Global Research and Funding Survey on Pulse Productivity and Sustainability

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for the Productivity and Sustainability Committee

International Year of Pulses 2016

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Executive Summary

The year 2016 has been designated the International Year of Pulses (IYP) by the Food and Agriculture Organization (FAO) of the United Nations. The IYP offers an opportunity to focus global attention on this important group of crops, the role they play in human and animal nutrition, their current and potential productivity, and their contribution to sustainable agriculture. Numerous experts are collaborating to broaden and deepen our understanding of the current situation and to highlight future research needs by means of development of a ten-year global research strategy.

As part of IYP-related activities organized through the Global Pulse Confederation, this survey was undertaken to provide an overview of current subjects of and investment in research on pulse crop productivity and sustainability. Forty-two individuals with relevant research expertise were contacted for research information and a further 17 were contacted for funding information. Twenty-four of the 42 research contacts (54%), representing 30 countries, and 15 of the 17 funding contacts (88%) responded to a research survey with detailed research and funding information respectively.

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A number of common themes emerged from the research surveys. Strikingly, the overarching visions for pulse crop research did not vary a great deal between developed and developing nations. There is a strong desire and action across all national and global research and funding agencies to develop genomics tools for breeding programs, to conduct state-of-the-art breeding programs for improvement in genetic gain, pest resistance and quality, to improve crop production and crop protection practices for farmers, to produce food in a sustainable manner, to transfer information in a useable form to farmers, to help make farming profitable, and to develop new resilience in crops to meet the challenges of climate change, largely including drought and heat. In addition, all global funding agencies mention ending chronic hunger, providing nutritional foodstuffs to end malnutrition, and focusing on maternal health and the gender gap. These themes resonate around the world and across economies.

Global funding for pulse crop productivity and sustainability is estimated to be at least US $175 million per year. This does not include domestic funding in China. The major contributors to global funding for pulse crop productivity and sustainability research are CGIAR, USAID and the Bill and Melinda Gates Foundation. Most countries in North America and Europe maintain an international funding agency. In addition, most countries involved in pulse productivity and sustainability research have national funding programs; in particular, the United States, Canada, Brazil, Australia, Europe, India and presumably China have substantial national funding programs at the federal and provincial/state levels. As well, some countries have grower check-off programs which help to fund research (eg. Canada, US, Mexico, and Australia). While there are exceptions, little private sector investment exists, largely at the near commercial level and in related fields such as inoculant and crop protection product development.

Gaps and opportunities include several overarching themes:

- Breeding and Genetics
- Genomics: New Tools and Technologies
- Germplasm – Collection, Management, Analysis, Use
- Yield
- Functionality
- Agronomy
- Systems and Sustainability
- Systems Research
- Response to Climate Variability, Biotic and Abiotic Resistance, Reliability of Response to Climate Change and Weather Effects
- Quantification of the Role Pulses Play in the Cropping System
- Soils
- Supply Chain
- Scaling up, Technology Transfer, Value Chain Constraints
- Why are Pulses Not Being Grown?
- General
- Funding Uncertainties
- Development of a Forum for Communication with China
- Training of Future Research Personnel

1. Introduction

The year 2016 has been designated the International Year of Pulses (IYP) by the Food and Agriculture Organization (FAO) of the United Nations. The IYP offers an opportunity to focus global attention on this important group of crops, the role they play in human and animal nutrition, their current and potential productivity, and their contribution to sustainable agriculture. Numerous experts are collaborating to broaden and deepen our understanding of the current situation and to highlight future research needs by means of development of a ten-year global research strategy.

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Target crops include those pulse crops defined as dry grain legumes by the United Nations Food and Agriculture Organization (FAO) (Appendix 1).

