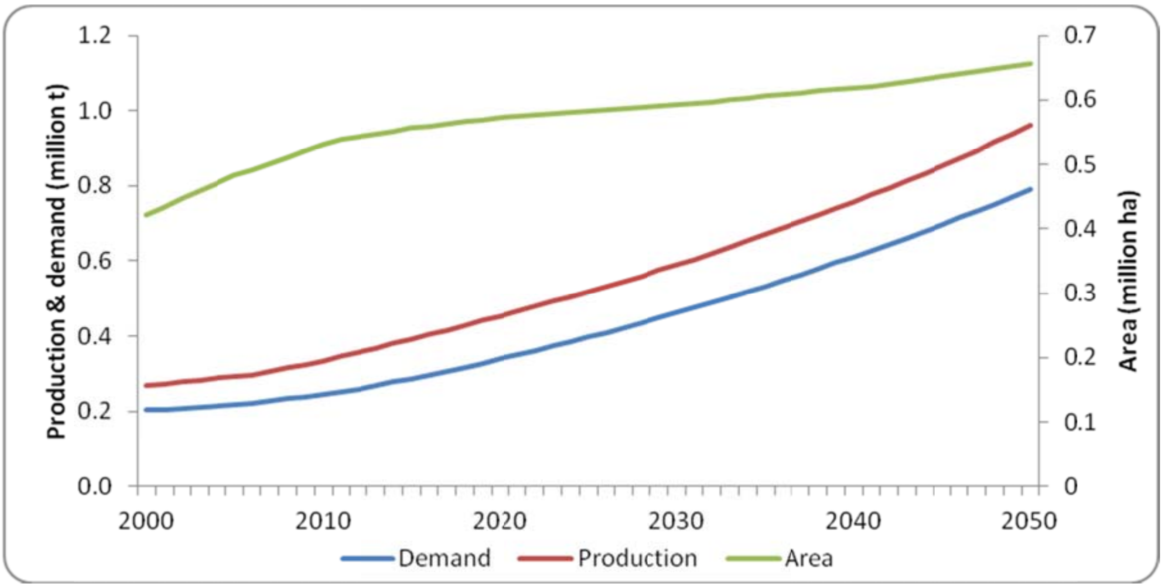


Figure 14: Area, demand and supply projections for pigeonpea in ESA

- There will be a surplus of production of pigeonpea in ESA 2000 through 2050. Yield improvements are estimated to drive this production surplus
- Area under pigeonpea stagnates after increasing at a slow rate after 2015.

South and South East Asia (SSEA)

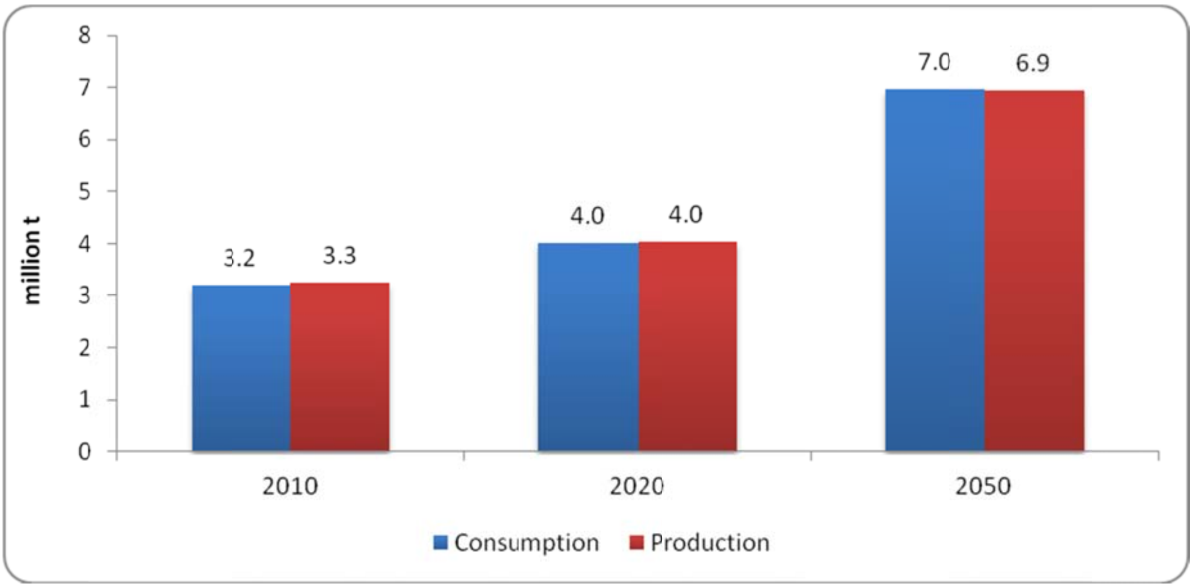


Figure 15: Production and consumption of pigeonpea in SSEA

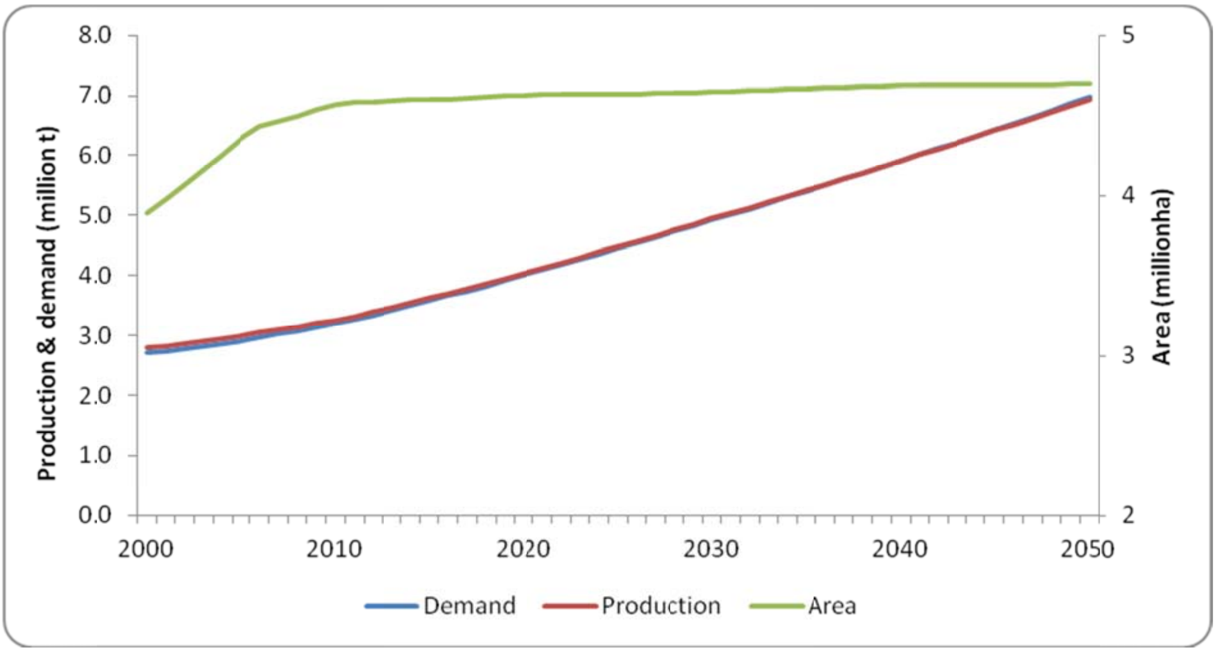


Figure 16: Area, demand and supply projections for pigeonpea in SSEA

- Pigeonpea production just equals demand from 2000 to 2050 in SSEA.
- Production increases are mainly contributed by yield gains since area under pigeonpea stagnates beyond 2008 in SSEA.
- Aggregate production and consumption more than doubles in 2050 compared to the level in 2000 which was 3 million tonnes.

Soybean

Eastern and Southern Africa (ESA)

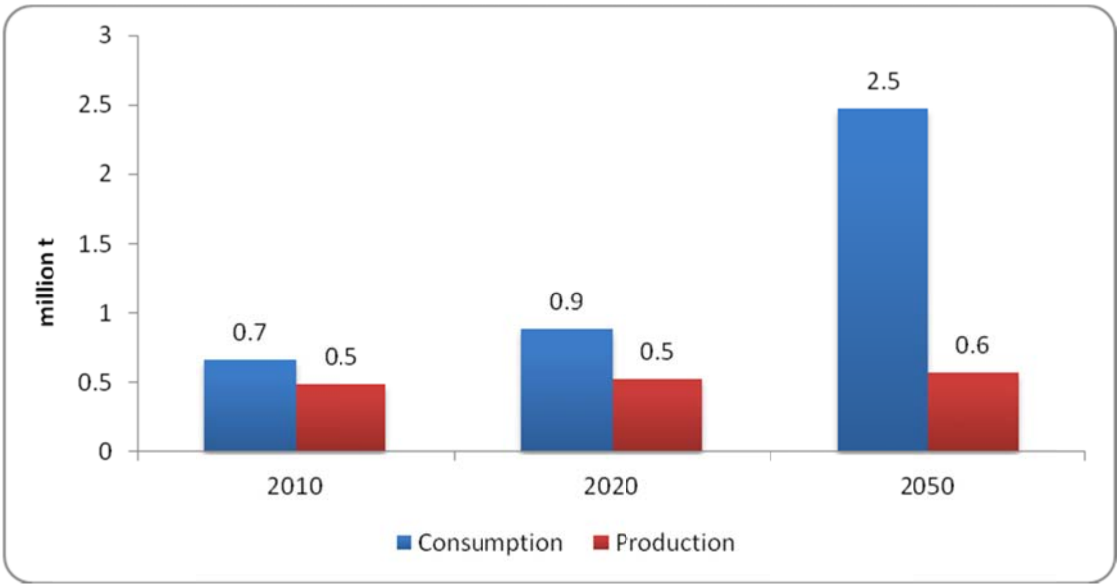


Figure 17: Production and consumption of soybean in ESA

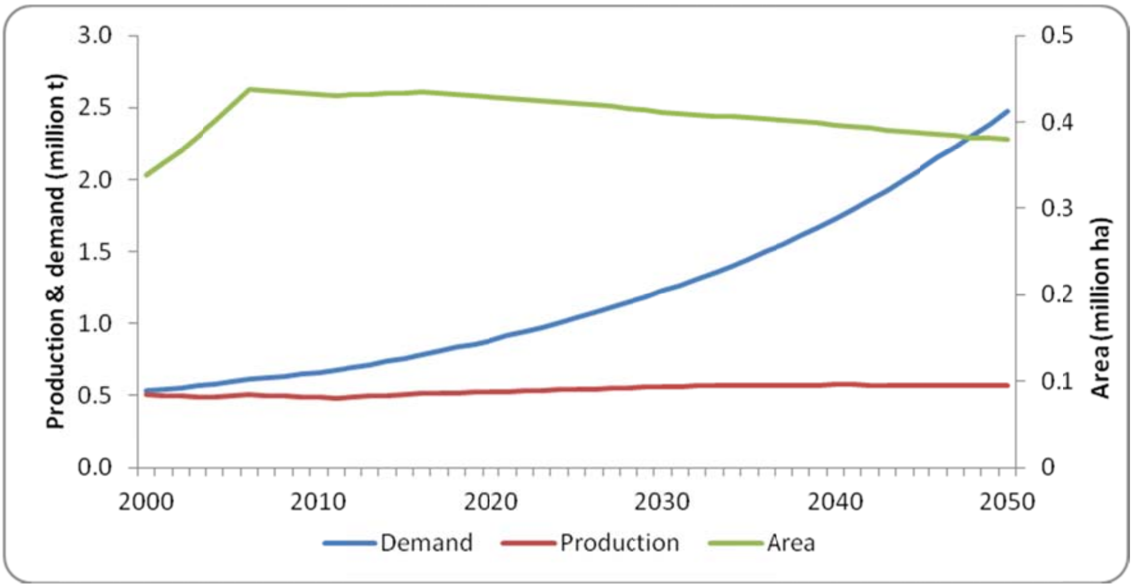


Figure 18: Area, demand and supply projections for soybean in ESA

- Almost a five-fold increase in soybean demand is estimated in ESA in 2050 compared to its level in 2000 which is not matched by domestic production
- Area under soybean in ESA decreases during the period between 2000 and 2050
- Yield levels are estimated to drop from 1500 to 1130 kg/ha between 2000 and 2010.
- There is a gap of 77% between production and demand by 2050.

Western and Central Africa (WCA)

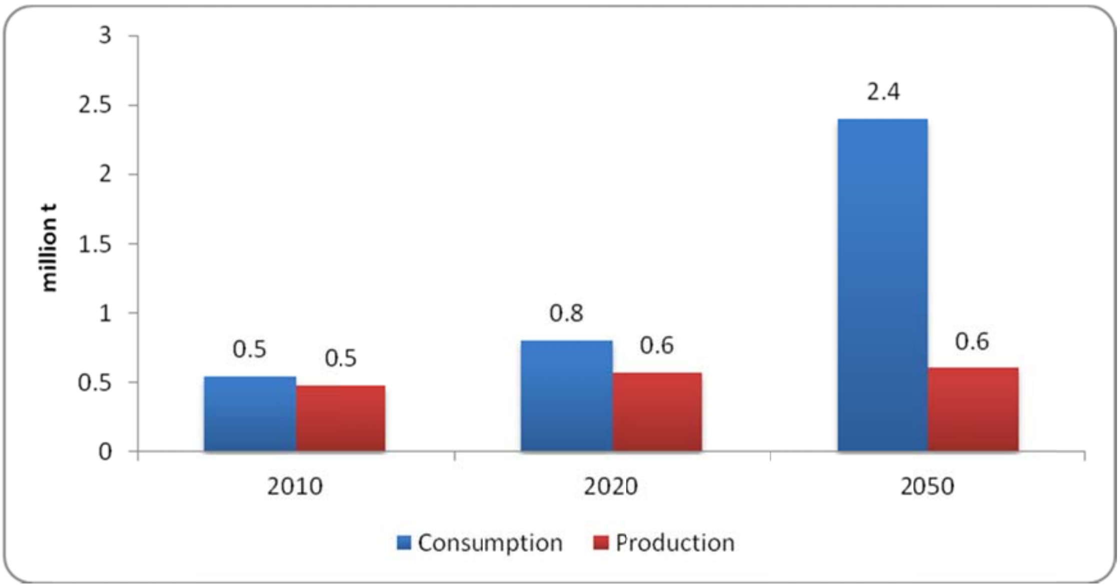


Figure 17: Production and consumption of soybean in WCA

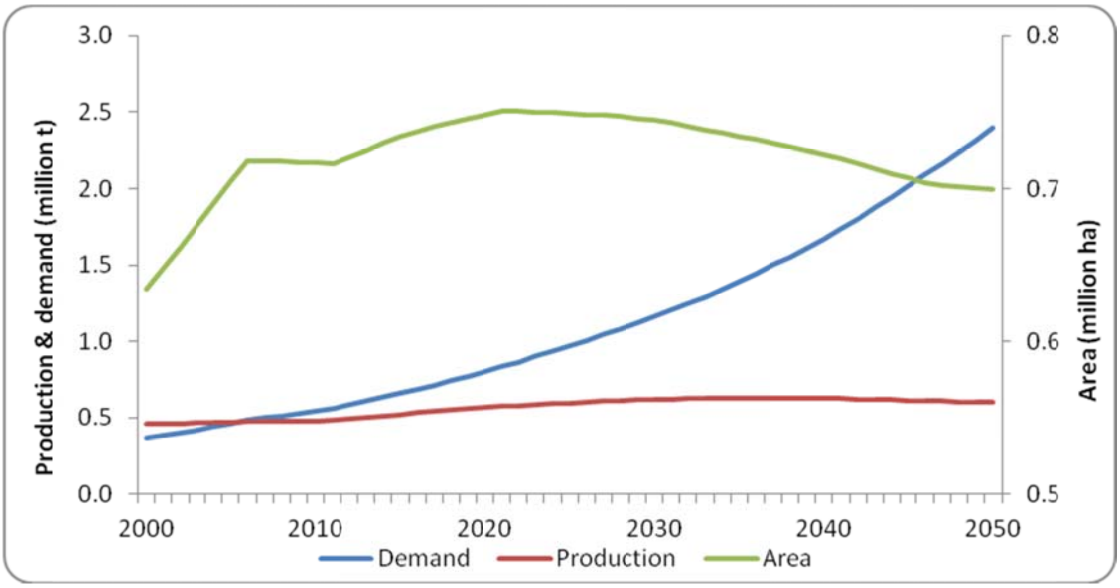


Figure 18: Area, demand and supply projections for soybean in WCA

- While domestic production and area under soybean continue to stagnate, demand for soybean is projected to increase exponentially.
- The high growth rate of population could be the main driver of demand in sub-Saharan Africa.

Reference

Rosegrant MW, Msangi, Ringler C, Sulser TB, Zhiu T and Cline SA. 2008. International Model for Policy Analysis of Agricultural Commodities and Trade: Model description. Washington DC, USA: International Food Policy Research Institute. 49pp.

Appendix 7. Ex-ante economic, nutritional and environmental impacts of legume R4D

Methods and Data

An economic surplus model (Alston et al. 1995) was used to derive summary measures of the potential impacts of legumes improvement under certain reasonable assumptions for research starting in 2011 and benefits accruing from 2014 (beginning of adoption of improved technologies) to 2020. The benefits were measured based on a parallel downward shift in the (linear) supply curve following research. The annual flows of gross economic benefits from crop improvement were estimated for each of the countries and aggregated, with the aggregate benefits finally discounted to derive the present value (in 2011) of total net benefits from the intervention. The key parameters that determine the magnitude of the economic benefits are: (1) the expected technology adoption in terms of area under improved technologies; (2) expected yield gains following adoption; and (3) pre-research levels of production and prices.

Specifically, the economic surplus empirical model for an open economy was used to calculate the economic benefits for each country from a downward shift in the supply curve. In an open economy, economic surplus measures can be derived using formulas presented in Alston et al. (1995) – i.e., change in economic Surplus (ΔES) = $P_0Q_0K_t\,(1+0.5K_t\varepsilon)$; where K_t is the supply shift representing cost reduction per ton of output as a proportion of product price (P); P_0 represents pre-research price for 2006–2008 (US$/ton); Q_0 is pre-research level of production for 2006–2008; and ε is the price elasticity of supply. The research-induced supply shift parameter, K, is the single most important parameter influencing total economic surplus results from unit cost reductions and was derived as $K_t = A_t\,(\Delta Y/Y)/\varepsilon$ where $\Delta Y/Y$ is the average proportional yield increase per hectare, with the elasticity of supply (ε) used to convert the gross production effect of research-induced yield changes to a gross unit production cost effect.

Annual supply shifts were then projected based on projected adoption profile for improved technologies (A_t) for the period from 2014 to 2020 for research starting in 2011. Adoption (A_t) is assumed to follow the logistic diffusion curve starting in 2014 with less than 1% of the area put under improved technologies in 2014. In view of the already available pool of improved technologies some of which would only need investments in seed production and distribution, a research lag of only three years was assumed from the year of initial research investment in 2011 to the beginning of adoption of technologies in 2014. Table 1 presents the values of some of the key project-, technology-, and market-related parameters used in the projection of impacts of legumes research and extension. The values of these parameters and others were assembled from several sources—such as project proposal, past empirical work (e.g., Alston et al. 1995; Alene et al. 2009), and others (e.g. FAOSTAT). Figure 1 presents the projected technology adoption profiles for legumes implied by the expected values of the technology parameters.