2. Survey Methodology

A detailed survey was developed which covered research topics from genomics through to environmental footprint, technology transfer, funding sources, and gaps and opportunities. This survey was emailed to 42 research personnel in or with connections to Australia, south-east Asia, China, India, Turkey, North Africa, Sub-Saharan Africa, Europe, North America, Central America, and South America. Twenty-seven responded, and 24 (representing 30 countries) either submitted a response via email or were interviewed via phone or skype (Appendix 3). Sixteen funding personnel were contacted, and interviews were conducted via email, phone or skype with 14 respondents (Appendix 3). Statistics were gathered from FAOSTAT, from summary documents provided from Global Trade Data Base by Saskatchewan Agriculture, and from Stat Publishing (Tables 1 and 2). Research and funding survey information was augmented by internet links sent by respondents and via internet search (Table 3).

It should be noted that the survey findings rest primarily on input from a relatively small set of experts and do not represent a comprehensive characterization of all pulse-related research funding and activity.

3. Global Statistics

There is substantial world production of, and trade in, pulse crops, indicating their tradition and desirability as a food in many regions of the world (Tables1 and 2) (it should be noted that reporting agencies do not necessarily utilize the same regional or country breakdowns, leading to a slight difference in numbers of countries or regions reported on Tables 1 and 2).

Table 1: World Production of Major Pulse Crops 2013

Country or Region	Crop Kind '000 Tonnes pea	lentil	chickpea	dry bean	faba bean	pigeonpea	cowpea	other pulses	total
Europe	3,024.0	91.8	156.3	506.4	580.2	-	24.0	1,143.5	*5,526.3*
Africa	730.4	217.4	670.4	6,031.7	1,420.5	729.2	7,782.1	1,125.4	18,707.1
Western Asia	25.2	555.6	650.3	240.0	62.8	-	1,314.0	39.2	2,887.2
Central Asia	76.0	2.1	19.7	71.9	13.5	-	-	88.1	271.3
Southern Asia	839.1	1,543.8	9,895.4	4,009.8	5.4	3,039.6	14.2	1,534.1	20,881.5
Eastern Asia (mainly China)	1,567.3	150.0	10.0	1,441.1	1,586.1	-	13.2	133.3	4,900.9
Southeastern Asia	68.0	0.9	490.0	4,301.4	-	579.7	116.3	300.9	5,857.2
Oceania	262.8	327.3	813.3	53.0	297.5	-	-	513.2	2,267.1
Northern America (Canada and US)	4,669.3	2,400.5	330.8	1,320.9	-	-	29.0	-	8,750.4
Central America	5.2	1.6	209.9	2,035.3	59.0	2.0	-	29.2	2,342.1
South America	181.5	11.0	59.6	3,402.1	139.5	0.5	19.0	2.4	3,815.4
Total Production	**11,448.7**	**5,301.9**	**13,305.7**	**23,413.5**	**4,164.6**	**4,350.9**	**9,311.7**	**4,909.5**	**76,206.4**

**data compiled from FAOSTAT*

Table 2: World Trade in Pulse Crops, 2013

Country or Region	Export, Import*	Crop Kind '000 Tonnes** pea	lentil	chickpea	dry bean	faba bean	pigeonpea	mung bean	cowpea
Europe	Export	873.4	35.7	200.4	125.0	330.9	2.8	7.1	0.4
Africa	Export	186.2	8.0	113.5	478.4	65.3	185.7	9.5	0.4
Middle East and Arabian Peninsula	Export	47.6	255.7	55.1	10.2	10.4	-	0.0	0.0
Russian Federation	Export	336.0	8.5	180.0	0.5	-	-	2.3	-
Central Asia	Export	8.7	3.0	0.4	36.8	-	-	-	-
Southern Asia	Export	15.1	22.6	405.2	5.0	0.1	1.8	1.4	0.0
China	Export	1.4	15.9	0.0	800.9	13.3	0.05	120.4	7.2
Pacific	Export	-	-	-	-	-	-	0.2	-
Southeastern Asia	Export	0.6	0.9	18.4	1,427.6	0.4	188.4	581.8	0.0
Oceania	Export	189.2	316.8	550.6	63.3	309.5	0.0	61.0	0.2
Northern America (Canada and US)	Export	3,275.0	2,017.1	107.5	747.6	11.7	-	3.0	7.8
Central America	Export	2.4	0.3	113.6	106.3	0.4	-	0.0	0.0
South America	Export	42.5	0.1	66.3	203.0	3.0	1.6	6.0	13.3
Total Exports	**44,345 T**	**4,978.1**	**2,684.6**	**1,811.0**	**4,004.6**	**745.0**	**380.3**	**792.8**	**29.4**
Europe	Import	613.3	225.9	183.9	587.4	85.3	1.3	25.8	4.9
Africa	Import	228.6	258.1	165.7	351.5	345.4	1.0	20.3	6.8
Middle East and Arabian Peninsula	Import	138.5	568.7	319.3	133.7	794.6	-	0.4	1.0
Russian Federation	Import	9.0	3.0	1.5	22.0	0.1	0.0	0.3	0.2
Central Asia	Import	5.9	1.6	1.1	5.8	-	-	-	-
Southern Asia	Import	1,840.9	1,148.4	860.9	1,002.2	1.8	384.0	666.4	9.1
China	Import	1,034.5	0.9	0.6	65.5	3.0	-	13.1	-
Pacific	Import	14.5	0.3	1.9	110.0	4.9	0.0	85.3	4.7
Southeastern Asia	Import	73.9	10.1	15.6	221.4	19.0	0.7	179.9	3.2
Oceania	Import	13.2	3.5	2.1	15.3	28.0	0.7	1.3	0.2
Northern America (Canada and US)	Import	167.3	37.2	36.5	205.5	5.1	-	27.6	8.0
Central America	Import	19.0	51.9	2.4	212.1	3.2	0.0	1.0	0.2
South America	Import	126.0	194.4	27.3	416.4	1.6	2.3	1.4	1.4
Total Imports	**38,062 T**	**4,284.7**	**2,504.0**	**1,618.7**	**3,348.8**	**1,292.0**	**390.2**	**1,022.8**	**39.7**

**data compiled from FAOSTAT, StatPub, and Global Trade Atlas (with help from Saskatchewan Agriculture)*

***reasons for discrepancies between total import and export quantities are unclear, perhaps reporting error, duplication of reporting, or periodicity, or a combination*

4. Summary of Research Results

4.1 Research Overview

A number of common themes emerged from the research surveys. Strikingly, the overarching visions for pulse crop research did not vary a great deal between developed and developing nations. There is a strong desire and action across all national and global research and funding agencies to develop genomics tools for breeding programs, to conduct state-of-the-art breeding programs for improvement in genetic gain, pest resistance and quality, to improve crop production and crop protection practices for farmers, to produce food in a sustainable manner, to transfer information in a useable form to farmers, to help make farming profitable, and to develop new resilience in crops to meet the challenges of climate change, largely including drought and heat. In addition, all global funding agencies mention ending chronic hunger, providing nutritional foodstuffs to end malnutrition, and focusing on maternal health and the gender gap. These themes resonate around the world and across economies.

Plant breeding activities occur in all world regions, focusing on the species of interest in a particular region or country. Plant breeding goals are similar everywhere: increased yield, increased adaptation, increased resilience, increased resistance to biotic and abiotic stress, increased quality. Genomics research is common in labs located in North America, the EU, Australia, South America and India. This research is often conducted via global collaboration and with a global viewpoint in mind, driven by common interest in a particular species and sharing the workload among labs in different countries. Robust linkages exist among researchers across world regions. The genomes of many pulse crop species have been or are in the process of being sequenced. Some transgenic work is underway in various labs, mainly looking at new avenues of disease resistance.