The food security and nutritional impacts of legume research and extension were calculated as the incremental per capita grain and protein availability associated with the incremental production attributable to research.

Biological nitrogen fixation (BNF) benefits were estimated as the replacement cost of an equivalent value of N from urea fertilizer based on FAOSTAT regional average urea producer prices, e.g. US$ 420 per metric ton in sub-Saharan Africa vs. US$ 375/ton in SSEA region. The quantity of BNF was estimated following Hall et al. (2008). The calculation is [aboveground biomass estimated from grain production/crop harvest index] x [crop-specific average shoot % N content] x [crop-specific average % of plant N that is atmospheric in origin] x [crop-specific multiplier to include belowground BNF]. For protein content, published values were used, e.g., Litzenberger (1973) demonstrated that bean contains 22 g of protein per 100 gr of beans.

Table 1. Values of key parameters used in the projection of impacts of Legumes R4D

Parameter	Values					
	Bean	Chickpea			Cowpea	Faba beans
	SSA, LAC	SSEA (ICRISAT)	ESA	CWANA, Ethiopia (ICARDA)	SSA	CWANA, Ethiopia (ICARDA)
Productivity change (%)	11-50	10-25	25	45-80	18-100	40-60
Adoption at year 10 (%)	14-52	10-30	25-40	20-35	5-26	15-20
Gestation lag (years until start of adoption)	3	3	3	3	3	3
Adoption lag (years until maximum adoption)	10	10	10	10	10	10
Elasticity of supply	1	0	0	0	1	1
Elasticity of demand	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic
Discount rate (%)	5	5	5	5	5	5
Project duration	2011-2020	2011–2020	2011–2020	2011–2020	2011-2020	2011–2020
Time path of benefits from investments	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020
Protein content (g protein/kg of grain)	220[1]	171[3]	171[3]	171[3]	240	300
Biological Nitrogen Fixation (kg N/ton of grain)	25 kg/ha/yr[4]	62[5]	62[5]	62[5]	50	86

[1] For South and South East Asia, the maximum adoption considered is 20%

[2] Assumption: 22g of protein/100 g of bean (Litzenberger SC. 1973)

[3] Calculated using figures from Gopalan et al. 2004

[4] Common bean fixes 50kg/ha/yr (Adrian Montanez 2000)

[5] Calculated using Hall et al. 2008

Parameter	Values							
	Groundnut			Lentils		Pigeonpea		Soybean
	SSEA	WCA	ICRISAT-ESA	SSEA (ICARDA)	CWANA	SSEA	ICRISAT-ESA	SSA
Productivity change (%)	10-20	15-35	25	10-20	55 -78	10-20	25	8-38
Adoption at year 10 (%)	10-25	3.4-15.6	30-40	10-25	20-25	10-30	25-40	19-27
Gestation lag (years until start of adoption)	3	3	3	3	3	3	3	3
Adoption lag (years until maximum adoption)	10	10	10	10	10	10	10	10
Elasticity of supply	0	0	1	0	0	0	1	1
Elasticity of demand	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic
Discount rate (%)	5	5	5	5	5	5	5	5
Project duration	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011–2020
Time path of benefits from investments	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020	2014–2020
Protein content (g protein/kg of grain)	401[3]	401[3]	401[3]	223[3]	223[3]	223[3]	223[3]	400[3]
Biological Nitrogen Fixation (kg N/ton of grain)	55[5]	55[5]	55[5]	50[5]	50[5]	50[5]	50[5]	76[5]

[1] For South and South East Asia, the maximum adoption considered is 20%

[2] Assumption: 22g of protein/100 g of bean (Litzenberger SC. 1973)

[3] Calculated using figures from Gopalan et al. 2004

[4] Common bean fixes 50kg/ha/yr (Adrian Montanez 2000)

[5] Calculated using Hall et al. 2008

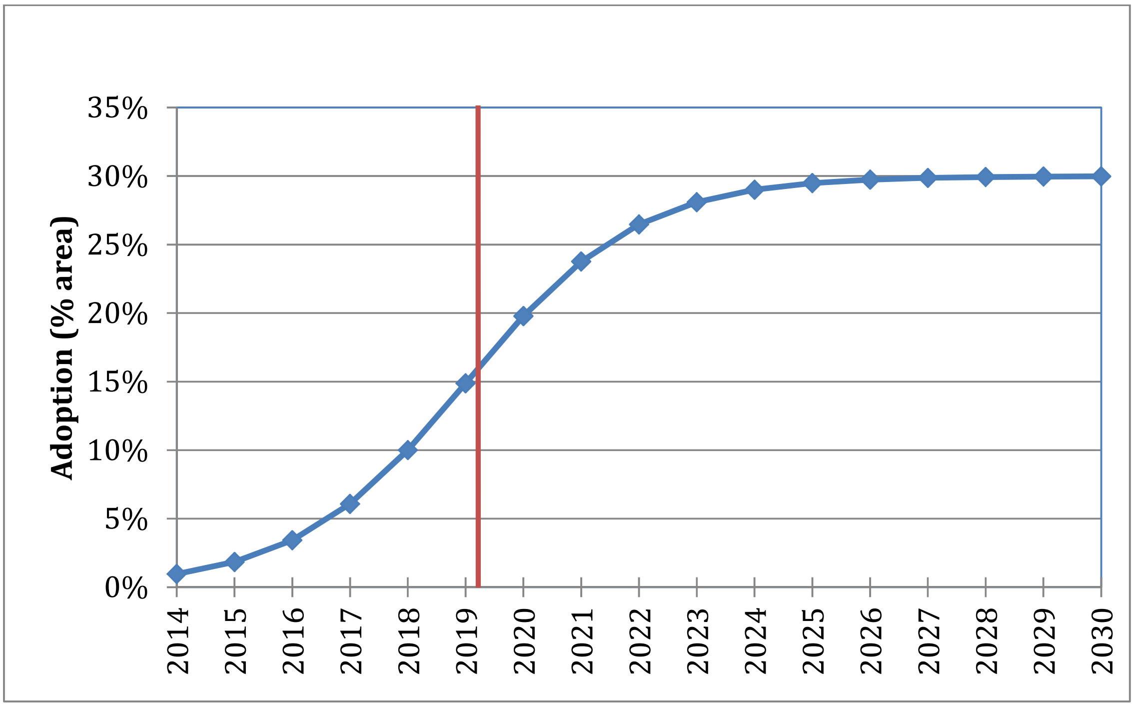


Figure 1. Projected adoption profile for legume technologies.

Adoption rates used to compute the value proposition are fully justified in the section on Adoption study results and the gains in productivity are highlighted in the section on Yield gaps and constraints to adoption.

Results

The summary measures of the ex-ante economic and poverty reduction impacts of legumes research and extension are presented in Table 1. Given the long lag between research investments and reaping the full benefits, the projections of benefits and returns under any short-term scenario represent more conservative estimates of the social profitability of research investments. Although subsequent benefits will not flow without further research and extension investments beyond 2020, the analysis that links project investments (2011–2013) to a finite stream of benefits (2014–2020) is bound to understate the true benefits.

The present value of gross benefits of legume research and extension is estimated at US$4,902 million, equivalent to US$ 535 million per year. Over the period 2014–2020, legume research is also projected to contribute to: (1) food security through increased availability of food (8,187,000 tons); (2) nutrition security through increased availability of protein (2,361,000 tons); and (3) environmental benefits through biological nitrogen fixation (442,000 tons) that also translates to a fertilizer cost saving of US$418 million. Legume research and extension will have the greatest economic impacts in South and South-East Asia and SSA where most of the poor are located accounting for over 50% of the projected economic benefits.

Tables 3 thru 9 contain information on potential impacts of legumes research by crop and by country level. For cowpea research, most of the benefits will accrue from Nigeria accounting for 87% of the NPV followed by Niger, Ghana, Cameroon and Benin. For soybean research, the potential impacts are higher in Nigeria accounting for 41% of the gross benefits in SSA, followed by South Africa, Uganda, Malawi and

Zambia. For groundnut research in WCA, 67% of the gross benefits will be derived from focusing R&D interventions in Nigeria, followed by Senegal, Ghana, Mali and Burkina Faso.

In South and South East Asia, most gross benefits will be derived by focusing the research and development interventions in India. In effect, 79% of the gross benefits that will accrue from chickpea research come from India followed by Pakistan. Likewise, 71% and 86% of the gross benefits are generated by focusing research and development interventions on groundnut and pigeonpea in India.

As for bean research in sub-Saharan Africa, greatest economic impact will be experienced in East and Southern Africa, accounting for 90% of the gross benefits. In West Africa, the potential benefits are highest in Cameroon, which accounts for 52% of the gross benefits. Projections for Latin America and Brazil, shows similar patterns with 65% of the gross benefits accruing from Brazil.

For chickpea in CWANA, it is expected that Ethiopia, Morocco and Syria will gain the highest economic impacts as indicated in Table 8. The potential impact of investment in faba bean research is expected to be the highest in Ethiopia and Morocco; the current adoption rate is low but the adaptive research program with high relevance and invigorated seed system are expected to increase adoption and expected benefits at levels much greater than currently computed. Impact of investment in lentil research will have more impact in Syria, Nepal, and Bangladesh as well as Turkey and Iran; the introduction of short season lentil varieties within the rice system is expected to increase in Bangladesh, and this is expected to increase lentil area as well as benefits form lentil research.

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Table 2. Summary measures of potential impacts of investment in legume research and extension activities, 2011–2020

Measure / Region	**Values**								
	Beans	**Chickpea**	**Cowpea**	**Faba beans**	**Groundnut**	**Lentil**	**Pigeonpea**	**Soybean**	**Total**
Present value of gross benefits (US$ million)									
Sub-Saharan Africa	355	121	558	69	492	43	53	53	1744
West & Central Africa	35		546		236			25	842
East & Southern Africa	320	121	12	69	256	43	53	28	902
CWANA		932		49		541			1522
LAC including ARGBRA	423								423
South and South East Asia		327			583	68	235		1213
Total	***778***	***1380***	***558***	***118***	***1075***	***652***	***288***	***53***	***4902***
Annual gross benefits (US$ million)									
Sub-Saharan Africa	51	18	80	9	83	5	10	8	264
West & Central Africa	5		78		35			4	122
East & Southern Africa	46	18	2	9	48	5	10	4	142
CWANA		116		6		68			190
LAC including ARGBRA	60								60
South and South East Asia						21			21
Total	***111***	***134***	***80***	***15***	***83***	***94***	***10***	***8***	***535***
Incremental food availability (‘000 tons)									
Sub-Saharan Africa	849	51	1546	41	811	15	17	187	3517
West & Central Africa	77		1502		747			72	2398
East & Southern Africa	772	51	44	41	64	15	17	115	1119
CWANA		207		18		116			341
LAC including ARGBRA	1094								1094
South and South East Asia		889			1694	147	505		3235
Total	***1943***	***1147***	***1546***	***59***	***2505***	***278***	***522***	***187***	***8187***

Measure / Region	**Values**								
	Beans	**Chickpea**	**Cowpea**	**Faba beans**	**Groundnut**	**Lentil**	**Pigeonpea**	**Soybean**	**Total**
Incremental protein availability ('000 tons)									
Sub-Saharan Africa	187	6	371	12	299	4	0	75	954
West & Central Africa	17		360		299			29	705
East & Southern Africa	170	6	11	12		4		46	249
CWANA		35		5		29			69
LAC including ARGBRA	241								241
South and South East Asia		244			645	50	158		1097
Total	***428***	***285***	***371***	***17***	***944***	***83***	***158***	***75***	***2361***
Incremental nitrogen fixation ('000 tons)									
Sub-Saharan Africa	22	4	77	3	45	1	1	14	167
West & Central Africa	2		75		41			5	123
East & Southern Africa	20	4	2	3	4	1	1	9	44
CWANA		16		1		6			23
LAC including ARGBRA	27								27
South and South East Asia		92			87	10	36		225
Total	***49***	***112***	***77***	***4***	***132***	***17***	***37***	***14***	***442***
Cost savings from fertilizers (million US$)									
Sub-Saharan Africa	24	17	55	14	34	4	4	10	162
West & Central Africa	2		53		18			2	75
East & Southern Africa	22	17	2	14	16	4	4	8	87
CWANA		72		7		28			107
LAC including ARGBRA	14								14
South and South East Asia		54			54	6	21		135
Total	***38***	***143***	***55***	***21***	***88***	***38***	***25***	***10***	***418***

Table 3. Potential impacts of cowpea research by country in Sub-Saharan Africa, 2011–2020.

	Adoption by 2020* (%)	Yield change (%)	NPV (US$)	Annual (US$)	Incremental Food Availability (tons)	Incremental Protein Availability (tons)	Incremental Nitrogen Fixation (tons)	Savings (US$)
Sub-Saharan Africa	15	49	558,396,983	79,770,998	1,546,405	371,137	77,320	54,574,732
Benin	20	30[c]	6,954,719	993,531	17,444	4,187	872	615,086
Burkina Faso	5	35[a]	4,883,110	697,587	21,495	5,159	1,075	779,777
Cameroon	24	18[b]	8,474,164	1,210,595	29,229	7,015	1,461	1,026,107
D.R. Congo	16	30[c]	2,389,450	341,350	7,601	1,824	380	268,341
Ghana	24	30[d]	9,335,985	1,333,712	33,165	7,960	1,658	1,163,953
Kenya	10	39[c]	2,694,612	384,945	8,923	2,142	446	319,073
Malawi	5	25[j]	1,049,495	149,928	2,683	644	134	97,196
Mali	18	69[e]	4,427,786	632,541	2,683	644	134	97,196
Mozambique	6	100[f]	3,124,257	446,322	14,135	3,392	707	510,387
Niger	5	100[f]	14,822,924	2,117,561	174,884	41,972	8,744	6,354,620
Nigeria	26	53[f, g]	489,350,517	69,907,217	1,178,294	282,791	58,915	41,368,892
Senegal	18	33[h]	3,660,773	522,968	13,693	3,286	685	484,142
South Africa	10	39[c]	286,044	40,863	856	205	43	30,594
Tanzania	21	31[k]	2,141,708	305,958	9,430	2,263	472	332,508
Togo	13	22[i]	1,835,369	262,196	5,202	1,248	260	184,456
Uganda	9	39[c]	2,846,596	406,657	8,498	2,040	425	304,456

Notes:
[a] Muleba et al. (1997); [b] Kitch et al. (1998); [c] Regional average yield gain; [d] Asafo-Adjei et al. (2005); [e] Toure and B.B. Singh (2005). [f] ICRISAT (2011); [g] Kamara et al. (2010); [h] Hall et al. (2003); [i] IITA (1984); [j] Mbwaga et al. (2009); [k] Mligo and Singh (2007).

* 2020 adoption rates were projected based on the popular logistic adoption function using the values given in Table 1 for key parameters and the maximum/ceiling adoption rates (i.e. beyond 2020) obtained from the expert opinion surveys conducted in 2010 under the DIVA project (Diffusion and Impact of Improved Varieties in Africa).

Table 4. Potential impacts of soybean research by country in Sub-Saharan Africa, 2011–2020

	Adoption by 2020 * (%)	Yield change (%)	NPV (US$)	Annual (US$)	Incremental Food Availability (tons)	Incremental Protein Availability (tons)	Incremental Nitrogen Fixation (tons)	Savings (US$)
Sub-Saharan Africa	24	20	52,847,482	7,549,640	187,169	74,868	14,225	9,960,791
Benin	24	17 [a]	205,164	29,309	744	298	57	52,252
Burkina Faso	23	17 [a]	69,430	9,919	595	238	45	41,757
Burundi	23	11 [a]	82,608	11,801	195	78	15	13678
Cameroon	21	17 [a]	56,455	8,065	658	263	50	46,229
D.R. Congo	27	17 [a]	695,615	99,374	1,897	759	144	133,194
Ghana	25	17 [a]	1,255,659	179,380	3,837	1,535	292	269,433
Kenya	20	8 [f]	33,882	4,840	82	33	6	5790
Malawi	27	38 [f]	5,324,910	760,701	12,884	5,154	979	904,667
Mali	23	17 [a]	116,987	16,712	420	168	32	29468
Mozambique	27	28 [a]	411,233	58,748	1258	503	96	88361
Nigeria	24	17 [e, f]	22,188,596	3,169,799	63,450	25,380	4,822	4,455,281
South Africa	25	28 [a]	10,113,491	1,444,784	56,089	22,436	4,263	3,938,415
Tanzania	21	19 [d]	40,687	5,812	200	229	43	40,182
Uganda	26	22 [c, g]	6,899,810	985,687	25,338	10,135	1,926	1,779,170
Zambia	19	28 [a]	1,675,720	239,389	8,004	3,202	608	562,052
Zimbabwe	27	18 [b]	3,677,235	525,319	11518	4607	875	808747

Notes:
[a] Regional average yield gain; [b] Pompi et al. (1998); [c] Laker-Ojok (1994); [d] Malema (2005); [e] Tefera et al. (2010);
[f] ICRISAT (2011); [g] Tukamuhabwa et al. (2012).

* 2020 adoption rates were projected based on the popular logistic adoption function using the values given in Table 1 for key parameters and the maximum/ceiling adoption rates (i.e. beyond 2020) obtained from the expert opinion surveys conducted in 2010 under the DIVA project (Diffusion and Impact of Improved Varieties in Africa).

Table 5. Potential impacts of groundnut research by country in West and Central Africa, 2011–2020

Country	Adoption ceiling rate	Adoption at 10 years	Yield gains	NPV (US$)	Annual (US$)	Incremental Food Availability (tons)	Savings (US$)	Incremental Nitrogen Fixation (tons)	Incremental Protein Availability (tons)
Angola	7.5	3.4	20	738,949	107,336	2549.545	61,660	140	1,020
Benin	10	4.4	20	1,230,151	179,646	4267.127	102,647	234	1,707
Burkina Faso*	25	10.0	20	6,326,162	936,193	22237.371	527,872	1,217	8,895
Cameroon	12.5	5.3	25	2,581,212	378,417	8988.532	215,383	492	3,595
CAR	10	4.4	25	2,136,307	312,000	7410.916	178,259	406	2,964
Congo	10	4.4	20	322,895	47,158	1120.133	26,943	61	448
Cote d'Ivoire	10	4.4	25	878,402	128,287	2756.911	66,314	151	1,103
DRC	10	4.4	25	5,044,756	736,768	17500.417	420,948	958	7,000
Gambia	10	4.4	25	1,431,742	209,101	4966.758	119,468	272	1,987
Ghana	20	10.0	25	12,402,160	1,835,641	43601.930	1,034,870	2,387	17,441
Guinea	10	4.4	20	3,265,426	476,903	14856.794	357,360	813	5,943
Guinea Bissau	10	4.4	20	369,874	54,019	1283.106	30,863	70	513
Liberia	10	4.4	20	70,450	10,289	244.394	5,879	13	98
Mali	35	13.8	25	10,903,745	1,619,403	41402.830	979,313	2,266	16,561
Mauritania	10	4.4	20	11,142	1,627	38.652	930	2	15
Niger	30	11.9	15	3,379,201	500,952	14713.552	348,663	805	5,885
Nigeria	40	15.6	35	158,680,312	23,594,668	469078.886	11,082,194	25,677	187,632
Senegal	35	13.8	25	24,004,996	3,565,175	84683.483	2,003,043	4,636	33,873
Sierra Leone	10	4.4	20	1,051,355	153,546	3647.183	87,728	200	1,459
Togo	10	4.4	20	746,993	109,095	1823.028	43,850	100	729
West and Central Africa				**235,576,230**	**34,956,224**	**747171.548**	**17,694,188**	**40,900**	**298,869**

Potential impact of investment in bean research by country in sub-Saharan Africa, AGRBRA and LAC, 2011-2020

The impact of bean research was estimated using an economic surplus method discussed in section 1, assuming adoption rates and yield changes presented in Tables 6 and 7. Based on the evidence of high adoption potential of improved bean varieties discussed in the adoption studies for subsaharan Africa, Central America and parts of Brazil, adoption ceiling was set at 40-70% (Kalyebara et al. 2008; Sperling and Munyaneza 1995; Odendo et al. 2004; Katungi and Gebeyehu 2010; Janssen et al. 1992; Viana 1998; Pachico 1987; Pachico 1989). High adoption rates is a result of many bean varieties released to match the micro niches (Sperling and Munyaneza, 1995). The impact of new legume varieties is critically related to the effectiveness of seed production and distribution[1]. The adoption rates were derived from a logistic function, assuming an initial adoption of 0.15-1 based on the expert opnion on the adoption of the varieties released[2] in the country in the last 3 years.