Agronomy and systems research programs exist in most countries for which information was gathered. Environmental footprint, greenhouse gas and carbon capture studies are generally more developed and more of a focus in developed countries. Climate change is on everyone's mind and many respondents mention research gaps and opportunities focused on resistance to heat and drought and the combination thereof, along with the potential for new insect and disease problems. There is a general understanding of the need for flexibility in breeding and agronomy research with various scenarios of climate change. Pulse crops appear to offer several avenues of mitigation, including the addition of organic N to soils and a reduction in use of inorganic N, and a lower carbon footprint:

- "There are two reasons that nitrogen fertilizer has a large impact on the energy balance of crop production. First, nitrogen is the nutrient required in the highest quantities worldwide for growing crops. Second, nitrogen fertilizer has an energy footprint that is over 7.5 times larger than other fertilizers such as phosphate and potash. Up to 70% of the non-renewable energy used in crop production in Canada is attributable to inorganic fertilizers, particularly nitrogen. Today, 40% of the world's dietary protein needs is supplied by these nitrogen fertilizers" (http://www.pulsecanada.com/environment/sustainability/non-renewable-energy).

- "Analysed per unit of cultivated area, the introduction of grain legumes into intensive crop rotations with a high proportion of cereals and intensive N-fertilisation leads to a reduced energy use, global warming potential, ozone formation and acidification as well as eco- and human toxicity. The main reasons for this are a reduced application of N-fertilisers (no N to the grain legume and less N to the following crop), improved possibilities for using reduced tillage techniques and greater diversification of the crop rotation, which helps to reduce problems caused by weeds and pathogens (and therefore pesticide applications)" (Nemecek et al. 2008. Environmental impacts of introducing grain legumes in European crop rotations. EJA 28(3): 380-393; http://www.sciencedirect.com/science/article/pii/S1161030107001104).

- "When soil is fertilized with nitrogen in the form of fertilizer, manure or crop residues, soil microorganisms convert some of this nitrogen to nitrous oxide, a gas which can escape to the atmosphere. Nitrous oxide is a powerful greenhouse gas; with 298 times the global warming potential of carbon dioxide. Nitrous oxide represents 60% of the greenhouse gas emissions from Canadian agriculture and the application of nitrogen fertilizer represents the largest source of nitrous oxide from Canadian agricultural soils (35% of direct emission)" (http://www.pulsecanada.com/environment/sustainability/low-carbon-footprint).

In addition, pulse crops are known to contribute to sustainability of cropping systems via improvement of soil health, and some pulse crops are well adapted to dryland production systems, needing and using relatively less water than some other crops (http://www.pulsecanada.com/environment/sustainability/sustainable-cropping-systems).

There is increasing awareness of the soil microbial community and the plant-microbe interface as a new frontier of research, particularly in developed countries, including organizations like Eurolegume and institutes like the University of Saskatchewan and Agriculture & Agri-Food Canada (also see Sections 4.2.7 and 4.2.8) (http://www.nature.com/news/microbiology-create-a-global-microbiome-effort-1.18636; http://www.eurolegume.eu/ ;Walley, 2015, pers. comm.; Gan, 2015, pers. comm.). Work is underway in the development and commercialization of microbials for crop protection as well as for nutrient uptake (http://www.bioag.novozymes.com/en/products/Pages/default.aspx).

Technology transfer programs for pulse crops exists in most countries to a greater or lesser degree. Most respondents consider this an area of weakness and would like to see it strengthened. Developed countries are concerned that extension services in general, including those for pulse crops, are often on the front line when it comes to making budget cuts and downsizing. The inclusion of technology transfer activities is a focal point for success in accessing funding from most granting programs for developing countries. IDRC, for example, has a program called "scaling up" which it brings into play for promising research developments.

4.2 Summary of Research Responses by Region

4.2.1 Australia

Australia carries out breeding activities on pea, chickpea, faba bean, lentil, lupin (Department of Agriculture and Food, Western Australia (DAFWA), recently privatized), vetch, and mung bean (Queensland Department of Agriculture and Food (QLD DAF). Pea, chickpea, faba bean and lentil are all part of Pulse Breeding Australia, a major initiative begun in 2006 by Grains Research and Development Corporation (GRDC), with the vision to "*see pulses expand to >15% of the cropping area so as to underpin the productivity, profitability and sustainability of Australian grain farming systems".*

Pre-breeding and genomics activities are linked across federal and state institutions and universities. There are also some international collaborations, for example basic science and PhD projects through the Australia India Strategic Research Fund (AISRF), and the Mung Bean Improvement Network through Queensland Department of Agriculture and Fisheries (also see 4.2.2, Southeast Asia).

Agronomy and systems research is largely carried out at the state level. Budgets in this area of research have been tight in some states but there is some thought that pulse agronomy research will become a focus once again. Carbon sequestration and environmental footprint work is and will become more a focal point of research, including that funded by CSIRO.

GRDC is a major funding agency across each state. GRDC collects a check-off from farmers on pulse crops, and some of this funding is matched by the federal government. GRDC acts as an overseeing and coordinating body in projects where it has a financial stake.   Other funding is available at the state and university level and within CSIRO.

4.2.2 China

No direct information was obtained from China. There is undoubtedly a vast research network in China of various pulse species of global interest; however, it was not possible within the time available for the current survey to gain specific information.

It would seem to be beneficial to try to establish a forum for communication that includes Chinese pulse researchers for future mutual benefit.

4.2.3 South and Southeast Asia

4.2.3.1 AVRDC: The World Vegetable Centre

The World Vegetable Centre has its head office in Taiwan and has district offices in Thailand, Solomon Islands, India (Hyderabad), Uzbekistan (Tashkent), Tanzania and Mali.

The AVRDC (the World Vegetable Centre) has two pulse crop initiatives, neither of which is conducted in the countries of Southeast Asia but rather in Central Asia and South Asia (see Section 4.5.2.2 and Appendix 2.2. respectively).

4.2.3.2 India

The main pulses in India include chickpea, pigeonpea, pea, lentil, cowpea, mung bean, bean, faba bean and grass pea, along with hyacinth bean, urd bean, and horse gram. Two national institutes conduct pulse research in India: the Indian Agricultural Research Institute (IARI), established in 1905, with its head office in New Delhi, and the Indian Institute of Pulses Research (IIPR), established in 1966, with its head office in Kanpur. These two institutes, along with the state agricultural universities, fall under the overarching Indian Council for Agricultural Research (ICAR):

- "The Indian Council of Agricultural Research (ICAR) is an autonomous organisation under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, Government of India. Formerly known as Imperial Council of Agricultural Research, it was **established on 16 July 1929** as a registered society under the Societies Registration Act, 1860 in pursuance of the report of the Royal Commission on Agriculture. The ICAR has its headquarters at New Delhi.
  The Council is the apex body for co-ordinating, guiding and managing research and education in agriculture including horticulture, fisheries and animal sciences in the entire country. With **101 ICAR institutes** and **71 agricultural universities** spread across the country this is one of the largest national agricultural systems in the world" (http://www.icar.org.in/).

- "During the fifties, the advancement of scientific disciplines constituted the core program of IARI and provided the base for its fast expansion in the 1960's and 1970's. It attained the status of a Deemed University in the year 1958. The green revolution that brought smiles to millions of Indians bloomed from the fields of IARI with the development of famous wheat varieties which contributed an estimated one billion tonnes of addition production. As the Mother of several ICAR institutions, IARI continues to be the leading institution for agricultural research, education and extension in the country" (http://www.iari.res.in/).

- "Indian Institute of Pulses Research (IIPR) was established as national Institute by the Indian Council of Agricultural Research (ICAR) for basic, strategic and applied research on major pulse crops. The Institute is involved in generation of basic information, development of high yielding varieties and appropriate production and protection technologies, production of breeder seeds, demonstration and transfer of technologies, and strategic coordination of pulses research through wide network of testing centres across the country.