On-farm trial evaluation results summarized in PABRA annual reports indicate that most of the newly released varieties and those at pre-released stage outperform popular commercial local checks in most of the countries (PABRA 2012)[3]. Kalyebara and Andima (2006) report a yield increase of 30-50% from the improved varieties across a number of countries in sub-Saharan Africa. The Impact assessment studies in Central America also report high yield increases from adoption of new beans cultivars (Janssen et al. 1992; Viana 1998; Pachico 1987; Pachico 1989). Following this evidence, yield changes were assumed to range from 25-40%. Some countries have released climbing bean cultivars that increase yield gains.

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[1] The PABRA 2012, reports about 35,000 tons of seed produced in 2.5 years across 15 countries but with varying capacity.

[2] A total of 74 varieties with multiple stress resistance have been released in various countries during 2008-2011: Burundi (3), E & W DRC (11), Rwanda (9), Uganda (2), Ethiopia (4), Madagascar (3), Malawi (9), Mozambique (4), S. Tanzania (5), Zambia (2), Zimbabwe (4), S DRC (4), South Africa (3) and Cameroon (7) (PABRA 2012 annual report). One hundred and thirteen (113) are at pre-release stage in 11 countries including two in West and central African countries.

[3] For example, in Kenya, drought tolerant varieties at prerelease stage but already introduced in the farming communities through participatory variety selection have a yield advantage of 54-115% during long and short rainy seasons (Karanja et al. 2012).

Table 6. Potential impact of investment in bean research by country in sub-Saharan Africa, 2011-2020

Country	Yield change (%)	Adoption rate (%)	NPV of the economic benefits (US$) at 5% discount rate	Additional food supply (tons)	Additional availability of protein (tons)	Additional N (BNF)(tons)	NPV of cost savings (US$) at discount rate 5%
SSA			**353,912,010**	**848,996**	**186,779**	**21,226**	**24,421,185**
Benin	25	24	9,101,934	17,107	3,764	428	447,159
Cameroon	25	24	18,012,248	33,855	7,448	846	884,905
Chad	25	24	4,683,600	17,606	3,873	440	461,825
Togo	25	24	2,947,737	8,344	1,836	209	218,099
WCA			**34,745,518**	**76,912**	**16,921**	**1,923**	**2,011,988**
Burundi	25	40	20,506,783	42,396	9,327	1,060	1,184,809
DRC	30	38	13,572,449	28,036	6,168	701	733,330
Ethiopia	30	40	11,295,808	63,792	14,034	1,595	621,778
Kenya	30	38	35,763,264	94,436	20,776	2,361	1,709,377
Rwanda	40	41	17,154,626	114,970	25,293	2,874	5,319,088
Tanzania	40	38	104,284,279	148,701	32,714	3,718	5,182,099
Uganda	30	44	46,584,394	123,377	27,143	3,084	2,469,389
Angola	25	30	14,435,154	26,999	5,940	675	709,170
Madagascar	12	30	2,874,363	7,205	1,585	180	152,150
Malawi	25	38	17,030,774	57,675	12,689	1,442	3,169,168
Mozambique	11	39	4,648,892	7,675	1,688	192	168,281
South Africa	30	39	11,281,811	21,230	4,671	531	446,327
Swaziland	25	39	120,750	227	50	6	4,979
Zambia	25	52	9,148,344	16,490	3,628	412	343,341
Zimbabwe	39	52	10,464,802	18,875	4,152	472	195,911
Total			**319,166,493**	**772,084**	**169,858**	**19,303**	**22,409,197**

Table 7. Potential impact of investment in bean research by country in Latin America and Brazil, 2011-2020

Country	Yield change (%)	Adoption rate (%)	NPV of the economic benefits (US$) at 5% discount rate	Additional food supply (tons)	Additional availability of protein (tons)	Additional N (BNF)(tons)	NPV of cost savings (US$) at discount rate 5%
Total Brazil+ LAC			**423,332,743**	**1,094,871**	**240,872**	**27,372**	**14,059,953**
Brazil	**30**	**24**	**277,865,525**	**516,110**	**113,544**	**12,903**	**8,846,392**
LAC			**145,467,217**	**578,761**	**127,327**	**14,469**	**5,213,561**
Colombia	30	32	18,282,897	29,843	6,566	746	589,749
Mexico	30	24	65,630,523	144,262	31,738	3,607	2,646,374
Venezuela	30	30	6,045,990	8,150	1,793	204	49,724
Haiti	25	30	8,178,678	10,587	2,329	265	193,442
Guatemala	30	28	16,982,504	32,481	7,146	812	637,729
Elsalvador	30	31	10,224,216	15,015	3,303	375	302,055
Honduras	30	29	6,276,551	12,007	2,641	300	275,045
Nicaragua	30	30	11,501,398	33,584	7,388	840	461,798
Costa Rica	30	34	569,217	1,666	367	42	41,436
Panama	30	30	353,763	639	141	16	16,209
Ecuador	30	30	1,421,482	290,528	63,916	7,263	44,931

Table 8. Summary of the potential impact of investment in Chickpea, Lentil, and Faba beans research by country in ICARDA region (CWANA, SSEA, and SSA), 2011-2020

Crop	Region	Country	Estimated adoption rate in 2020	Increase in Yields	NPV gains (US$)	Annual income (US$)	Additional food supply (tons/yr)	Additional availability of protein (tons/yr)	Additional N (BNF)(tons/yr)	NPV of cost savings (US$) at discount rate 5%
Chickpea	CWANA	Iran	25	1430	395,948,569	49,493,571	100,197	17,134	7,757	34,757,997
	CWANA	Morocco	20	1448	52,623,746	6,577,968	10,593	1,811	835	3,748,795
	CWANA	Turkey	20	1336	358,109,810	44,763,726	67,597	11,559	5,329	23,923,209
	CWANA	Syria	35	1913	124,899,965	15,612,496	28,188	4,820	2,138	9,556,970
	Total	CWANA			931,582,090	116,447,761	206,575	35,324	16,059	71,986,972
	SSA	Ethiopia	25	1148	76,286,350	9,535,794	33,827	5,784	2,617	11,745,798
	Grand total				1,007,868,440	125,983,555	240,402	41,109	18,676	83,732,770
Lentil	CWANA	Iran	25	1567	164,643,222	20,580,403	38,445	9,650	2,083	9,335,579
	CWANA	Turkey	20	1625	228,267,572	28,533,447	44,955	11,284	2,483	11,125,600
	CWANA	Syria	25	1918	148,153,517	18,519,190	32,750	8,220	1,775	7,952,551
	Total	CWANA			541,064,311	67,633,039	116,150	29,154	6,341	28,413,730
	SSEA	Nepal	25	1679	118,336,428	14,792,054	41,823	10,498	2,267	10,155,871
	SSEA	Bangladesh	20	1580	50,316,081	6,289,510	15,438	3,875	853	3,820,751
	Total	SSEA			168,652,509	21,081,564	57,262	14,373	3,119	13,976,623
	SSA	Ethiopia	20	1393	42,611,203	5,326,400	15,018	3,769	829	3,716,661
	Grant total				752,328,024	94,041,003	188,429	47,296	10,290	46,107,014
Faba Bean	CWANA	Morocco	15	1264	49,019,472	6,127,434	17,958	5,387	1,447	6,514,872
	SSA	Ethiopia	20	787	69,276,545	8,659,568	40,784	12,235	3,191	14,296,648
	Grand total				118,296,017	14,787,002	58,743	17,623	4,638	20,811,520

Table 9. A summary of the potential impact of investment in chickpeas by country in East and Southern Africa (ESA), 2011-2020

Country	Adoption (%	Yield change (%)	Gross NPV (US$): 5% discount rate	Annual income (US$)	Additional food supply (tons/yr)	Additional N (BNF)(tons/yr)	NPV of cost savings (US$) 5%
Eritrea	25	25	338,189	61,602	111	8	35,718
Ethiopia	40	25	36,075,670	6,581,804	14,310	1,030	4,616,612
Kenya	25	25	5,864	1,068	2	0	576
Malawi	25	25	4,102,920	747,357	1,347	97	434,516
Uganda	25	25	3,846,819	700,707	1,142	82	368,460
Tanzania	25	25	400,333	72,922	124	9	40,050
Zimbabwe	25	25	38,984	7,101	12	1	3,825
Total			**44,808,779**	**8,172,560**	**17,048**	**1,227**	**5,499,757**

Table 10. A summary of the potential impact of investment in pigeonpeas by country in East and Southern Africa (ESA), 2011-2020

Country	Adoption (%	Yield change (%)	Gross NPV (US$): 5% discount rate	Annual income (US$)	Additional food supply (tons/yr)	Additional N (BNF)(tons/yr)	NPV of cost savings (US$) 5%
Burundi	25	25	256,996	46,812	86	4	19,486
Comoros	25	25	35,912	6,541	12	1	2,686
Kenya	40	25	16,387,925	2,989,885	5,336	279	1,250,221
Malawi	30	25	20,512,780	3,738,449	6,289	317	1,420,232
Uganda	25	25	7,366,776	1,341,876	3,179	160	717,817
Tanzania	30	25	8,350,712	1,521,915	2,096	106	394,485
Total			**52,911,102**	**9,645,478**	**16,998**	**867**	**3,804,927**

Table 11. A summary of the potential impact of investment in groundnuts by country in East and Southern Africa (ESA), 2011-2020

Country	Adoption (%	Yield change (%)	Gross NPV (US$): 5% discount rate	Annual income (US$)	Additional food supply (tons/yr)	Additional N (BNF)(tons/yr)	NPV of cost savings (US$) 5%
Botswana	30	25	104,243	18,998	23	1	5,708
Burundi	30	25	1,745,625	318,140	393	22	96,362
Comoros	30	25	167,623	30,549	38	2	9,250
Eritrea	30	25	400,382	72,970	131	7	32,198
Ethiopia	30	25	7,464,008	1,360,313	1,861	102	456,540
Kenya	35	25	8,274,496	1,508,830	1,284	70	314,812
Madagascar	30	25	20,637,684	3,761,212	2,187	120	536,388
Malawi	40	25	39,704,786	7,243,916	13,488	738	3,308,178
Mauritius	30	25	69,702	12,703	14	1	3,469
Mozambique	30	25	13,945,091	2,541,489	4,048	222	992,887
Namibia	30	25	43,375	7,905	13	1	3,154
Réunion	30	25	256,647	46,774	58	3	14,180
Rwanda	30	25	1,139,567	207,686	436	24	106,842
Somalia	30	25	993,821	181,124	224	12	54,872
South Africa	30	25	12,174,616	2,218,820	3,154	173	773,672
Swaziland	30	25	684,464	124,743	151	8	37,054
Uganda	40	25	42,806,494	7,809,805	21,997	1,204	5,395,271
Tanzania	30	25	73,308,011	13,360,365	7,029	385	1,723,944
Zambia	30	25	13,808,108	2,516,524	3,065	168	751,724
Zimbabwe	30	25	18,451,991	3,362,870	4,097	224	1,004,828
Total			**256,180,734**	**46,705,738**	**63,691**	**3,487**	**15,621,333**

Table 12. Summary measures of potential impacts of investment in legume research and extension activities for anchor and spillover countries in South and Southeast Asia, 2011–2020

Country	Chickpeas	Groundnut	Lentils	Pigeonpeas	Country/ Region total
	Present value of gross benefits (million US$)				
Indonesia		38			**38**
Lao PDR		0.5			**0**
Cambodia		0.5			**0**
Thailand		1			**1**
Viet Nam		20			**20**
Bangladesh	0.1	1	6		**7**
Myanmar	24	104	0.0	33	**161**
Nepal	0.2		21	1	**22**
Pakistan	46	2	0.3		**48**
Sri Lanka		0.3			**0**
India	257	416	41	201	**915**
Crop total	**327**	**583**	**68**	**235**	**1,214**
	Increased food availability ('000 t)				
Indonesia		80.7			**81**
Lao PDR		1.9			**2**
Cambodia		1.4			**1**
Thailand		2.8			**3**
Viet Nam		43.0			**43**
Bangladesh	0.4	2.5	18.3		**21**
Myanmar	98.6	356.4	0.1	146.4	**601**
Nepal	0.4		34.7	1.0	**36**
Pakistan	119.8	2.6	0.6		**123**
Sri Lanka		0.6			**1**
India	670.0	1,202.3	93.5	357.5	**2,323**
Crop total	**889**	**1,694**	**147**	**505**	**3,236**
	Increased protein availability ('000 t)				
Indonesia		26.5			**26**
Lao PDR		0.6			**1**
Cambodia		0.5			**0**
Thailand		0.9			**1**
Viet Nam		14.1			**14**
Bangladesh	0.0	1.0	4.6		**6**
Myanmar	16.9	116.9	0.0	32.6	**166**
Nepal	0.1		8.7	0.2	**9**
Pakistan	47.2	1.6	0.2		**49**
Sri Lanka		0.2			**0**
India	180.0	482.1	36.9	125.3	**824**
Crop total	**244**	**645**	**50**	**158**	**1,097**

Country	Chickpeas	Groundnut	Lentils	Pigeonpeas	Country/ Region total
	Increased nitrogen fixation (t)				
Indonesia		3,616			**3,616**
Lao PDR		85			**85**
Cambodia		63			**63**
Thailand		125			**125**
Viet Nam		1,928			**1,928**
Bangladesh	31	138	920		**1,089**
Myanmar	7,099	15,964	5	7,377	**30,445**
Nepal	29		1,750	52	**1,832**
Pakistan	9,485	223	46		**9,754**
Sri Lanka		33			**33**
India	75,804	65,815	7,401	28,311	**177,332**
Crop total	**92,448**	**87,990**	**10,122**	**35,740**	**226,301**
	Fertilizer cost savings due to N fixation ('000 US$)				
Indonesia		2,576			**2,576**
Lao PDR		60			**60**
Cambodia		45			**45**
Thailand		89			**89**
Viet Nam		1,373			**1,373**
Bangladesh	18	80	920		**1,018**
Myanmar	4,137	11,370	3	4,299	**19,808**
Nepal	17		1,020	30	**1,067**
Pakistan	5,527	130	27		**5,684**
Sri Lanka		19			**19**
India	44,173	38,353	4,313	16,498	**103,337**
Crop total	**53,873**	**54,095**	**6,282**	**20,827**	**135,077**
	Incremental production (t), 2022				
Indonesia		14,680			**14,680**
Lao PDR		343			**343**
Cambodia		258			**258**
Thailand		508			**508**
Viet Nam		7,827			**7,827**
Bangladesh	431	458	3,318		**4,208**
Myanmar	17,927	64,807	17	26,613	**109,363**
Nepal	74		6,314	187	**6,576**
Pakistan	34,218	740	167		**35,125**
Sri Lanka		111			**111**
India	191,423	218,605	26,700	102,133	**538,861**
Crop total	**244,074**	**308,336**	**36,516**	**128,933**	**717,859**

Appendix 8. Analysis of historic research on targeted legumes

Diseases

Disease resistance has played a major role in breeding programs of legumes. Objectives have long been to reduce risks associated with production, thereby providing farmers increased security to motivate investing in the crop. Most released cultivars have some degree of enhanced disease resistance, especially for fungal and/or viral pathogens. Such advances must now be maintained as breeders address even more challenging issues.

Several foliar diseases reduce soybean yield in Africa including bacterial pustule, frog eye and viruses, but soybean rust caused by the fungus *Phakopsora pachyrhizi* is now endemic in soybean growing areas of west, east and southern Africa, with yield losses from 8 - 53% in Uganda in 1996 (Tukamuhabwa et al. 2001) and 40 - 80% in southern Africa (Levy 2005; Twizeyimana et al. 2008; Kumudini et al. 2008). Only a few new cultivars bred in Nigeria and Uganda are resistant.

Bean research in the 1970's and 80's focused on genetic resistance to six major diseases: bean common mosaic virus (BCMV), bean golden yellow mosaic virus (BGYMV), anthracnose, common bacterial blight, rust, and angular leaf spot. Some twenty-thousand genebank accessions were evaluated for most of these diseases. Virtually all cultivars planted in lowland neotropics carry resistance to BCMV, and by 1998 an estimated 40% of beans in Central America were improved varieties resistant to BGYMV (Viana 1998; Johnson and Klass 1999). In Africa the presence of bean common mosaic necrotic virus made necessary the use of the recessive *bc-3* gene. A gene based marker for this gene is being implemented (Naderpour et al. 2010). Lines resistant to angular leaf spot became popular, especially EMGOPA Ouro in Brazil and CAL 143 in six countries in southern Africa. Intense cultivation led to greater problems with soil borne pathogens (*Pythium* and *Fusarium* species), and resistant cultivars were widely adapted in western Kenya. Implementation of molecular markers for early generation selection improved the efficiency of the breeding program by 60% (Miklas et al. 2006; Beebe et al. 2000).

Fusarium wilt (FW), caused by *Fusarium oxysporum* Schl. f. sp. ciceris, is the most important disease of chickpea, and can cause up to 100% plant mortality. More than 100 accessions resistant to FW have been identified (Sharma et al. 2009, 2010), and have served to develop resistant cultivars (Pande et al. 2005), but interaction between drought and FW infection is complex. Moderate resistance to other important diseases have been identified (Pande et al. 2005, 2006, 2007) such as: botrytis gray mold in eastern India, Nepal, and Bangladesh; ascochyta blight (AB), caused by *Ascochyta rabiei* in Northern India, Pakistan, Central Asia and north Africa. Gene pyramiding has resulted in high levels of AB resistance and molecular markers closely linked to two major QTL are ready for marker-assisted breeding. Breeding lines with moderate resistance to botrytis gray mold (BGM) have been developed (ICCV 98502, ICCV 98503, and ICCV 98505). Low levels of resistance exist for dry root rot (DRR), caused by *Rhizoctonia bataticola* which is emerging where chickpea is subjected to terminal drought, while no resistance is yet known for collar rot (CR) caused by *Sclerotium*.