- The Institute has its origin from the All India Coordinated Pulses Improvement Project (AICPIP) which was established at the Indian Agricultural Research Institute (IARI), New Delhi in 1966. Later in 1978, AICPIP was shifted to the Regional Station of IARI at Kanpur under the name of Project Directorate (Pulses). It was further elevated as Directorate of Pulses Research (DPR) in 1984 and became an independent entity under the umbrella of ICAR. In 1993, it was restructured as the Indian Institute of Pulses Research and the AICPIP was trifurcated into three coordinated projects one each on chickpea, pigeonpea and MULLaRP (mungbean, urdbean, lentil, lathyrus, rajmash and fieldpea). Since 1993, the Institute is playing a key role in strengthening nutritional security, soil health and sustainable production" (http://www.iipr.res.in/).

CLAN is an organization which fosters research and partnership on pulse crops across India and other Asian countries (http://ceg.icrisat.org/clan/).

Two CGIAR institutes have offices in India: ICRISAT in Hyderabad, and ICARDA in Bhopal. The World Vegetable Centre (AVRDC) has an office and facilities on the ICRISAT campus in Hyderabad (see Appendix 2.2).

Pulse plant breeding goals include a major focus on crop improvement, resistance / tolerance to diseases, insect pests and drought, plant architecture, early maturity, development of plants amenable to mechanical harvesting, and improvement in quality. Hybrid systems in pigeonpea based on cytoplasmic male sterility are in development. Wide crossing and marker-assisted selection are in use, and genomics programs, transgenic and gene pyramiding programs are in development.

General agronomic practices for pulse crops have been developed and/or are in progress, specific to local soils and conditions. Numerous cropping systems involving pulse crops are being studied. Research programs on pulse crop effects on soil quality, macro- and micro-nutrient use, mode of application, residual effect, nitrogen fixation, and inoculants, and phosphate-solubilising bacteria studies are ongoing. Macro- and micro-nutrient studies are in place. Crop protection programs against insect pests are being developed, including monitoring programs, mechanical and cultural control methodologies.

Some studies have been conducted on water use efficiency in pulse crops. Pulse crops are thought to use about 20% of the water of some cereal crops. More work is needed here.

India is a source of biodiversity for several pulse crop species, and much material has been collected, evaluated, characterized and documented. Wild biodiversity is being used for introgression studies in several pulse crops.

Environmental footprint- related research has not been studied to any extent in India.

India has a diverse network of extension services (ICAR, Agricultural Extension Division), with front-line extension centres (Krishni Vigyan Vendras) and a program of field days, demonstration plots both small and large scale, radio and television programming, written material, use of farmer associations and commodity-based associations.

Pulse research funding is almost all from public sector sources; most agencies have a national mandate. Funding is generally project-based on about a three- to five-year project cycle.

4.2.4 Middle East and Central Asia

4.2.4.1 Turkey

Pea production dates back 9,000 years to the agriculture of Catalhöyük, a large Neolithic settlement in Anatolia. Turkey has a recent history of pulse research dating back to the 1930s. The current research focus is on chickpea, lentil and common bean. Pulse crops are well understood with respect to their role in sustainable agriculture, soil tilth, soil nitrogen, as a break crop, and in reducing fossil fuels used in farming operations. Major organizations are the Turkish General Directorate of Agricultural Research (GDAR), universities, state and private seed companies and the Scientific and Technological Research Council of Turkey (TUBITAK).

Plant breeding activities focus on germplasm development, breeding for resistance to biotic and abiotic stress and quality. Standard genomics techniques are utilized including tissue culture, marker-assisted selection and double haploidy. Agronomy studies focus on basic aspects of agronomy, fertilizer use, systems research, disease management, and irrigation studies. Turkey is the centre of origin for many pulse crops, so collection and characterization of wild species and land races along with conservation in national gene banks is undertaken both domestically and with international collaboration.

Technology transfer to farmers is via demonstration extension program through state and private organizations. Research is funded by GDAR, TUBITAK, the private sector, the EU, and ICARDA.

4.2.4.2 Central Asia

The World Vegetable Centre (AVRDC) leads a pulse crop initiative in Turkmenistan:

"Beans with Benefits": Integrating improved mungbean as a catch crop into the dryland systems of South and Central Asia for increased smallholder farmer income and more sustainable production systems" is a recently-launched project aimed at promoting mungbean in Uzbekistan and Pakistan (http://avrdc.org/beans-with-benefits-begins/).

4.2.5 Africa

Common bean, cowpea and pigeonpea are the most important crops in West Africa (WA); bean, lentil, chickpea and pigeonpea in eastern and southern Africa (ESA); faba bean, cowpea, chickpea and lentil in Northern Africa (NA).

There is a long history of research in all regions both through national programs and international initiatives. Universities, regional and national research institutes (NARS) and international institutes are all active in pulse crop research. IITA and partner national programs have been cooperating in cowpea improvement for the past 40 years in WA. Research in NA likewise has been underway since the 1970s; pulses were neglected in earlier years in NA as wheat was a major research focus. CGIAR (through International Centre for Agriculture Research in Dry Areas (ICARDA and other global funding agencies have a presence in NA.

Major breeding programs exist in ESA: chickpea and lentil in Ethiopia, pigeonpea in Kenya, dry beans across the region ESA and WA; faba bean, chickpea and lentil in NA. As a major focus in WA, cowpea breeding is currently focuses on yield, quality, improved resistance to selected pests and diseases, including resistance to the parasitic weed Striga gesnerioides, as well as drought and low-P tolerance.

Through collaboration with University of California at Riverside the cowpea genome sequence is being finalized. IITA will focus on re-sequencing and RNA-sequencing for better targeting of marker development. A transgenic cowpea line bearing resistance to the legume pod borer *Maruca vitrata* is under evaluation in confined field trials in the region. There is Chinese collaboration in the sequencing of faba bean. RILS populations of faba bean, chickpea and lentil are available at ICARDA.

There is some focus on the subjects of agronomy and systems; sustainability issues are not a focus. Herbicide tolerant faba bean, chickpea and lentil lines are under development at ICARDA. Chemical control recommendations for orobanche have been developed in Egypt. Chickpea and lentil are being studied for drought tolerance in NA; raised-bed technology is being studied in Egypt.

The ICARDA genebank, now based in Lebanon and Morocco, hold around 34,000 accessions of cultivated lentil, faba bean and chickpea.

Technology transfer to scientists is via internet, conferences, and publications. Farmers receive information through extension and technology transfer programs via farmer coops and associations, and government agents. Information is also transferred via radio and magazines (eg. Seeds of Gold published by Egerton University). Some cell phone related technology transfer and Integrated Pest Management work is being done. There is a capacity building program underway through ICARDA.

Research funding is received via global funding agencies: Gates Foundation is the leading donor, along with CGIAR funding through the CRP on Grain Legumes, and direct funding from other countries' international funding agencies. There is some funding via national governments as well. The granting process would appear straightforward, via competitive proposal calls, which are seen to be biased toward the more developed institutes and well-known scientists. The application process through the internet is problematic as many scientists in the region either do not or cannot readily access the internet, or signal strength is unreliable.

4.2.6 Europe

There has been increasing concern in the European agricultural research community over the past decade about the decrease in agricultural interest in pulse crops:

- "Legume cropping has been in decline throughout Europe. Legumes are often considered not sufficiently profitable in comparison to other major crops such as cereals or oilseed brassicas, in a context where crop profitability is largely determined by subsidies set by decision-makers. The decrease in the legume cultivation area causes a decrease in the support for legume research… Legume research in the USA, Australia and Canada, unlike that in Europe, demonstrates how a feasible and sustainable link between basic science, applied research and end-users may be established and maintained… Organizations such as Pulse Australia and Pulse Canada thrive much better than their counterparts in Europe, in spite of the latter being the home to many of the finest discoveries in legume research, especially its basic science. This is the reason why legumes occupied less than 2% of European arable area in 2007-2009, in contrast to 6% in Australia and 10% in Canada, and why the EU imports over 70% of its plant- derived protein, including 21-32 Mt soy meal annually from 2000 to 2007" (Mikic, Rubiales, Smykal, Stoddard, 2011: The Legume Manifesto. Field Veg. Crop Res. 48 (2011): 253-258; also http://lsc1.nsseme.com/?opt=manifesto).