Bacterial blight (*Xanthomonas campestris* pv. *vignicola* (Burkholder) Dye can cause up to 65% yield loss in cowpea (Sikirou 1999). However, genes conferring resistance to bacterial blight have been found and transferred to several improved varieties. According to Singh (1993) the following varieties, IT86D-719 and IT90K-277-2 were developed for resistance to bacterial blight and bacterial pustule. Among the seed borne viruses damaging cowpea yield are blackeye mosaic potyvirus (BICMV), cowpea aphid borne mosaic potyvirus (CABMV), cowpea severe mosaic comovirus (CPSMV) and cowpea mosaic (CPMV) (Hampton et al. (1997). Some combinations of the viruses such as BICMV+CMV or BICMV+CPSMV can cause significant crop yield losses (Anderson et al. 1994). Sources of genes for resistance have been detected in some germplasm lines, e.g. BICMV in TVu 2657 (Ouattara and Chambliss (1991), CPSMV in TVu1948 and TVu2480 (Fulton and Allen 1982) and these genes have been incorporated in improved varieties. Some lines such as IT98K-133-1, IT99K-573-1-1 have resistance to CPMoV, CABMV and CPMMV9 (TL II 2008-2009 Annual Report).

Lentil suffers from many of the same pathogens as chickpea. Losses to vascular wilt caused by *Fusarium oxysporum* vary from 5-12% and may reach 72% in Syria (Bayaa et al. 1986) or complete crop failure in India (Khare 1981). Differences in pathogenicity have been noticed (Erskine and Bayya 1996). Resistance sources were identified in both cultivated and wild germplasm (Bayaa et al. 1995; Erskine et al. 1994; Hamdi et al. 1991; Kannaiyan and Nene 1976; Khare 1981; Omar et al. 1988), resulting in many improved varieties for different countries. However, like chickpeas, high resistance to collar rot (*Sclerotium rolfsii* Sacc.) and dry root rot (*Rhizoctonia* spp.) has not been identified. Rust caused by *Uromyces vicia-fabae* is a serious constraint worldwide (Singh et al. 1986; Negussie et al. 2005). Screening of germplasm has identified resistance donors (Bejiga et al. 1995; Singh and Sandhu 1988) that produced resistant varieties in Bangladesh, Pakistan, Ethiopia, Morocco, and India. Ascochyta blight caused by *Ascochyta fabae* f.sp. lent is limits yield of winter lentils in the cool humid climates (Erskine et al. 1994; Gossen and Morrall 1983). Differential reaction of some lines suggests pathogenic variability. Useful resistance sources were identified in cultivated accessions and in wild species such as *Lens orientalis*, *L. odemensis*, *L. nigricans* and *L. ervoides* (Ahmad and Morrall 1996; Cromey et al. 1987; Iqbal et al. 1990; Singh et al. 1982; Bayaa and Erskine 1994). Resistant varieties have been released in India, Pakistan, Canada, and Australia. *Stemphylium botryosum* may cause up to 62% yield reduction in Bangladesh (Bakr 1993), and has been reported from northeast India (Sinha and Singh 1991), causing more than 90% yield loss (Sinha and Singh 1993). The genotype ILL 4605 has been reported to have resistance. Collaborative efforts between ICARDA and Bangladesh national programs have resulted in development of tolerant varieties.

Faba bean is affected by at least five important foliar diseases (Ascochyta blight, chocolate spot, rust, powdery mildew and Cercospora leaf spot), different root rot complexes, and at least seven viruses (Sillero et al. 2010; Bayaa et al. 2004, Saxena 1991; Bond et al. 1994; van Leur et al. 2006). Resistance sources were identified for Ascochyta blight, chocolate spot, and rust at ICARDA (Hanounik and Roberston 1989; Bayaa et al. 2004) and in other advanced centers (Bernier and Conner 1982; Rashid and Bernier 1986a; Bond et al. 1994). More than 40 breeding lines were developed for rust (Rashid and Bernier 1986b; ICARDA 1987; Bond et al. 1994); 46 for ascochyta blight (Rashid et al. 1991a,b; Maurin and Tivoli 1992; Lawsawadsiri 1995; Ramsey et al. 1995; Sillero et al. 2001; Ondrej and Hunady 2007); and 39 for botrytis (Kharrat et al. 2006). Inbred lines were reported in Canada as sources of resistance to BYMV (Gadh and Bernier 1984), but only line 2N138, was highly resistant to the necrotic strain of this virus. ICARDA found sources for both BLRV and for BYMV (Bond et al. 1994; Robertson et al. 1996; Kumari and Makkouk 2003). Lines were sent to different NARS and several varieties were released by EIAR in Ethiopia for resistance to chocolate spot. Breeders have transferred resistance to root rot organisms to locally-adapted varieties for production on vertisols. The variety 'Walki' was developed for water-logged areas of Ethiopia.

Leaf spots (early and late leaf spot) are widespread in groundnut growing areas, and cause yield losses of more than 50% if proper control measures are not applied (Gibbons 1980 and Subrahmanyam et al. 1984). Stem and pod rot pathogen (*Sclerotium rolfsii*) causes an average of 10-25% yield loss. Aflatoxin contamination affects groundnut trade and profitability worldwide (Felicia et al. 2008). Groundnut rosette disease (GRD) is the most devastating disease of groundnut in sub-Saharan Africa (Zummermann 1907, Reddy 1991). GRD causes an annual yield loss of US$ 156 million in SSA. Several rosette resistant groundnut varieties were released in ESA and WCA such as ICGV-SM-90704, ICG 12991, ICGV-SM-99568, ICGV 93437 (Ntare et al. 2002, Padgham et al. 1990, Naidu et al. 1999).

Fusarium wilt caused by *Fusarium udum*, and sterility mosaic disease (SMD) caused by pigeonpea sterility mosaic virus (PPSMV) are the major biotic constraints to pigeonpea production worldwide. The annual losses due to wilt have been estimated at US$ 71 million in India and US$ 5 million in Eastern Africa (Reddy et al. 1998). Annual yield losses to SMD in India and Nepal are estimated at

US$ 282 million (Kannaiyan et al. 1984). Combined resistance to wilt and SMD have been found in a few accessions in the mini-core collection (Sharma et al. 2012), and several pigeonpea varieties resistant to both diseases have been released in Asia, Africa, Australia and USA (Gwata et al. 2006, Rangaswamy et al. 2005, Reddy et al. 1998, Sharma and Pande 2011; Sharma et al. 2012). Recently, Phytophthora blight caused by *Phytophthora drechsleri* f sp. cajani is emerging as a major threat to pigeonpea production (Sharma et al. 2006; Pande et al. 2011).

Insects

While all legumes suffer losses to insect pests, these are major limitations in chickpea, cowpea and pigeonpea. Integrated Pest Management systems, including host resistance where available, has been the focus of research on control methods.

Helicoverpa armigera is a serious pest on both chickpea and pigeonpea, causing an estimated loss of US$ 317 million in pigeonpea (ICRISAT 1992). Globally, it causes an estimated loss of over US$ 2 billion annually, despite over US$ 1 billion worth of insecticides used to control this pest (Sharma 2005). More than 14,000 chickpea accessions and 15,000 pigeonpea accessions have been screened for resistance and only moderate levels of resistance have been identified, leading to the release of cultivars (Gowda and Gaur 2004; Sharma 2005). High levels of *Helicoverpa* antibiosis have been identified in accessions of *Cicer reticulatum*, *C. bijugum, C. pinnatifidum*, and *C. judaicum* (Sharma et al. 2005a,b), followed by interspecific crosses involving *C. reticulatum* and the cultigen (Clement et al. 2009; Mallikarjuna et al. 2007). Similarly, high levels of antibiosis to *Helicoverpa* have been identified in accessions belonging to *Cajanus scarabaeoides, C. sericeus* and *C. acutifolius* (Sujana et al. 2008), with crosses to *C. scarabaeoides* and *C. acutifolius* to enhance the level of resistance. The use of microbial pathogens including *H. armigera* nuclear polyhedrosis virus (HaNPV), entomopathogenic fungi, *Nomuraea rileyi,* bacteria, *Bacillus thuringiensis* (*Bt*), nematodes, and natural plant products such as neem, custard apple, and karanj kernel extracts have shown some potential to control *H. armigera* (Sharma 2005; Visalakshmi et al. 2005, 2006; Saxena and Ahmad 1997; Chen et al. 2011). In India and Australia, insecticides including endosulfan, cypermethrin, profenophos, spinosad, and indoxacarb have been found to be effective for *H. armigera* control on chickpea (Murray et al. 2005). Methomyl, cypermethrin, profenophos, spinosad, and indoxacarb have been found to be effective for *H. armigera* control on pigeonpea (Murray et al. 2005; Sharma 2005). Given the ineffectiveness of individual control methods and the lack of high levels of resistance, integrated pest management (IPM) is considered necessary (Sharma 2006). In addition, the development of transgenic plants (e.g., using one or more Bt genes) seems to be the approach of greatest potential for enhancing resistance of chickpea and pigeonpea to *H. armigera.*

Maruca vitrata is emerging as a major pest of pigeonpea (Sharma et al. 1999), and has been investigated as a major pest of cowpea for many years. Control methods in cowpea include bio-pesticides based on neem and papaya leaf extracts, entomopathogenic fungi (*Beauveira bassiana, Metarhizium anisopliae* and *Neozygites fresenii*) (Tamò et al. 2003), and a Multi-Nucleopolyhedrosis Virus (*Mavi*MNPV) (Srinivasan et al. 2007). The association of the virus with neem oil gave more than double yields compared to the unsprayed plot. Synthetic pheromones of *M. vitrata* have been employed to optimize traps and to monitor field populations (Downham et al. 2004). Natural enemies have been identified and the technology for the establishment of *A. taragamae* was determined prior to releases (Dannon et al. 2012). Bt cowpea has been produced (Popelka et al. 2006) and confined field trials carried out in Nigeria show the gene to be efficacious against Maruca (AATF 2012). The easily transformed cowpea line does not have farmers and consumers' preferred traits hence efforts will be made to transfer the Bt gene to improved varieties that are well received by farmers and consumers. Studies on the effects of the Bt endotoxin on natural enemies of the pod borer *M. vitrata* (*Phanerotoma leucobasis* and *A. taragamae)* suggest that the probability of significant effects on these parasitoids remains low (Tamò et al. 2007). Management recommendations have been developed for the effective and safe deployment of Bt-cowpea (Huesing et al. 2012) as well as models for insect resistance management (IRM).

Control of flower thrips (*Megalurothrips sjostedti)* has also been a priority in cowpea, identifying resistance in three local West African varieties that was determined to be antibiosis mediated by polyphenols and other compounds (Alabi et al. 2006). Biological control was attempted by the introduction of the hymenopteran parasitoid, *Ceranisus femoratus,* from Cameroon, concluding that *C. femoratus* alone will not offer acceptable control to *M. sjostedti* in all agro-ecological zones. Efforts are underway at ICARDA to develop chickpea varieties with resistance to the leaf miner, *L. cicerina*. High levels of resistance have been observed in desi chickpeas to bruchids (*Callosobruchus* spp.).

Drought

Drought is one of the important constraints to crop production in the tropics. In South Asia, chickpea is largely grown during the post-rainy season on limited residual soil moisture. The chickpea area in northern and north-eastern states of India decreased from 5.15 m ha in the 1970s to 0.96 m ha during 2005-06, while in the central and southern states it increased from 2.05 m ha to 4.67 m ha during the same period (Gaur et al. 2008b), further aggravating the effects of the combined stresses of terminal drought and high temperatures at the reproductive phase. Faba bean (*Vicia faba* L.) is relatively sensitive to water deficits (McDonald and Paulsen 1997; Amede and Schubert 2003; Plies Balzer et al. 1995) and drought is considered the major cause of yield instability (Bond et al. 1994; Abdelmula et al. 1999; Siddique et al. 2001). In Ethiopia and the Mediterranean basin, the crop is grown largely on residual soil moisture (Sau and Mınguez 2000). Water stress can cause heavy yield losses of lentil depending on the crop stage, drought severity, evaporative demand of the atmosphere and moisture holding capacity of the soil (Erskine et al. 1994; Subbarao et al. 1995; Wery et al. 1994). Annual losses to drought in groundnut production are estimated at US$ 520 million (at the market prices of 1994), and almost half of it (US$ 208 million) can be recovered through genetic enhancement for drought resistance (Johansen and Nigam 1996). Drought tolerant groundnut varieties were released for cultivation (Birthal et al. 2011) and new sources of tolerance to drought (Upadhyaya 2005; Hamidou et al. 2012) have been identified. An estimated 60% of common bean production is under the risk of moisture deficits, including some 780,000 ha in Africa (Wortmann et al. 1998). Directed genetic improvement for drought tolerance received increasing attention during the 1990s and later (Singh et al. 2001; Beebe et al. 2008). Tolerant cultivars of the small red grain class were released in Nicaragua, Rwanda and Malawi.

Multiple physiological mechanisms confer drought tolerance in legumes. In common bean, improved mobilization of photosynthate to grain can improve yield under both stressed and favorable conditions (Beebe et al. 2008; Klaedtke et al. 2012). Poor remobilization is an ancestral trait tracing to the wild progenitor, and is still amenable to further genetic improvement. *P. acutifolius* (tepary bean) in particular has potential to improve mobilization of photosynthate to grain, and a base population of common bean-tepary introgression lines already exists for this purpose (Muñoz et al. 2006). In chickpea, root traits that result in more efficient extraction of available soil moisture are being exploited (Gaur et al. 2008a). Studies at ICRISAT on root growth parameters of 12 contrasting chickpea genotypes showed a clear positive relationship between root biomass and the seed yield under moisture stress conditions (Kashiwagi et al. 2005a). The drought tolerant chickpea line, ICC 4958, expressed 30% higher root biomass than the popular variety Annigeri (Saxena et al. 1993). Short duration lentil varieties avoid drought at the reproductive stage when high temperatures and water deficits induce rapid senescence and early maturity (Erskine et al. 1994; Shrestha et al. 2006a). Under short season rainfed environments of South Asia, superior performance has been correlated with rapid canopy cover, early phenology and high harvest index (Shrestha et al. 2005). Pigeonpea can tolerate very low relative water content without lethal effects, and hybrid pigeonpea exhibits a more vigorous root system that gives the crop up to 40% higher yield on farm. There is evidence of genotypic variation for seed yield pigeonpea under water stress (Nam et al. 2001; Deshmukh et al. 2009). Generally, medium to long duration pigeonpea genotypes are usually exposed to terminal drought conditions while short duration material can be exposed to intermittent drought spells.

Pigeonpea occasionally sheds lower leaves to reduce the evaporative surface. On the other hand, pigeonpea is known to be extremely sensitive to water logging (Chauhan et al. 1997). Recent research has shown the existence of genotypic variation for water logging resistance in the minicore collection (Krishnamurthy et al. 2011).

High and low temperatures

A study of climatic factors that limit common bean yields suggested that in many regions, high temperatures are already the most limiting factor, and that improved heat tolerance could benefit 7.2 million hectares of common bean, some of which could benefit by drought tolerance (Beebe et al. 2011). Interspecific progenies of common and tepary beans have expressed useful levels of heat tolerance in Puerto Rico (Porch, pers. comm.). Research by the CRP on Climate Change has shown that high temperature stress (above 30^0C) will be widespread in East and Southern Africa, India, South East Asia and Northern Latin America, which are important groundnut growing areas. Vara Prasad et al. (1999) showed that 34^0C is threshold temperature for pollen production in groundnut. Heat stress even for a few days during flowering and pod filling stages drastically reduces seed yield in lentil because of damage to reproductive organs, accelerated rate of plant development and shortened period of growth of reproductive organs (Boote et al. 2005; Siddique et al. 2002; personal observation). Most of the progress in breeding for terminal heat escape has been made in development of short duration lentil varieties without compromising yield level. Putative tolerant genotypes for heat (ILL 3597, Sel # 33108, 33109, 33110 and 33113) can be used by breeding programs to introgress gene(s)/QTLs into agronomically superior backgrounds for target environments.

Chilling temperatures during the early reproductive growth have been reported to cause yield losses in chickpea in many parts of Asia, particularly in high latitudes and hilly areas (Srinivasan et al. 1999). Several chickpea breeding lines are able to set pods at temperatures between 12^oC to 15^oC. A pollen selection method has been developed and successfully applied for transferring cold tolerance from ICCV 88516 to the popular variety Amethyst in Australia (Clarke et al. 2004). Winter hardiness of lentil is affected not only by cold tolerance but also by tolerance to frost, water-logging and freeze-thaw cycles (Erskine et al. 1981). Ali et al. (1991, 1999) screened lentil cultivars under different temperature regimes and identified cold hardy genotypes.

Edaphic problems

Soil constraints and especially low soil fertility limit legume yields across the tropics in smallholder agriculture. Short of extensive use of inputs, solutions must combine both crop management and crop adaptation to sub-optimal conditions. Modest progress was registered in breeding common bean for adaptation to low fertility soils (Singh et al. 2003). Root traits for efficient acquisition of nutrients have been elucidated (Beebe et al. 2006; Liao et al. 2004; Yan et al. 2004), and could contribute to improved efficiency in fertilizer use. Parallel to this has been the expanded use of interspecific crosses with sister species adapted to stressful soil environments: *P. coccineus* for aluminum tolerance, and *P. acutifolius* for a fine root system for excellent soil exploration (Butare et al. 2011a, 2011b). Promising lines expressing tolerance to drought and low soil fertility in experimental conditions have been developed (Beebe 2013). Pigeonpea has also the capacity to cope with low soil phosphorus (Adu-Gyamfi et al. 1989) because of its capacity of roots to secrete pissidic acid to insoluble phosphorus from the soil (Ae et al. 1990). The efficiency of soybean to fix nitrogen can be limited by soil phosphorus deficiency (Kamara et al. 2008), and therefore phosphorus has implications for the nitrogen status of the entire system. In a study of nitrogen x phosphorus interactions on soybean productivity in northeast Nigeria, nitrogen fertilizer did not affect grain yield and yield while phosphorus fertilizer increased grain yield by 46-95% at 20 kg phosphorus/ha and by 51-316% at 40 kg/ha. This study concluded that application of nitrogen fertilizer is not critical for soybean production in the study area (Kamara et al. 2007). Application of phosphorus to four soybean cultivars significantly increased dry matter and grain yield of succeeding maize in both locations in the two years. In Angonia district of Mozambique, phosphorus application improved nodulation and yield of promiscuous soybean varieties, but had no effect on the non-promiscuous commercial varieties.

The use of phosphate solubilizing bacteria of the genera of *Pseudomonas*, *Bacillus* and *Rhizobium* as inoculants simultaneously increases phosphorus uptake by the plant and crop yield (Khan et al. 2009; He et al. 2002; Khan and Joergesen 2009; Chen et al. 2006). The phosphate solubilizing bacteria (PSB) and plant growth promoting rhizobacteria (PGPR) together could reduce phosphorus fertilizer application by 50% without any significant reduction of crop yield (Jilani et al. 2007; Yazdani et al. 2009).

Salinity and aluminum toxicity

Saline soils limit chickpea production in many parts of Asia. About 36.0 m ha land is saline in South Asia (23.2 m ha in India, 10.5 m ha in Pakistan, 2.5 m ha in Bangladesh). Screening of over 250 chickpea germplasm accessions (including 211 accessions form the mini-core collection) and breeding lines/cultivars revealed wide variation for salinity tolerance. Singh et al. (2008) screened groundnut genotypes for salinity tolerance and genotypic differences were observed. Lentils are considered to be highly susceptible to salinity; however, Ashraf and Waheed (1990) screened 133 lentil genotypes and identified ILL5845, ILL6451, ILL6788, ILL6793 and ILL6796 as putative tolerant lines. Wild relatives of lentil also showed high tolerance to salinity in *L. culinaris* ssp. *orientalis* (Hamwieh et al. 2010). A screening of the pigeonpea mini-core collection also revealed important genotypic differences in salinity tolerance, especially in wild relatives such as *Cajanus platicarpus* and *Cajanus sericeus* (Srivastava et al. 2006). In addition, sodic soils (soils containing sodium salts and that are alkaline in nature) are also found in India (0.6 m ha), Bangladesh (0.5 m ha), China (0.4 m ha), and Iran (0.7 m ha) (Abrol et al. 1988).

Aluminum toxicity is the single most important factor that effects plant growth and yield under acid soils. Screening groundnut genotypes for aluminum toxicity have been reported (Boshou et al. 2000), indicating feasibility of genetic enhancement for tolerance to salinity and aluminum toxicity. An interspecific cross of a drought tolerant common bean line SER 16 with *P. coccineus* accession G35346 for aluminum tolerance produced lines with aluminum tolerance superior to that of SER 16 (Butare et al. 2011a, 2011b). In lentil, iron deficiency is a common soil disorder especially in high pH soils, causing 18-25% yield losses in susceptible genotypes in India and up to 47% in Syria (Ali et al. 2000; Erskine et al. 1993).

Nitrogen fixation

Legumes fix atmospheric nitrogen (termed symbiotic nitrogen fixation or SNF), and increase access to nutrients such as phosphorus (Giller 2001; Shapiro and Sanders 2002; Adu-Gyamfi et al. 2007). Herridge et al. (2008) estimated that 50% nitrogen fixed by a chickpea crop remains underground and is available to the following crop. Symbiotic fixation of nitrogen is sensitive to even modest soil water deficits (Sinclair et al. 2007). Sufficient numbers of compatible rhizobia are often not naturally occurring in most of the soils where grain legumes are cultivated (Marufu et al. 1995), and there is need for rhizobia application to seeds (Catroux et al. 2001). Inoculation of common bean with selected strains in Central America resulted in an average of 14% yield increase, but with wide variability over sites (Acuña et al. 2001).

Most crops in this proposal have shown promise for a positive contribution of nitrogen fixation to legume yields and/or system productivity. Common beans with climbing growth habit consistently fix more nitrogen than bush types due to longer growth cycle and vegetative vigor (Graham and Rosas 1977). Recent work suggests that selection for drought tolerance in bush type common beans has improved SNF capacity under both water limited and favorable conditions in a greenhouse trial (Devi et al. 2012). The high nodulating chickpea line ICC 4948 fixed more nitrogen and yielded 31% more than its low nodulating version (Fried et al. 1983). Due to their indeterminate growth habit, faba beans continued assimilating nitrogen for a longer period than pea, reaching about 315 kg nitrogen/ha after 110 days (Jensen et al. 2010), and in another study varying from 153.4 kg/ha to 306.4 kg/ha depending on the environments (Lu et al. 2010). Both biomass and seed yield of lentil are closely dependent on nitrogen fixing ability, especially during reproductive growth (Sinclair and De Wit 1975).

Many studies of symbiotic nitrogen fixation have focused on soybeans. In Zimbabwe, soybean fixed more than 150 kg nitrogen/ha when grown in association with effective *Bradyrhizobia* (Mapfumo et al. 2001). Most high yielding soybean cultivars from USA have specific requirements for *Rhizobium japonicum* (Pulver et al. 1982), but production of efficient inoculants and distribution to small-scale farmers is still a constraint and constrains the direct use of imported germplasm. IITA's major success in the past was the development of promiscuous soybean varieties that nodulate freely with existing soil *Rhizobia* (Kueneman et al. 1984). Adoption of promiscuously nodulating soybean varieties increased by 228% between 2000 and 2003.

System benefits have been documented for several legumes. Promiscuous soybean breeding lines left a nitrogen balance of from –8 to 43 kg nitrogen/ha, and maize growing after soybean had significantly higher grain yield (1.2–2.3-fold increase compared to the maize control) (Sanginga et al. 2002). Similarly, Pare et al. (1993) demonstrated that maize whole-plant dry matter yields were enhanced following faba bean as compared to continuous maize. Wright (1990) also observed significant yield increases (12%) in the second cereal following faba bean compared to nitrogen fertilized continuous cereals. Climbing common beans can have a positive effect on maize yields in association (Pineda et al. 1994) or rotation (Sanginga and Woolmer 2009). However, the efficiency of soybean to fix nitrogen can be limited by soil phosphorus deficiency (Kamara et al. 2008), and management of phosphorus nutrition is a critical factor in exploiting SNF.

Phenology

Early maturity is essentially a simple trait that is favored in many crops by farmers around the world. While drought avoidance is often cited as major motive for early maturity, many other reasons influence the preference for early maturity, including the exploitation of short season niches, and the need to obtain food after a "hunger period". Selection of earliness *per se* is not scientifically challenging, but rather the combination of earliness with other traits that might be associated with late maturity, especially high yield and in some cases disease and pest resistance. Chickpea improvement has focused on developing short-duration cultivars that escape terminal drought and heat stress, and that fit in cropping systems with a narrow cropping window. The extra-short duration kabuli variety ICCV 2, which matures in about 85 days, was instrumental in expanding cultivation of kabuli chickpeas in tropical environments in Southern India, Myanmar, and in rainfed rice fallow lands (Gowda and Gaur 2004). Chickpea yields have more than doubled from 600 to 1400 kg/ha in Andhra Pradesh, India, stimulating a four-fold increase in area sown and an added grain value of US$ 69 million. Super-early breeding lines that mature in 75-80 days have also been developed.

Similarly, short duration lentil varieties in South Asia avoid drought at the reproductive stage (Erskine et al. 1994; Shrestha et al. 2006a). Superior performance has been correlated with rapid canopy cover, early phenology and high harvest index (Shrestha et al. 2005). Most of the progress in breeding for terminal heat escape has been due to short duration varieties without compromising yield level.

In groundnut, breeding for short-duration varieties with drought tolerance was important in agro-ecological regions with short growing seasons (100-110 days) either due to end of season drought or short cropping window in multiple cropping systems (Nigam et al. 1991). Breeding for short-duration in groundnut has become more relevant with the predicted decline of length of growing period by 5% or more across the tropics due to climate change.

Weeds

Weeds (parasitic and non-parasitic) remain a major production constraint to grain legume production, as these crops are poor competitors to weeds prevalent in the production system. Non-parasitic weeds compete with the crop for light and nutrients, often leading to significant yield losses of up to 40% in legume crops (Tepe et al. 2005; Ali and Gupta 2012). Manual weeding has become uneconomical and impractical for many smallholder farmers due to high labor wages. During the last 25 years, weed menace and non-availability of machine harvest have been the major factors in area reduction under faba bean (100,000 ha), chickpea (50,000 ha) and lentil (60,000 ha) in North Africa. While weeds may not always cause severe yield losses, in absence of their effective control, they may lead to abandoning of cultivation. Weed control demands long hours of hand labor and possible expensive hired labor if this is available.

Agricultural production systems are intensifying across the different agro-ecological zones in West and North Africa and West Asia in response to increase in population pressure, demand, and opportunities for product marketing. The intensification of land use has however led to serious problems of soil fertility and parasitic weed infestation. Coupled with drought, these have caused a progressive decline in crop yields leading to food insecurity. Since 1967, IITA has maintained a collection of cowpea germplasm that now exceeds 15,000 accessions of cultivated varieties from over 100 countries and over 500 accessions of wild cowpea relatives that have been characterized and evaluated its germplasm collection for desirable traits including resistance to parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii* (Singh 2002a, 2005). The local cowpea variety Kanannado Brown has desirable traits of adaptation to relay intercropping, with a creeping habit, and the ability to smother weeds.

Orobanche crenata can reduce yield of faba bean severely in infested areas such as Morocco. Yield losses were reported from 7 to 80% depending on levels of infestation (Gressel et al. 2004). Nearly 80% of the Moroccan fields were infected by Orobanche (Mesa-Garcia and L. Garcia-Torres 1991). Efforts have been made to identify sources of tolerance (Khalil et al 2004a) and lines tolerant of Orobanche were developed in faba bean (Khalil et al. 2004a; Khalil and Erskine 1999; Maalouf et al. 2011). The resulting resistance may reflect a combination of resistance mechanisms that could be more durable than single gene resistances (Rubiales et al. 2006). Lentil can also be parasitized by *Orobanche crenata* as well as *O. aegyptiaca* and *O. ramose*, important pests in the Mediterranean Basin and Middle East on several food legume crops (Rubiales et al. 2006). Screening of 1774 germplasm accessions did not show genetic resistance to orobanche (Erskine et al. 1994). Only recently have potential resistance sources been reported in Spanish germplasm (Fernandez-Aparicio et al. 2008). Wild germplasm of *Lens ervoides, L. odemensis* and *L. orientalis* showed higher resistance against *O. crenata.* Two accessions, ILWL 361 and LENS166/92 showed true resistance to Orobanche (Fernandez-Aparicio et al. 2009).

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Appendix 9. Successes and constraints analysis of targeted legume adoption

Socioeconomics and targeting studies conducted under the Tropical Legumes II project (http://www.icrisat.org/impi-tl-2.htm) show that adoption of new varieties has been low and slow, with varieties that were released 15–20 years ago still occupying much of the area under grain legume production. Adoption of more promising varieties is limited by lack of access to information on available varieties, availability of varieties with desirable production and consumption attributes, and inadequate seed supply. The major drivers of dissemination of research products and adoption by farmers are farmers' access to new information and awareness; expected benefits and local availability of new technologies; market access and opportunities (performance of input and output value chains); and access to credit and other policies to enable farmer investment in new technologies. The uptake of technologies by farmers depends on whether a particular technology addresses key production constraints and has highly preferred traits. Institutional constraints to adoption include weak extension services and lack of physical and economic access to improved seed. While institutional and policy factors may hinder the uptake of otherwise profitable varieties and practices, addressing the needs and priorities of smallholder farmers and other actors along the value chain is the necessary condition for greater technology uptake and impacts.

Adoption may also be constrained by the effectiveness of grain legume improvement programs in the development and release of improved varieties. For example, since the 1970s groundnut improvement programs have developed and released 87 improved varieties in West and Central Africa alone, but the release intensities are found to be low. After 1990, annual variety release rates were estimated to be only 0.57 in Senegal, 0.67 in Nigeria, 1 variety in Niger, 1.33 in Burkina Faso, and 2.19 varieties in Mali. The low variety release intensity is largely explained by the inexistence of variety release procedures in countries such as Niger, the stringent procedure in countries such as Nigeria, and Senegal. In addition, public research systems in many countries face variety release procedures that do not favor legumes. In Kenya, for instance, the variety release system charges a fixed fee for a crop trial where grain legume breeders, with fewer entries, face higher per-variety costs. The length of the variety release process has led to cases where the same groundnut variety has been released many years apart in two neighboring countries.

For example, soybean is a non-traditional crop and smallholder farmers have to rely on outside suppliers to acquire quality seeds of improved varieties. Several factors limit the interest of existing seed systems (e.g., commercial seed companies) in improved seed of grain legumes. First, public-sector seed production has not been able to meet the demand for initial quantities of high-quality foundation seed stocks because priority is generally given to more commercial crops, such as hybrid maize. Furthermore, the legume seed industry offers low profitability because farmers recycle varieties multiple times once they receive the initial germplasm. Soybean’s high protein and oil content reduces seed viability over time. Many grain legumes also have a high seeding rate and low multiplication ratios. Groundnut, for example, has a high seeding rate of 60 kg/ha but a low multiplication ratio of around 10, and this poses challenges in producing large quantities of seed and distributing it to producers who are widely scattered in the rural community (Ndjeunga et al. 2006). Seed production often takes place in higher potential areas, with seed stores also being concentrated in zones of higher population density or those with better infrastructure. Thus, when the seed of promising varieties is made available locally, it tends to be too expensive and/or sold in large packages only suitable for larger-scale farmers. Many farmers have also become accustomed to receiving free seed and do not appreciate the investment required in high-value seed, especially in areas where crop failure is common. These factors explain well why the commercial (public or private) seed industry for legumes has often been slow to emerge in both developing and industrialized countries (Tripp 2011).

The seed-demand side also has a number of constraints. At the most fundamental level, many farmers simply do not know about new varieties (i.e. their potential advantages, where to access them, or how to manage them). The use of farmer participatory variety selection in grain legume improvement under the Tropical Legumes II project has increased the levels of awareness about the performances of new varieties among farmers. The adoption of new varieties by farmers has been enhanced by their involvement in the breeding activities. In Mali, for example, farmers had adopted the improved cowpea line IT98K-499-35 (to which they gave the name 'Jiguiya' which translates to 'hope') even before it was officially released by the releasing authority in the country. The involvement of farmers in variety selection will increase the level of adoption of new varieties.

The observed low private sector participation in the seed systems may indicate a market failure and the need for stronger public support for legume seed production and distribution at least in the early stage until demand is high to attract private sector seed companies. Given the limited interest of the private sector and the characteristics of legume crops, current efforts to produce and deliver seed focused on local and community based seed systems. These include seed loans, seed villages, seed banks, community seed enterprises, seed exchange programs, farmer research groups, seed fairs and small seed packs (Tripp 2011). It is important to build on the strengths and adaptability of the informal approaches and enhance the opportunity to increase both seed supply and quality through the participation of local seed producers, farmer groups, and agro-dealers with capacity building and monitoring to produce and market quality seed. The transition between a community based systems and a sustainable commercial seed system remains a challenge. The importance of quasi-formal or market based channels increases with the availability of new farmer-preferred varieties that creates incentives for the emergence of markets and trade in the supply of the new seeds.

Beans in sub-Saharan Africa

Sperling and Munyaneza (1995) and Kalyebara et al. (2008) documented adoption of improved beans at the national level. These studies measure adoption rates and extent of adoption but do not focus on the full set of the factors that could constrain or facilitate adoption of these varieties. These studies were supplemented by additional information generated through community follow up studies. Though conducted on small scale, these studies provide some insights into the barriers of adoption in specific locations that is relevant to many other parts of the region with similar production context.

The literature shows mixed results regarding adoption of improved bean technologies. A study conducted in 2005 across five countries (Tanzania, Uganda, Rwanda, DRC and Malawi) show high adoption of varieties released in 1980s and 1990s (Kalyebara et al. 2008). Sperling and Munyaneza (1995) used a nationwide household data and estimated adoption rate of 40% and intensity of 10-20% for climbing beans in Rwanda after about 7 years of intervention. High adoption of these varieties was explained by their attractive attributes selected with active involvement of farmers and investment in seed delivery (Odendo at al. 2002; David at al. 2002; David and Sperling 1999). In the 1990s, studies of local seed systems were undertaken to reveal how farmers obtain seed as the context for introducing improved varieties (Sperling et al. 1996; Rubyogo et al. 2010). Decentralized seed production was pursued with a range of local partners to reduce transport costs and final price to farmers. Comparing sites defined by degree of seed system intervention, the authors also noted high adoption in areas where seed dissemination was higher, implying that adoption of legume varieties depend greatly on the effort invested in dissemination. The problem of dissemination of new varieties is exacerbated by biases brought in by private sector when public investment in the dissemination is weak. Farmers with good access to markets, tend to select varieties that they are certain have market demand and private seed producers also tend to invest in the multiplication and marketing of seed for varieties already popular on the market (Odendo et al. 2004, Rubyogo et al. 2010).

Also contributing to high adoption of improved bean varieties has been high number of varieties released and disseminated over time. Kalyebara et al. (2008) study covered 184 improved varieties.

Sperling and Munyaneza elaborate how disseminating many varieties was able to sustain diffusion of improved varieties after a root rot epiphytotic broke out in 1991 in Rwanda, attacking a popular variety. A high number of varieties increases the chance of farmers finding an appropriate match.

Table 6: Adoption of new varieties in study countries, 2008

Location	Year when first new varieties were released	Adoption rate* (% of households)	% of total bean area occupied by new varieties in 2003-5
D.R. Congo	1989	82	68
Malawi	1993	55	46
Rwanda	1985	64	43
Tanzania	1985	81	56
Uganda	1994	53	31

Source: Kalyebara et al. (2008). The studies used sample sizes between 250-750 selected to represent all bean growing agroecological zones at national level.

The high incidence, diversity and severity of biophysical stresses and socioeconomic problems faced by farmers lead them to demand a wide range of production and grain attributes to match their conditions that can only be met through a diversity of varieties (Sperling et al. 1993; Katungi et al. 2011a). Odendo et al. (2004) report over 11 traits preferred by farmers during on farm evaluation of root rot resistant bean varieties in Western Kenya. The result is partial adoption of any individual variety and high variety diversity at micro and macro levels, with the possibility of low yield gains at farm level but improved yield stability as noted in Ethiopia (Katungi et al. 2010). For example, in more severe production constraints, such as those experienced in parts of drought-prone areas of Kenya, farmers continue to cultivate a relatively drought resistant local variety but with inferior consumption attributes alongside a variety of the preferred market class but with low resistance to drought (Katungi et al. 2011a).

Unlike improved varieties, the adoption of improved crop management, particularly soil fertility replenishment inputs, has been modest (Kalyebara et al. 2008; Katungi et al. 2011b). This has been attributed to problems on the supply and demand side. On the supply side, there has been low investment in dissemination of information about their profitability, application under different conditions, and risk aversion advantages. Kalyebara et al. (2008) report only 1% to 12% of farmers trained in use of bean management technologies during dissemination of bean varieties int the 1980s and 1990s. Katungi et al. (2011b) and Negash (2007) also found significant positive effects of access to extension and credit in the use of fertilizers on bean in the central rift valley areas and Southern regions of Ethiopia, a country where extension reach has been low but is increasing.

On the demand side, use of recommended crop management practices is constrained by several factors at farm as well as community level. Common bean is grown in a highly complex farming systems mainly by women who have limited access to production resources (i.e. labour, quality land, credit and information (Ellis et al. 2007; Sida 2010). Yet the dissemination approaches for management inputs to enhance the profitability of use on beans and other legumes alike have not received the level of research attention that matches the level of complexity and gender characteristics of the farmer. As Gebreselassie (2006) elaborates with the case of Ethiopia, general recommendations might limit the profitability of input use for some crops when grown in complex systems.

A complexity of farming systems also means that crops and agricultural enterprises that interact to complement their agronomic performance may compete for farmer limited resources. It has been observed that use of management inputs such fertilizers and certified seed has been low in bean production even in locations were such inputs are widely diffused but are used on other crops (for example, chemical fertilizers in maize in Kenya or potato in Nothern province of Rwanda). This can be interpreted as low competitiveness of legumes relative to other crops that the design of CRP for

Grain Legumes should take into account. Kelly et al. (2001) analyzed fertilizer use profitability on key crops (including climbing bean and potato) in Rwanda using a value cost ratio and found high profitability for potato (more than 8) compared to climbing bean (more than 3).

Chickpea in South Asia

A study conducted in Uttar Pradesh of India during the 2002-06 rabi season showed that about 310 farmers used improved chickpea varieties (DCP 92-3 and JG 315) and 45% in non-project villages in Hamirpur district. Recently, improved chickpea varieties have replaced almost 75% of local varieties and are expected to cover 90% of area soon. Over a period of 3-4 years (2002-06), adoption of a full chickpea technology package increased from about 10% farmers in 2002-3 to 45% farmers in 2004-5 with positive response in project villages (Singh et al. 2008).

In Nepal, only six varieties have been released over the last two decades. About 8% of farmers used improved varieties in 1999/2000 and the adoption was highest in western region. The popular improved varieties of choice were Koseli, Sita, Tara, Trishul, Dhanush, Radhe and Avrodhi. The adoption was possible due to the efforts of National Agricultural Research Council (NARC) under a research and action project on secondary crops. Reasons reported for non-adoption of improved varieties were non-availability of seed and lack of knowledge about improved management practices and IPM (Pande et al. 2003).

In Myanmar, chickpea is an important food legume and it is mainly grown in central dry zone of the country with an estimated area of over 200,000 hectares. The Department of Agricultural Research (DAR) has strong collaboration with ICRISAT in chickpea R&D leading to the release of six chickpea varieties. Yezin 3 and Yezin 4 released in 2000 and Yezin 5 and Yezin 6 in 2004 have wide adaptation as evidenced by their release in two or more countries. Yezin 3 to Yezin 6 covered about 82% of total chickpea area in Myanmar. The adoption of improved varieties was 91% in Sagaing Division, 71% in Mandalay and 72% in Magway Division. Yezin 3 (ICCV 2) was the most popular variety grown on about 55% of area followed by Yezin 4 (ICCV 88202) with 22% coverage of area. Yezin 5 (ICCV 3) and Yezin 6 (ICCV 92944) covered 4% and 1% area, respectively (Than et al. 2007).

Cowpea in Sub-Saharan Africa

Household survey evidence of adoption of improved cowpea

A large number of improved cowpea varieties have been released in several countries, but lack of comprehensive and up-to-date information on the generation and adoption of improved varieties has limited our efforts to assess the adoption and impacts of these in Sub-Saharan Africa. The few adoption studies showing promising levels of uptake of cowpea varieties have been localized and mostly in northern Nigeria, and were not representative of the larger recommendation domains in each country. However, the estimates were indicative of the possible successes that could be realized if the same efforts and investments could be replicated elsewhere in the respective countries. In a study conducted in 1999 in Kano and Jigawa states in northern Nigeria, for example, Kristjanson et al. (2002) found that some 38% of the cowpea area was planted to improved dual-purpose cowpea varieties. An extrapolation from adoption rates estimated that about 1.4 million hectares of the potential cowpea area across the dry savanna of West Africa could be under improved varieties. In a study conducted in 2004 on the role of a pilot farmer-to-farmer diffusion of improved cowpea in Kano and Kaduna states in northern Nigeria where the number of beneficiaries increased from 4,000 farmers in 1999 to 27,000 in 2003, Alene and Manyong (2006) showed that over 70% of the farmers in the project villages adopted improved varieties. Similar studies on adoption of improved cowpea varieties in other parts of northern Nigeria showed adoption estimates of 56% of the sample households in Bauchi and Gombe states (Agwu 2004), 40% of cowpea area in Borno state in 2007 (Gadbo and Amaza 2010), and up to 75% farmers in TL II project areas of Kano and Borno States.

In Ghana, Sanders (1994) reported on a new variety, Vallenga, which was released in 1987 and introduced on more than 20,000 ha in the north already in early 1990s. In 2007, Abatania et al. (2000) found adoption estimates of 16% of the cowpea area in the Northern and Upper West regions. The continued dominance of old improved varieties that were introduced several decades ago means that adoption studies should distinguish between old and new improved varieties. This lack of distinction probably explains the significant variability in adoption estimates for particular regions and countries. In northern Senegal, for example, Schwartz et al. (1990) found that the introduction of an early maturing cowpea variety in 1985 doubled the area sown to cowpeas and increased the national production from the previous 15-year average of 17,800 to 66,000 tons in that year. Boys et al. (2007), on the other hand, found that less than 4% of the sample households surveyed in 2004 adopted new cowpea varieties. In Burkina Faso, Sanders (1994) found that already by 1992 diffusion of eight new cowpea varieties was almost 100% of the cowpea area.

The estimated yield differentials between improved and traditional cowpea varieties vary greatly depending on the production techniques. In Niger and Cameroon, the yield advantage was estimated to range from 25 to 46% depending on the region (Sterns and Bernsten 1994; Mazzucato and Ly 1994). The yield advantage of the most recent NARS releases in Senegal was about 40% in on-farm trials over older improved varieties. The available evidence of economic returns to cowpea research show positive returns ranging from as low as 3% in northern Cameroon to as high as 32–92% in Senegal, suggesting that research and technology transfer activities on cowpeas in Africa have contributed to increased productivity of the agricultural sector in several countries. The benefits of cowpea research are also in the form of gains due to maintaining yields over time in an increasingly difficult environment. Sanders (1994) estimates about 25-50% aversion in yield loss due to the development and diffusion of improved varieties. According to his estimates for Burkina Faso and Mali, the annual benefits to maintaining farmers’ yields ranged from $0.8 to $4.8 million per year between 1984 and 1992 with the most conservative assumption of 25% yield decline in the absence of new varieties.

Expert survey evidence of adoption of improved cowpea

In 2010, IITA carried out a survey of national cowpea improvement programs in 16 countries, which together account for over 95% of the total cowpea production in Sub-Saharan Africa (Alene et al. 2012). Table 7 presents the expert estimates of adoption of improved cowpea varieties in Sub-Saharan Africa. The results showed that improved varieties accounted for an estimated 23% of the total cowpea area in Sub-Saharan Africa. However, the average adoption estimate of 23% for Sub-Saharan Africa masks important variations across sub-regions. In West and Central Africa, for example, nearly 50% of the cowpea area is under improved varieties, compared with 16% in East and Southern Africa. The highest adoption rates are recorded in D.R. Congo, Ghana, Cameroon, Guinea, Benin, Niger, and Mali where the share of improved cowpea area is between 50 and 87% of the total area under cowpea cultivation. Six countries (i.e. Zimbabwe, Togo, Nigeria, Tanzania, Senegal and Cote d'Ivoire) are classified in the middle category for improved cowpea adoption in Africa. These countries have reached adoption rates of at least 20% but fall below 50% of total cowpea area. Nigeria has largest number of released varieties and relatively higher research expenditures committed towards cowpea improvement programs in Africa but the country has a modest cowpea adoption rate estimated at 39% compared to other countries in the high-adoption category.

Table 7: Adoption of improved cowpea varieties in Sub-Saharan Africa, 2009

Country	Improved varieties (% cowpea area)	IITA-related varieties (% cowpea area)
Benin	51	45
Burkina Faso	10	5
Cameroon	71	50
D.R. Congo	87	51
Ghana	82	78
Guinea	62	60
Malawi	10	10
Mali	53	31
Mozambique	11	9
Niger	9	3
Nigeria	39	28
Senegal	27	19
Tanzania	31	31
Togo	40	40
Uganda	15	15
Zambia	17	11
All	24	16
Sub-Saharan Africa	**23**	**16**

The lowest adoption rates were reported for Malawi, Burkina Faso, Mozambique, and Zambia with rates below 20%. These countries except Mozambique have released few improved cowpea varieties and as such farmers have limited opportunities for selecting suitable/elite varieties. The pool of available improved varieties may not substantially address the needs of the cowpea producers and consumers in the changing biotic and socio-cultural environment. Malawi, Mozambique and Zambia have low to medium research expenditures committed towards cowpea improvement activities. It is noteworthy that apart from the Bean/Cowpea CRSP research program, no other major collaborative research program has been implemented in southern Africa that is of equal magnitude to those implemented in West and Central Africa.

The popular varieties in terms of farmer adoption are IT82E-32 covering 23% of the total cowpea area in Ghana, 11% in Benin and 2% in Cameroon followed by VITA-7 accounting for 22% of total cowpea area in Guinea and 13% in D.R. Congo. The adoption rate for variety IT81D-1137 is estimated at 17% in D.R. Congo and 14% in Benin. These varieties are attractive to the farmers because they embrace multiple attributes such as high yield potential, disease tolerance, and short maturity period. Other varieties with high single-country adoption rates are IT81D-985 or BR1 (30%) and *Lori Niebe* (18%) in Cameroon; IT82E-16 (8%) in Benin; H36 (33%) and Diamant (11%) in D.R. Congo; IT87D-1951 or Asetenapa (19%), ITXP-148-1 (Apagbaala) (14%), IT97K-499-35/Songtra (10%), and IT95K-193-2 (Bawutawuta) (6%) in Ghana; IT83S-899 (11%) in Guinea; Korobalen (IT89KD-374) (18%), Sangaraka (IT89KD-245) (12%), Yere wolo (PRL 73) (11%), and Djemani (PBL 22) (7%) in Mali. In Niger the famous improved cowpea varieties are KVX30-309-6G (10%), IT89KD-374-57 (9%), IT90K372-1-2 (8%), TN27-80 (7%) and TN5-78 (7%).

Groundnut in Sub-Saharan Africa and South Asia

Few studies have examined the adoption rates of improved groundnut varieties in sub-Saharan Africa. Most of these studies have been undertaken in and around project/program intervention sites. Adoption rates vary significantly from zero in Senegal to 59% in Zambia. A baseline household survey of adoption of improved groundnut varieties, conducted as part of the Groundnut Seed

Project in West and Central Africa, indicated adoption rates of 14% in Niger, 44% in Mali, and 32% in Nigeria (Ndjeunga et al. 2008). A similar baseline household survey of adoption of improved groundnut varieties, conducted as part of the Tropical Legumes II project, indicated adoption rates of 24% in Niger, 8% in Nigeria, and 3% in Mali. The discrepancies in the adoption rates are largely explained by the fact that the samples were not nationally representative and were localized in and around intervention sites.

In a recent nationally representative survey in Nigeria, the adoption rate of improved groundnut varieties was found to be 22% of the cultivated area. Using a nationally representative survey from Uganda, Kassie et al. (2010) estimated that 53% of the groundnut area was planted with improved varieties. These estimates are more or less consistent with expert opinion surveys carried out in various countries across Sub-Saharan Africa. Estimates from experts show adoption rates of 47% in Kenya, 57% in Malawi, 27% in Mali, 12% in Niger, 22% in Nigeria, 32% in Tanzania, and 56% in Uganda (Simtowe at al. 2012).

Asia is the largest producer of groundnut in the world. In India, production is concentrated in five states of Andhra Pradesh, Gujarat, Karnataka, Tamil Nadu and Maharashtra. ICRISAT and NARS have both released improved varieties which are high-yielding, disease-resistant and drought tolerant. In a study by ICRISAT, it was found that variety ICGS 44 was adopted in Andhra Pradesh to the extent of 98% during the rainy season, 58% during the post-rainy season and 32% during the summer season of 1997 in Guntur and West Godavari districts. Other varieties were adopted between the range of 17% and 60% in a few districts in South India. Longer duration varieties did not find favor with the farmers due to non-availability of seeds and longer duration. ICGV 91114, which was released in 2006 in Anantapur district of Andhra Pradesh, showed a very low level of adoption (0.2%), the main reasons being the deficiencies in the informal seed systems and lack of irrigation facilities. However, the variety was adopted during years of drought due to better crop and fodder yield (Birthal et al. 2011). The lack of adoption of ICGV 91114 was further investigated in 2011 in an ILRI study reported that haulm characteristics were not widely appreciated. However, milk yield is 0.5 liters more per day when this variety is used, a fact that was overlooked in the early stages of dairy intensification. The study also suggested that in order for the haulm yields to be appreciated, the dairy farmers could have been targeted for better acceptance. Nevertheless, strengthening farmer-to-farmer seed distribution would prove to be worthwhile. Recent baseline studies conducted under the Tropical Legumes II project in Karnataka and Tamil Nadu also underscored the fact that older groundnut varieties still predominate. In India, the baseline adoption level for TM-2 was reported to be 64-100% (Ndjeunga et al. 2009).

Pigeonpea in Sub-Saharan Africa and South Asia

Few studies have examined the adoption rates of improved pigeonpea varieties in sub-Saharan Africa. A nationally representative sample survey of uptake of improved pigeonpea varieties in Tanzania showed an actual adoption rate of 19% with a potential adoption of 62% had all pigeonpea growers been exposed to the varieties. Farmers who adopted are those exposed to varieties through participatory variety selection trials and those who were constrained by land holding and thus forced to intensify (Simtowe et al. 2011). Data from expert opinions from the DIVA project showed adoption rates ranging from 13% in Malawi to 60% in Kenya (Simtowe 2012). Expert opinion surveys indicated high adoption rate for pigeonpea in Kenya (60%), 40% in Tanzania, and 50% in Mali (Simtowe 2012).

India produces more than 80% of Asia's pigeonpea. Although there is little recent evidence on adoption of improved pigeonpea varieties in India, there had been earlier successes in short-cycle pigeonpea (Bantilan and Parthasarathy 1999) and recent innovations such as very short-duration varieties and the development of hybrid pigeonpea (Tripp 2011). In a separate study conducted in project villages in Uttar Pradesh, it was found that 80% of the area (190 ha) was planted with the improved pigeonpea variety NA 1. A total of 218 farmers of project villages grew this variety during

2005 rainy season. In neighboring areas involving 24 villages, more than 200 farmers adopted NA 1 over 25% of the pigeonpea area.

Soybean in Sub-Saharan Africa

Soybean constitutes an important component of the smallholder cropping systems in Africa and holds considerable potential for arresting soil fertility decline, enhancing household food and nutrition security, and raising rural incomes thus reducing poverty. Poor households in Nigeria, for example, account for the production of over 80% of soybean (Alene et al. 2009). The dramatic increase in world soybean prices has influenced domestic prices in Africa generated interest among farmers relative to other food or cash crops. Other factors have increased demand, such as for domestic processing for edible oil and for soybean meal targeted to the poultry feed industry. Africa is projected to have a deficit of 196,000 tons in 2020 and 450,000 tons in 2030 (Alene et al. 2012). Soybean production represents a significant opportunity for Africa to realize considerable foreign exchange savings through increased domestic production for import substitution.

Soybean production and productivity has increased through a value chain approach to technology development and dissemination. IITA developed and disseminated a range of improved varieties as well as household level soybean processing technologies coupled with product development aimed at promoting technology adoption. Currently, over 80 soybean-based agro-processing businesses exist in Nigeria. As women also handle much of the cowpea and soybean production, they can easily integrate production, processing, and marketing activities to generate cash incomes in addition to ensuring household food and nutrition security through increased home consumption. Promotion of soybean recipes in Nigeria led to increased local trading of soybean food products, with attendant improvement in the nutritional status of many Nigerians, particularly infants and school children. Increased demand for soybean-derived products in turn led to increased production of soybeans (World Bank 2009).

Household survey evidence of adoption of improved soybean

In Benue state of Nigeria, which is the major producer of soybean in the country, Sanginga et al. (1999) found that adoption of new varieties increased from mere 9% of farmers in 1989 to over 75% farmers in 1997, with the varieties occupying an estimated 30% of the total soybean land area. Analysis conducted using a Tobit model showed that farmers' socioeconomic characteristics and farmers' assessment of the attributes of improved varieties were both important in explaining their adoption behavior. The adoption of soybean varieties had a clear positive impact on household income generation and distribution, material welfare, human capital development, gender relations, resource use, social equity, and other social processes in the community. Akinola et al. (2009) measured the economic impacts of soybean-maize rotation research involving promiscuous soybean varieties in Nigeria, Ghana, Togo, and Benin. In 2005, about 40% of the sample households surveyed in northern Nigeria cultivated promiscuous soybean varieties in rotation with maize. The household survey data on adoption were used to extrapolate ceiling adoption rates that can be expected across the entire northern Guinea savanna of West Africa. Results showed that soybean-maize rotation research and extension generates a rate of return in the range of 35% to 43%. Alene et al. (2009) assessed the overall economic gains as well as the equity effects of alternative commodity research programs in Nigeria and found that, with a rate of return of 72%, each dollar invested in soybean research generates 46 dollars worth of benefits for the poor, relative to 70 dollars for all households. Poor households in Nigeria thus capture 66% of the benefits from soybean research. With a rate of return of 81%, each dollar invested in cowpea research on the other hand generates 53 dollars worth of benefits for the poor, relative to 99 dollars for all households. Poor households in Nigeria thus capture 54% of the benefits from cowpea research.

Expert survey evidence of adoption of improved soybean

In 2010, IITA carried out a survey of national soybean improvement programs in 14 countries, which together account for over 75% of the total soybean production in Sub-Saharan Africa (Alene et al.

2012). Table 8 presents the expert estimates of adoption of improved soybean varieties in Sub-Saharan Africa in 2009. Largely because soybean itself is new as a crop and its cultivation is made possible through improved varieties, the total soybean area in Cote d'Ivoire, Malawi, Zambia, and Zimbabwe is under improved varieties, whereas Uganda, Nigeria, and Ghana have adoption levels of over 90%. Of the 1.3 million hectares planted to soybean in Sub-Saharan Africa, about 0.7 million hectares (52%) were planted to IITA-related varieties, reflecting the important role that IITA plays in soybean genetic improvement in Sub-Saharan Africa. Of the total area planted to soybean, IITA-related varieties ranged from 2% in Benin to 75% and above in Cameroon, Cote d'Ivoire, Nigeria, and D.R. Congo. In Nigeria, about 82% of the soybean area was planted to IITA-related varieties. In Uganda, more than half of the soybean area was planted to IITA-developed varieties. IITA has thus made greater contribution to soybean improvement in West and Central Africa, relative to Eastern and Southern Africa. This is because of the fact that IITA's soybean breeding activities had in the past concentrated in West Africa and its influence in Southern Africa was minimal.

Two improved soybean varieties are widely cultivated in West and Central Africa. First, TGx 1448-2E, a shattering and frog eye leaf spot resistant IITA-bred variety is occupying slightly more than 60% of soybean area in Nigeria and more than 20% in Cameroon and Ghana. Second, TGx 1835-10E, another IITA-developed variety which is desired for its early maturity and resistance to soybean rust, pod shattering, and lodging dominates soybean area in Uganda (50%) and covers 26% and 6% of total land area in Kenya and Nigeria, respectively. The variety Anidaso (TGx 813-6D), which was released in 1992 in Ghana, covers 56% of area planted to soybean. Vuangi and Munanga are two most popular IITA-bred varieties in Uganda with resistance to pest and diseases, dehiscence and pod shattering and each occupies 55% and 35% of area planted to soybean, respectively. Bossier, a landrace with wide agro-ecological adaptation and intermediate maturity, was introduced in Tanzania in 1978 and it dominates soybean area coverage by occupying slightly below 50% of soybean area. Other varieties enjoying high adoption rate are Safari and Ocepara-4, occupying over 44% of soybean area in Zimbabwe and Malawi, respectively. Variety-specific adoption data show that it is only Benin, D.R. Congo, and Tanzania where dominant varieties are more than 20 years old. In D.R. Congo, not a single improved variety has been released since 1998, and this has limited farmers' choices and most continue cultivating old varieties.

Table 8: Adoption of improved soybean varieties in Sub Saharan Africa, 2009

Country	Improved varieties (% soybean area)	IITA-related varieties (% soybean area)
Benin	50	2
Cameroon	75	75
Cote d'Ivoire	100	78
D.R. Congo	100	100
Ghana	94	61
Kenya	74	42
Malawi	100	0
Nigeria	96	82
Tanzania	79	13
Togo	39	0
Uganda	97	53
Zambia	100	0
Zimbabwe	100	0
All	95	60
Sub-Saharan Africa	**82**	**52**

Note: Adoption rates of improved soybean varieties should be interpreted with caution because, in many countries, soybean was introduced as a new crop (via improved varieties) only recently. Adoption rates thus appear to be high, but the absolute area under soybean is small.

Machine harvesting

Manual harvest of legume crops is becoming increasingly uneconomical because of the rising labor cost and shortage of labor at the peak harvest time. Delay in harvesting of the crops leads to significant grain losses in the fields. Harvesting of legume crops is mechanized in the developed world. By contrast in developing countries, these crops are largely hand-harvested because of non-availability of improved varieties amenable to machine harvest. To use the combine-harvest machine, legumes varieties need to be modified for suitability to machine harvest. This requires development of varieties with erect and tall plants, strong stems, top pod bearing habits, synchronous maturity; and tolerance to lodging and pod shattering. Genetic variability for these traits exists in the germplasm. Mutants with upright growth habit have been identified and used for development of improved breeding lines in chickpea (Dahiya et al. 1990, Sandhu et al.1990, Lather 2000, Gaur et al. 2008) and lentil (Erskine and Goodrich 1991). An elite tall chickpea breeding line with upright growth habit yielded about 4 t ha-1 under high density planting (50 plants per m^2 compared to normal planting 33 plants per m^2) and was suitable for mechanical harvesting as the fruiting zone started at about 20 cm from the base (Lather 2000). In lentil also, Idleb 2 variety has been found suitable for machine harvest (El-Ashkar et al. 2003). The utilization of available genetic variability for plant traits in breeding programs will help in the development of improved breeding lines suitable for mechanical harvest. The cultivars suited to mechanical harvesting with herbicide application will reduce cost of cultivation and drudgery to women.

Nutrition and health

Akibode and Maredia (2011) indicate that many of the poorest countries in the world derive the highest proportion of their total dietary protein from grain legumes (10-20% or more). Low lysine content is the limiting constraint in cereal-dominated diets relative to human amino acid balance. Legumes are superior sources of lysine, and increase the biological value of the combined protein. The current WHO-endorsed index for protein quality is the protein digestibility-corrected amino acid score (PDCAAS) that estimates the true value of food protein for the human body. Experts recommend that foodstuffs of at least 70% PDCAAS should be consumed (Michaelsen et al. 2009). The PDCAAS values of cereals are around 35%, indicating their low protein quality when consumed in isolation. Grain legume PDCAAS range from 45-93% with soybean the highest in quality, while a cereal-legume combination in the proportions of 70/30 (weight/weight), can usually reach or exceed this PDCAAS threshold (Ejigui et al. 2007; Michaelsen et al. 2009). Thus, even in countries where a cereal is the dominant source of protein, every gram of legume protein potentiates another gram of cereal protein. Legumes also have other important positive effects. Enhanced iron concentration in beans was shown to improve iron status in Mexican school children (Haas et al. 2010). Grain legumes exhibit low glycemic index thus reducing the risk of obesity and diabetes (Foster-Powell K. et al. 2002). Grain legume consumption also has positive effects on colon and breast cancer (Correa 1981; Hangen and Bennink 2003; Thompson et al. 2008) and cardiovascular disease (Kabagambe et al. 2005). Preliminary tests with HIV/AIDS victims fed grain legumes shows an increase in cell counts of CD4 cells, a primary element of the immune system (M. Bennink, personal communication).

Aflatoxin contamination remains an important quality concern worldwide threatening its trade and profitability (Wu et al. 2008; Felicia et al. 2008), besides adversely affecting health of groundnut consumers. End-of-season drought not only reduces crop yield substantially but also predisposes groundnut to infection by aflatoxin producing fungi *Aspergillus flavus* and *A. parasiticus*. *A. flavus* and *A. parasiticus* can invade groundnut seed in the field before harvest, during post-harvest drying and curing, and in storage. Resistance to preharvest aflatoxin contamination (seed infection and aflatoxin production) remains a key in breeding for aflatoxin resistance (Nigam et al. 2009). Pod wall, seed coat and cotyledons are all potential barriers to the aflatoxin producing fungi (Mehan 1989). These three components of resistance are inherited independently (Upadhyaya et al. 2002, Utomo et al. 1990). Sources of resistance to all three types of resistances have been reported in the cultivated groundnut (Mehan 1989, Rao et al. 1995, Upadhyaya et al. 2001, Waliyar 1994). Wild

Arachis species have shown genetic variation for in vitro seed colonization (IVSC) and aflatoxin production (Thakur et al. 2000, Xue et al. 2004). The development of transgenic groundnut using either resistance associated genes/proteins (RAGs) or antifungal genes for resistance to *A. flavus* infection and associated aflatoxin contamination is an alternative solution to this complex problem. Seed infection and aflatoxin production show high genotype × environment interactions, with large variations between replications and samples, and requires development of reliable screening techniques that minimize the variations under field conditions.

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Appendix 10. Product Line logframes

Product Line 1.Drought and low-phosphorus tolerant common bean, cowpea and soybean

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Quantitative data available on degree of stress in different environments, and on interactions among the stresses (SC1)	On-station trials for drought and low P conducted in 5 countries (Y1) On-farm trials conducted at 50 sites for each crop (Y2)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA, NARS	Researchers have more focused and relevant research agenda
Common screening methods for tolerance to drought and low P stress developed (SC2)	At least 2 root and 3 shoot parameters applied to 4 legumes species (Y1)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA	Researchers screen and select germplasm and breeding lines more efficiently for drought and low P tolerance.
Field screening sites with managed stress conditions identified for phenotyping and breeding (SC2)	At least 1 tropical “hub” identified for each crop and stress, with a potential for multiple stresses (Y2)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA, NARS	Researchers have access to field sites with better uniformity and capacity for managed stress.
Sources of shoot traits (transpiration efficiency, water saving traits, and for sink strength) for tolerance to drought, and root traits for tolerance to low P in germplasm and breeding lines identified (SC2)	At least 500 lines/ accessions screened for at least two traits related to low P and drought tolerance in each crop (Y2) At least 3 elite sources for 2 traits related to low P and drought tolerance identified per crop (Y3)	Global	CIAT, IITA	Breeders incorporate traits and use trait selection in mainstream breeding for stress tolerance
Key alleles contributing to superior photoassimilate translocation under drought or low P stress in common bean and other species identified (SC2)	Transcriptome of 2 contrasting common bean and 2 tepary beans compared for identification of genes associated with grain filling under drought or low P (Y3) Transcriptome analysis under stress extended to other 2 legumes (Y5)	Global	CIAT	Breeders use favorable alleles in enhancing drought and low P tolerance

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
QTL for reduced flower abortion and enhanced pod formation under drought stress in common bean mapped (SC2)	QTL identified for differences in pod formation in common bean (Y4)	Global	CIAT	Breeders use molecular markers for efficient breeding for drought and low P tolerance
Gene based markers for improving drought and low P tolerance identified (SC2)	Markers for 2 key genes for root development identified (Y2) Markers for improved photoassimilate translocation developed (Y4)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA	Breeders use molecular markers for efficient breeding for drought and low P tolerance
Ideotypes with key traits and related genetic make-up for stressful production environments developed (SC2)	Lines with combinations of 2 or 3 traits available for testing (Y4) Lines with multiple traits tested at 5 stressful environments with partners from CRPs 1.1 and 1.2 (Y5)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT	Breeders, physiologists and agronomists use trait based approach, and orient research accordingly
Cultivars with enhanced yield and resource use efficiency in drought and P-limited environments developed and disseminated (SC2,SC3)	10 elite lines per crop with greater input use efficiency and 40% better yield under individual stress distributed to partners for testing (Y5) Seed availability of drought and low P tolerant cultivars enhanced (Y6)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA, NARS	Farmers benefit from 30% higher yields on farm, and from cultivars that also respond better to modest levels of inputs
Post- harvest processing technologies for common bean, cowpea and soybean refined and disseminated (SC4)	At least two post-harvest technologies for each crop disseminated to users (Y3)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA, NARS	Smallholder farmers and consumers benefit from reduced post-harvest losses and value added products
Capacity of NARS in research on drought and low P tolerance in grain legumes enhanced (SC5)	At least 30 NARS researchers provided short-term training on tools and techniques (e.g. phenotyping; molecular breeding) for improving abiotic stress tolerance in GLs (Y3)	SSA: Burkina Faso, Senegal, Ethiopia, Malawi, Nigeria LAC: Mexico, Honduras, Nicaragua	CIAT, IITA, NARS	NARS breeding programs more efficiently breed for abiotic stress tolerant cultivars of grain legumes

Product Line 2. Heat tolerant chickpea, common bean, faba bean and lentil

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Target areas and cropping systems requiring heat tolerant cultivars of chickpea, common bean, faba bean and lentil identified (SC1)	Database developed on current and potential areas to better target heat tolerant cultivars of chickpea, common bean, faba bean and lentil (Y1)	SSA: Ethiopia, Tanzania and Malawi LAC: Brazil, Honduras, Puerto Rico, Columbia CWANA: Iran, Morocco, Egypt, and Syria SSEA: India, Pakistan, Myanmar,Bangladesh	ICRISAT, ICARDA, CIAT, NARS	Farmers adopt heat tolerant cultivars of chickpea, common bean, faba bean and lentil in traditional and non-traditional areas
Phenotyping protocols for heat tolerance developed and sources of heat tolerance identified in each target legume species (SC2).	Field, greenhouse/growth chamber and laboratory screening methods developed and validated for chickpea, common bean, faba bean and lentil (Y2) 4-5 additional sources of heat tolerance identified in chickpea, common bean, faba bean and lentil (Y1)	Global	ICRISAT, ICARDA, CIAT	Researchers use high throughput phenotypic protocols for heat tolerance screening
Better understanding of the physiological mechanisms of heat tolerance (SC2)	Effect of varying levels of high temperatures on reproductive functions assessed in chickpea, common bean, faba bean and lentil (Y2) The reproductive behavior of contrasting genotypes for heat tolerance studied under heat and no stress conditions (Y3) Metabolic and biochemical pathways for heat tolerance studied (Y4)	Global	ICRISAT, ICARDA, CIAT	Legume breeders use more efficient selection methods for improving heat tolerance

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Interaction between heat and moisture stress understood (SC2)	The interaction between heat stress and drought stress at reproductive assessed (Y2) The effects of heat stress on severity of fusarium wilt and dry root rot assessed (Y2)	SSA: Ethiopia, Tanzania and Malawi LAC: Brazil, Honduras, Puerto Rico, Columbia CWANA: Iran, Morocco, Egypt, and Syria SSEA: India, Pakistan, Myanmar,Bangladesh	ICRISAT, ICARDA, CIAT	Breeders use more efficient selection procedures to identify stable heat tolerant and disease resistant breeding lines/cultivars of chickpea, common bean and lentil.
Candidate genes, molecular markers and novel breeding methods for heat tolerance identified/developed (SC2).	Candidate genes for heat tolerance identified (Y3) Molecular markers for heat tolerance identified and validated in chickpea (Y3), common bean (Y4), faba bean (Y4) and lentil (Y4) Gametophytic selection methods for heat tolerance developed in chickpea, common bean and lentil (Y4)	Global	ICRISAT, ICARDA, CIAT	Legume breeders use novel breeding approaches (e.g. MAS, GWS, gametophytic selection) for improving heat tolerance
Chickpea, common bean, faba bean and lentil breeding lines combining enhanced heat and dry root rot tolerance and improved grain quality available (SC2).	At least 15 heat tolerant breeding lines each in chickpea, common bean, faba bean and lentil with >30% higher yield compared to the heat sensitive cultivars under heat stress, and with improved grain quality developed (Y3) At least 10 breeding lines with heat tolerance and resistance to dry root rot developed (Y4)	SSA: Ethiopia, Tanzania and Malawi (chickpea, common bean) LAC: Brazil and Mexico (common bean) CWANA: Turkey, Iran, Morocco, and Syria (chickpea, faba bean, lentil) SSEA: India and Bangladesh (chickpea, lentil)	ICRISAT, ICARDA, CIAT	Greater choice available to farmers in heat tolerant cultivars of chickpea, common bean, faba bean and lentil

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
ICM practices for chickpea, common bean, faba bean and lentil crops grown under heat stress conditions developed (SC2).	Nutrient requirements established for chickpea, common bean, faba bean and lentil grown under heat stress conditions (Y3) IPM practices for pod borer standardized for chickpea grown under heat stress conditions (Y3)	SSA: Ethiopia, Tanzania and Malawi (chickpea, common bean, faba bean) LAC: Brazil and Mexico (common bean) CWANA: Turkey, Iran and Syria (chickpea, lentil) SSEA: India and Bangladesh (chickpea, lentil)	ICRISAT, ICARDA, CIAT, NARS	Farmers realize 20% higher yield from grain legumes by using ICM options
Area under cultivation of heat tolerant cultivars of chickpea, common bean, faba bean and lentil enhanced (SC3)	The available heat tolerant cultivars of chickpea evaluated by at least 1,000 farmers in India and Bangladesh (Y4), and common bean evaluated by 500 farmers in Brazil and Mexico (Y6)	SSA: Ethiopia, Tanzania and Malawi (chickpea, common bean, faba bean) LAC: Brazil and Mexico (common bean) CWANA: Turkey, Iran, Morocco, Egypt and Syria (chickpea, lentil) SSEA: India and Bangladesh (chickpea, lentil)	NARES	Higher and more stable chickpea, common bean, faba bean and lentil yields in heat prone environments and increased profit realized by the farmers
Genotype-environment combinations that provide optimum grain quality in chickpea, common bean, faba bean and lentil identified (SC4)	Effects of heat stress on grain quality assessed in chickpea, common bean and lentil (Y2) Genotype-environment combinations for optimum expression of grain quality traits identified for chickpea, common bean, faba bean and lentil (Y3)	SSA: Ethiopia, Tanzania and Malawi LAC: Brazil, Honduras, Puerto Rico, Columbia CWANA: Iran, Morocco, Egypt, and Syria SSEA: India, Pakistan, Myanmar,Bangladesh	ICRISAT, ICARDA, CIAT, NARS	Farmers harvest chickpea, common bean, faba bean and lentil with improved grain quality
Capacity of stakeholders in research and development on heat tolerance in grain legumes enhanced (SC5).	At least 30 NARS researchers provided short-term training on tools and techniques (e.g. molecular breeding, screening techniques) for studying and improving heat tolerance in grain legumes (Y1&2)	SSA: Ethiopia, Tanzania and Malawi LAC: Brazil, Honduras, Puerto Rico, Columbia CWANA: Iran, Morocco, Egypt, and Syria SSEA: India, Pakistan, Myanmar,Bangladesh	ICRISAT, ICARDA, CIAT, NARS	NARS breeding programs more efficiently develop heat tolerant cultivars of GLs

Product Line 3. Short-duration, drought tolerant and aflatoxin-free groundnut

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Target areas requiring short-duration, drought tolerant cultivars of groundnut, and aflatoxin management identified (SC1).	Data collected and compiled for areas prone to drought and aflatoxin contamination (Y1). At least one target area in each major groundnut growing region identified for short duration groundnut (Y2).	WCA: Mali, Senegal, Nigeria, Niger ESA: Malawi,Mozambique, Tanzania, Uganda SSA: India, Vietnam	ICRISAT, NARS	Groundnut research programs better targeted for drought and aflatoxin management.
High precision phenotyping tools for drought tolerance traits developed. (SC2)	Reliable techniques to phenotype for drought tolerance developed (Y2)	Global	ICRISAT	Scientists use reliable data in selecting parents/breeding lines for drought tolerance
New sources of traits related to drought tolerance, aflatoxin resistance and nutritional quality identified (SC2).	At least 5 new sources with drought tolerance identified (Y3) At least 5 new sources with low levels of aflatoxin contamination identified (Y5) GWI lines using amphidiploid developed (Y3) At least 20 nutrient dense (iron and zinc) sources identified (Y2) At least 15 new sources of protein, oil and high oleic/linoleic acid ratio identified (Y1).	WCA: Mali, Senegal, Nigeria, Niger ESA: Malawi,Mozambique, Tanzania, Uganda SSA: India, Vietnam	ICRISAT CIRAD UB, Brazil	Breeders use better sources with high drought tolerance, better nutritional quality and low or nil aflatoxin in breeding programs.
Transgenic events of groundnut with high levels of drought tolerance and resistance to aflatoxin contamination developed (SC2).	At least 5 transgenic events with improved drought tolerance developed (Y3). At least 5 transgenic events with low or no aflatoxin contamination developed and evaluated (Y5).	Global	ICRISAT	Scientists use transgenic groundnut with high levels of tolerance to drought and resistance to aflatoxin contamination

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Better understanding of mechanisms and genetics of drought tolerance and aflatoxin contamination (SC2).	Molecular mechanisms of drought-*A. flavus* interaction deciphered in resistant sources (Y3) Resistance associated proteins/genes (RAPS) associated with seed infection*, in-vitro* seed colonization and aflatoxin production identified (Y4). Feasibility of using host-induced gene silencing for reduced aflatoxin contamination assessed (Y5).	Global	ICRISAT US$A Louisiana State University (LSU)	Researchers use candidate genes for developing genetic engineering and marker-assisted breeding tools for groundnut improvement.
Genomic tools developed and integrated in breeding for drought tolerance (SC2).	At least two RIL populations developed using new drought tolerant sources (Y3). Molecular markers linked to QTL for drought traits identified (Y5).	Global	ICRISAT, NARS	Breeders use genomic tools for breeding drought tolerant cultivars

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Short-duration, drought tolerant, nutrient dense and low aflatoxin breeding lines/ varieties developed and shared with partners (SC2).	At least 20 short-duration breeding lines with low to moderate levels of resistance to rust and late-leaf spot and/or early leaf spot developed and shared with partners (Y3). At least 20 short-duration, rosette resistant breeding lines developed and shared with partners (Y3). At least 15 short-duration drought tolerant and aflatoxin resistant lines developed and shared with partners (Y5). At least 2-3 transgenic events with stable high levels of pro-vitamin A content developed and evaluated (Y4).	WCA: Mali, Senegal, Nigeria, Niger ESA: Malawi,Mozambique, Tanzania, Uganda SSA: India, Vietnam	ICRISAT, NARS	NARS partners use short-duration, drought tolerant, low or no aflatoxin breeding lines.
Enhanced adoption of short-duration, high-yielding groundnut cultivars and integrated crop management practices (SC4).	At least 2-3 farmer preferred varieties identified in each target location through FPVS trials (Y3). ICM for short duration varieties for different agro-ecologies developed and promoted (Y5).	WCA: Mali, Senegal, Nigeria, Niger ESA: Malawi,Mozambique, Tanzania, Uganda SSA: India, Vietnam	ICRISAT, NARS, NGOs, Farmer associations	Farmers benefit from increased productivity of groundnut.
Formal and informal seed systems strengthened to ensure availability of quality seed supply to farmers (SC4).	At least two new short-duration varieties available for seed production chain (Y3).	WCA: Mali, Senegal, Nigeria, Niger ESA: Malawi,Mozambique, Tanzania, Uganda SSA: India, Vietnam	ICRISAT, NARS, NGOs, Seed grower associations	Farmers use quality seed
Post- harvest processing technologies for reduced aflatoxin contamination and value added products refined and disseminated (SC4)	At least 2 post harvest technologies to reduce aflatoxin contamination disseminated (Y2) At least 2 value added products refined and made available (Y3)	Global	ICRISAT, NARS, Private Sector, NGOs	Consumers have access to safe and nutritious value added groundnut products.

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Capacity of stakeholders in research and development on short-duration, drought tolerance and aflatoxin management strengthened (SC5).	At least 2 training programs on groundnut improvement and management conducted (Y2).	Global	ICRISAT, NARS	NARS partners carry out R&D for drought, and aflatoxin management more efficiently.

Product Line 4.High nitrogen-fixing chickpea, common bean, faba bean and soybean

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Factor(s) limiting SNF in different production environments/crops identified (SC1)	Key sites characterized for climatic and soil factors affecting SNF (Y2) On station minus-one trials in five countries conducted (Y1) On farm minus-one trials at 10 sites in five countries conducted (Y2)	SSA: Ethiopia, Malawi, Nigeria, Rwanda Mozambique, Tanzania, KenyaLAC: Honduras, CWANA: Morocco, Syria, Egypt SSEA: India, Pakistan, Myanmar	CIAT, ICARDA, IITA, EIAR, Zamorano, N2Africa	Researchers focus on key constraints, through genetics, crop management, or both.
Agronomic practices for enhancing SNF developed (SC2)	Levels of key elements defined to address nutritional limitations to SNF (Y3) Value of conservation agriculture determined in enhancing SNF (Y3)	SSA: Ethiopia, Malawi, Nigeria, Rwanda Mozambique, Tanzania, KenyaLAC: Honduras, CWANA: Morocco, Syria, Egypt SSEA: India, Pakistan, Myanmar	CIAT, ICARDA, IITA, EIAR, Zamorano, N2Africa	Extension agents and development partners avail key information to enhance SNF
Improved sources of SNF with tolerance to other stresses identified (SC2)	Elite lines and sources of stress tolerance (drought, low P) screened for SNF under stress (Y2) Reference collections screened for SNF capacity (Y3)	SSA: Ethiopia, Malawi, Nigeria, Rwanda Mozambique, Tanzania, KenyaLAC: Honduras, CWANA: Morocco, Syria, Egypt SSEA: India, Pakistan, Myanmar	ICRISAT, CIAT, ICARDA, IITA, EIAR, Zamorano	Breeders access sources of SNF with multiple desirable traits
Breeding methods that permit selection for SNF developed (SC2)	15N natural abundance as a tool for SNF incorporated into breeding programs to evaluate elite lines (Y2) Breeding populations developed using elite SNF sources (Y3)	SSA: Ethiopia, Malawi, Nigeria, Rwanda Mozambique, Tanzania, KenyaLAC: Honduras, CWANA: Morocco, Syria, Egypt SSEA: India, Pakistan, Myanmar	CIAT, ICARDA, IITA, EIAR, Zamorano	Partners have access to cultivars with enhanced SNF capacity under stress conditions
Knowledge of GxE of SNF across crops/production systems generated (SC2)	Key traits that augment SNF in chickpea, common bean, faba bean and soybean identified (Y3)	Global	ICRISAT, CIAT, ICARDA, IITA	Breeders access additional genetic variability and trait-based selection criteria

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Climbing bean cultivars that result in 30-40% better yield in subsequent crop developed (SC2)	10 climbing beans that fix >50 kg/ha N identified (Y2) Climbing beans tested in maize based systems for improvement of maize yield (Y3)	SSA: Rwanda, Kenya	CIAT, RAB (Rwanda), KARI-Kenya, N2Africa	National programs consider SNF capacity in cultivar release. Extension personnel incorporate system benefits of climbing beans in discourse with farmers.
Genomic regions/ genes associated with high SNF identified (SC2)	Molecular markers/genes for SNF identified (Y3)	Global	ICRISAT, ICARDA, NARES i	Chickpea breeders target genes for enhanced SNF. Breeders of other crops have a model for identifying genes for higher SNF.
High nodulating and nitrogen fixing indigenous rhizobia identified and characterized (SC2)	5 rhizobial strains with ≥20% higher N fixation isolated (Y2) Rhizobial strains characterized by using 16S rDNA (Y3) Plant growth promoting traits of efficient rhizobial strains identified (Y3)	Global	ICRISAT, ICARDA, NARES	Rhizobium producers incorporate superior strains in commercial products Farmers have access to improved rhizobial strains
Efficient mass production technologies for rhizobial strains developed (SC2, SC4)	Technology developed for extending inoculum life by 50% under commercial conditions (Y3) Quality of rhizobial inoculants available in the market assessed (Y3)	Global	ICARDA, ICRISAT	Mass production technologies available to inoculum producers Inoculant producers are conscious of the quality of commercial products
Capacity of partners for high quality *Rhizobium* inoculum production enhanced (SC5)	10 technicians from industry and NARS trained (Y3)	SSA: Ethiopia, Malawi, Nigeria, Rwanda Mozambique, Tanzania, KenyaLAC: Honduras, CWANA: Morocco, Syria, Egypt SSEA: India, Pakistan, Myanmar	ICARDA, ICRISAT, NARES	Inoculant producers incorporate superior practices in the production of commercial inoculants

Product Line 5. Insect-smart chickpea, cowpea and pigeonpea production systems

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Information on insect-plant host-environment interactions generated for better targeting of the pest control interventions, and to mitigate the effects of climate change (SC1).	Information on biology, population dynamics, and forecasting of pest outbreaks generated for use in research on HPR, and for IPM (Y2)	SSA: Ethiopia, Tanzania, Nigeria, BurkinaFaso, Senegal, Kenya, Malawi SSEA: India, Pakistan, Myanmar	ICRISAT, IITA, ICARDA, NARS	Researchers use information for better timing of control interventions
Diverse sources of resistance to the target pests identified and information on mechanisms and inheritance of resistance generated (SC2).	At least 5 – 10 diverse sources of resistance to target pests in different crops identified and made available to NARS partners (Y2) Information generated on mechanisms and genetics of resistance to target pests in different crops (Y5).	Global	ICRISAT, IITA, ICARDA	Researchers use diverse resistance sources in crop improvement programs
Interspecific derivatives of chickpea, cowpea, and pigeonpea with high levels of resistance to the target pests developed (SC2).	At least 5 interspecific derivatives with resistance genes introgressed from the wild relatives into the cultigen in chickpea and pigeonpea developed and shared with NARS (Y4).	Global	ICRISAT, IITA, ICARDA	Researchers use insect resistant interspecific derivatives to increase the levels, and diversify resistance to target pests

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Chickpea, cowpea, and pigeonpea cultivars with high levels of resistance to target insects through integrated breeding methods developed (SC2).	At least 2 – 3 improved cowpea, pigeonpea, and chickpea varieties with high levels of resistance/tolerance to flower thrips, pod borers, and pod fly identified (Y5). The practical utility of RNAi in *Helicoverpa* management in grain legumes demonstrated (Y5) At least 3 chickpea, cowpea and pigeonpea transgenic events with *Bt* genes for resistance to pod borers bio-assayed under greenhouse and contained field conditions (Y3).	Global	ICRISAT, IITA, ARIs, NARS	Breeders use better genetic and genomic resources in resistance breeding programs.
Biosafety of transgenic chickpea, cowpea, and pigeonpea to the non-target natural enemies assessed (SC2).	Biosafety of transgenic chickpea, cowpea, and pigeonpea events for the non-target organisms assessed (Y6)	Global	ICRISAT, IITA	Researchers use the information on non-target effects for decision making to deploy transgenic plants for pest management
Industrially produced quality solid/liquid formulations of emulsifiable neem oil and entomopathogens developed, and the potential natural enemies for inundative releases identified for use in farmers' fields (SC4).	Seed coating for cowpea seeds combining entomopathogens available to farmers in West Africa (Y3) Entomopathogens with potential for pest management made available to NARS/industry (Y3) One industrially produced biopesticide combining emulsifiable neem oil and viral entomopathogens made available to farmers in West Africa and Asia (Y4). Information on compatibility of various biocontrol agents with natural plant products made available to NARS/industry (Y5)	SSA: Ethiopia, Tanzania, Nigeria, Burkina Faso, Senegal, Kenya, Malawi SSEA: India, Pakistan, Myanmar	ICRISAT, IITA, NARS, Dry Grain Pulses CRSP Norwegian University of Science and Technology, Trondheim	Farmers use virulent biological control agents for effective control of *Maruca, Helicoverpa* and *Spodoptera*

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
An IPM system based on rational application of pesticides, agronomic practices, and pest-resistant cultivars developed (SC2).	An IPM system based on rational application of pesticides, agronomic practices, and crop cultivars developed (Y3)	SSA: Ethiopia, Tanzania, Nigeria, BurkinaFaso, Senegal, Kenya, Malawi SSEA: India, Pakistan, Myanmar	IITA, ICARDA, CRISAT, NARS	Farmers use IPM practices for pest management in grain lergumes
Capacity of the stakeholders enhanced in research on host plant resistance (including genomics and transgenics) and IPM (SC5).	At least 2 training programs on platform technologies for insect-pest management in legumes for NARS partners conducted (Y1-2)	SSA: Ethiopia, Tanzania, Nigeria, BurkinaFaso, Senegal, Kenya, Malawi SSEA: India, Pakistan, Myanmar	IIITA, ICARDA, ICRISAT, NARS	Farmers use IPM practices to maximize profits.

Product Line 6. Extra-early chickpea and lentil varieties

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Constraints and opportunities for extra-early chickpea and lentil varieties in target areas and cropping systems identified (SC1).	Database developed on current and potential areas for extra-early chickpea and lentil varieties (Y1).	SSEA: India, Pakistan, Myanmar, Nepal, Bangladesh SSA: Ethiopia, Malawi, Tanzania	ICRISAT, ICARDA, NARS	Research better targeted for developing extra-early chickpea and lentil varieties.
Extra-early diverse germplasm with resistance to key biotic and abiotic stresses identified (SC2).	New sources for extra-early maturity identified (Y2). New sources for resistance to biotic and abiotic stresses identified (Y2).	Global	ICRISAT, ICARDA	Breeders use diverse germplasm in breeding programs
Novel genes for earliness and molecular markers linked to these genes identified (SC2).	Novel genes for earliness identified by studying allelic relationships of genes (Y3) Molecular markers linked to major early flowering genes identified (Y4)	Global	ICRISAT, ICARDA	Enhanced efficiency of chickpea and lentil breeding programs by using novel genes and breeding approaches
Extra-early breeding lines with adaptation to different short season environments and improved grain quality developed (SC2).	At least 20 extra-early breeding lines with multiple resistance developed and shared with NARS partners (Y3). At least 10 extra-early breeding lines with improved grain quality traits developed and shared with NARS partners (Y3).	SSEA: India, Pakistan, Myanmar, Nepal, Bangladesh SSA: Ethiopia, Malawi, Tanzania	ICRISAT, ICARDA, NARS	NARS partners use extra-early breeding lines
Integrated crop management practices for extra-early varieties of chickpea and lentil for short season environments developed (SC2).	5 extra early lines with new package of agronomic practices in various production systems tested (Y4). ICM package for extra-early chickpea and lentil varieties developed for different agro-ecologies (Y5).	SSEA: India, Pakistan, Myanmar, Nepal, Bangladesh SSA: Ethiopia, Malawi, Tanzania	ICRISAT, ICARDA, NARS	Farmers realize higher benefits by using extra-early varieties and matching ICM options

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Seed availability of extra-early varieties enhanced (SC3).	At least 5 new extra-early varieties available for seed production chain (Y5).	SSEA: India, Pakistan, Myanmar, Nepal, Bangladesh SSA: Ethiopia, Malawi, Tanzania	ICRISAT, ICARDA, NARS, NGOs, Public and Private Seed Sectors, Seed Growers' Groups	Horizontal expansion of chickpea and lentil cultivation through increased adoption of improved varieties in new niches
Enhanced marketing of chickpea for immature green grains as a vegetable (SC4).	Testing of new genotypes for green pod availability in off-season (Y4)	SSEA: India	ICRISAT, Public and Private Seed Sectors, Seed Growers' Groups	Consumers use fresh green chickpea and farmers get extra income
Capacity of stakeholders on aspects related to development and cultivation of extra early legumes strengthened (SC5).	At least 2 training programs for NARS partners conducted (Y2, Y3).	SSEA: India, Pakistan, Myanmar, Nepal, Bangladesh SSA: Ethiopia, Malawi, Tanzania	ICRISAT, ICARDA	NARS partners conduct research more efficiently

Product Line 7. Herbicide tolerant, machine-harvestable chickpea, faba bean, lentil varieties

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
The scopes and implications of the cultivation of herbicide tolerant cultivars and mechanical harvesting of legumes assessed and documented (SC1)	A report on scope and implications of the cultivation of herbicide tolerant legume cultivars and mechanical harvesting of legumes prepared (Y1)	SSA: Ethiopia, Malawi CWANA: Turkey, Syria, Iran, Morocco, Egypt SSEA: India, Pakistan, Myanmar	ICRISAT, ICARDA, NARS	Research better targeted for developing herbicide tolerant machine-harvestable legume varieties
Screening methods for tolerance to herbicides and parasitic weeds standardized (SC2)	Field and laboratory screening methods for tolerance to herbicides and parasitic weeds developed and validated (Y1)	Global	ICRISAT, ICARDA, ARIs	Breeding programs use more efficient screening methods for tolerance to herbicides and parasitic weeds.
Germplasm sources for tolerance to herbicides and parasitic weeds, and traits required for suitability of crop to mechanical harvesting identified (SC2)	Germplasm sub-sets and breeding lines screened for herbicide and parasitic weed tolerance (Y2) Plant type for machine harvest and genotypes with desired traits identified (Y2)	Global	ICRISAT, ICARDA, NARS	Enhanced use of diverse germplasm by breeding programs
Candidate genes and molecular markers for herbicide and parasitic weed tolerance identified and validated (SC2)	Candidate genes and molecular markers identified and validated for herbicide tolerance in chickpea, faba bean and lentil (Y4) Molecular markers identified and validated for parasitic weed tolerance in faba bean and lentil (Y4)	Global	ICRISAT, ICARDA, ARIs, NARS	Higher precision and efficiency of breeding programs through integration of molecular and breeding approaches

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Breeding lines/cultivars combining herbicide tolerance and traits suitable for machine harvest developed and disseminated (SC2, SC3)	At least 10 breeding lines combining herbicide tolerance and traits suitable for machine harvest developed each in chickpea, faba bean and lentil (Y5) Cultivars suitable for mechanical harvesting disseminated to the farmers (Y6) Transgenic events generated and evaluated for herbicide tolerance in chickpea (Y5)	SSA: Ethiopia, Malawi CWANA: Turkey, Syria, Iran, Morocco, Egypt SSEA: India, Pakistan, Myanmar	ICRISAT, ICARDA, NARS	The NARS breeding programs more efficiently develop chickpea and lentil cultivars tolerant to herbicides and parasitic weeds, and suitable to mechanical harvesting Farmers grow machine harvestable chickpea and lentil cultivars.
Crop-specific economical machine harvest systems and integrated weed management module developed and tested on elite lines (SC2, SC4)	Appropriate harvest machines, herbicides and cultural practices assessed for target legumes (Y5)	SSA: Ethiopia, Malawi CWANA: Turkey, Syria, Iran, Morocco, Egypt SSEA: India, Pakistan, Myanmar	ICRISAT, ICARDA, NARS	Farmers adopt crop-specific and economical systems of integrated weed management and machine harvesting for higher income
Capacity of NARS in research on herbicide tolerance and machine harvest amenability in grain legumes enhanced (SC5)	At least two short-term training organized for NARS researchers on legume improvement for herbicide tolerance and mechanical harvesting (Y1-2)	SSA: Ethiopia, Malawi CWANA: Turkey, Syria, Iran, Morocco, Egypt SSEA: India, Pakistan, Myanmar	ICRISAT, ICARDA, NARS	NARS breeding programs more efficiently breed chickpea and lentil cultivars with tolerance to herbicides and parasitic weeds, and suitable to mechanical harvesting

Product Line 8. Pigeonpea hybrids and management practices

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
Different CMS systems for hybrid production developed and evaluated (SC2).	Potential of different CMS systems for producing high yielding hybrids evaluated (Y3).	Global	ICRISAT, NARS	Efficient hybrid development programs
Genes/QTLs for fertility restoration identified (SC2).	At least one mapping population for fertility restoration genes developed (Y3). Molecular markers linked to fertility restorer genes / QTLs identified (Y5).	Global	ICRISAT, NARS	Breeding programs use molecular markers for transferring fertility restorer genes.
Hybrid parents with resistance to key biotic and abiotic stresses developed and characterized (SC2).	At least 10 diverse hybrid parents (A-, B-, R-lines) of pigeonpea with resistance to wilt, *Phytopthora* and SMD developed (Y3) At least 10 parental lines with resistance to pod borers identified and shared with the NARS partners (Y4). At least 2-3 genetically engineered hybrid parents developed for resistance to pod borers and SMD (Y5).	Global	ICRISAT, NARS	Breeding programs use resistant sources for developing parents/hybrids.
Pigeonpea hybrids with at least 25% higher yield than the commercial cultivars, and with high levels of disease/insect resistance developed (SC2).	At least 2 - 3 hybrids with 25 – 30 higher yield than the best available cultivars developed and shared with NARS partners (Y3).	SSEA: India, Myanmar ESA: Malawi, Tanzania, Kenya, Uganda	ICRISAT, NARS	Farmers realize higher productivity of pigeonpea and increased income.
Seed production systems for hybrid parents and hybrids refined for different agro-ecologies (SC4).	Most suitable locations for large-scale production of hybrid seeds identified in target regions (Y1). Efficient system for using natural pollinators and honey bees developed (Y2).	SSEA: India, Myanmar ESA: Malawi, Tanzania, Kenya, Uganda	ICRISAT, NARS	Farmers use quality hybrid seeds

Output targets	Milestones	Target region/countries	Lead institutes	Outcomes
ICM technologies for pigeonpea hybrids developed and promoted (SC2).	ICM technologies including seed treatment, spacing, fertilizer doses and need based application of pesticides developed and promoted in different agro-ecologies (Y3).	SSEA: India, Myanmar ESA: Malawi, Tanzania, Kenya, Uganda	ICRISAT, NARS	Farmers use ICM practices to realize increased yield of hybrid pigeonpea.
Commercial hybrids cultivated on over 100, 000 ha. (SC3).	Large numbers (>1000) of field demonstrations on hybrids organized (Y1). At least 4 NGOs/farmer groups facilitate the scaling-up of hybrid seed production (Y3). Commercial hybrid cultivation production promoted in at least 100,000 ha (Y4).	SSEA: India	ICRISAT, NARS, Public and Private Seed Sectors, Seed Growers' Groups	Farmers realize higher productivity of pigeonpea and increased income.
Post-harvest processing technologies for pigeonpea refined and disseminated (SC4).	At least 2 post harvest processing technologies made available to stakeholders (Y3)	SSEA: India, Myanmar ESA: Malawi, Tanzania, Kenya, Uganda	ICRISAT, NARS, Public and Private Seed Sectors, Seed Growers' Groups	Consumers have access to better quality pigeonpea products.
Enhanced capacity of stakeholders in pigeonpea hybrid research and seed production (SC5).	Capacity of NARS partners in producing seed of the parental lines and hybrids strengthened (Y2). At least 2 - 3 entrepreneurs facilitated for producing and selling quality hybrid pigeonpea seed (Y2). Knowledge and skills of seed producers on hybrid seed production, and post-harvest handling enhanced (Y3). At least 3 students (including one woman) completed (PhD) theses research in hybrid pigeonpea research (Y5).	SSEA: India, Myanmar ESA: Malawi, Tanzania, Kenya, Uganda	ICRISAT, NARS, Public and Private Seed Sectors, Farmers' groups	More efficient pigeonpea hybrid research and development programs.