Building upon this concern, several international initiatives have recently been undertaken to attempt to bring increased attention to pulse crops, including but not limited to:

- The formation of LEGATO 2014-2017, a project "conceived to promote the culture of grain legumes in Europe by identifying priority issues currently limiting grain legume cultivation and devising solutions in term of novel varietal development, culture practices, and food uses." (http://www.legato-fp7.eu/index.html).

- The founding of the International Legume Society in 2011, "with two primary missions. One of them is to treasure the rich legume research tradition of the former European

Association for Grain Legume Research (AEP), with emphasis on carrying out its triennial legume-devoted conferences. Another one is to fulfill a long-term strategy of linking together the research on all legumes worldwide, from grain and forage legumes pharmaceutical and ornamental ones and from the Old World to the Americas" (http://ils.nsseme.com/#about).

- The Pulse Crop Genetic Improvement Network*:* *(http://www.niab.com/pages/id/169/Pulse_Crop_Genetic_Improvement_Network; also www.pcgin.org).*

- The formation of EUROLEGUME 2014-2017 (Enhancing of legumes growing in Europe through sustainable cropping for protein supply for food and feed), "an international research project funded by the 7th Research Framework Programme of the European Union. In agreement with the tight relation between genotype and environment, rootsystem architecture (RSA) and development has received an increased amount of attention due to advances in phenotyping capabilities. However, low focus on belowground characteristics of leguminous plants in plant breeding and a limited number of high-yielding cultivars with good resistance to abiotic and biotic stresses has been obtained. Currently, broad diversity of Rhizobia and arbuscular mycorhizal fungi is referred, although there is a lack of genotypic evaluation as well as of efficiency of particular strains in biological nitrogen fixation in diverse agro-ecological conditions" (http://www.eurolegume.eu/).

There is a long tradition of pulse crop cultivation, consumption and research, and a good general knowledge of the benefits of pulse crops to the rotation, in Europe. Policy initiatives in France are leading to a renewed interest in pulse crops to meet the need for a reduced environmental footprint in agriculture and the demand for plant-based protein. Collaborations are good across Europe, and international projects like LEGATO and national organizations like Peamust (INRA, France) promote working level collaborations.

Breeding programs exist in Europe for pea, broad (faba) bean, dry bean, lentil, chickpea, lupin; in addition there is some research on *Lathyrus sativa*, grass pea. Private sector breeding programs exist in Europe, although their numbers and scope have reduced over the past decade. The existence of private sector breeding companies suggests that there is a value proposition in variety commercialization, which is likely via seed-based royalties on varieties protected by plant breeders' rights, and due to a tradition of acknowledgement in the farm community of the role and rights of the plant breeder and the value of plant breeding. Genomics programs exist and European scientists are a part of sequencing consortia of various pulse crop species.

Basic agronomy is well-understood and systems research is in progress. Some work has begun on pulse crops in organic farming and intercropping, along with consideration of pulse crops in changing climate scenarios.

Technology transfer is important and is required in research funding applications. Extension services exist, and are generally publically funded.

Budgets are static, according to survey respondents, and it also appears that funding for pulse crop research ranges from strategic to ad-hoc. Respondents note that there is also a dichotomy between research applications needing to be "scientifically innovative" and the reality of the need for strong applied research programs.

4.2.7 North America

4.2.7.1 Canada

Canada has strong breeding programs in pea, lentil, chickpea, dry bean, and faba bean. Breeding in pea and lentil began in the 1970s; dry bean, chickpea and faba bean are more recent additions. Most breeding work is carried out at the Crop Development Centre at the University of Saskatchewan, with additional programs at the University of Guelph, and in western Canada via Agriculture and Agri-Food Canada. Genomics collaborations exist with these organizations and the National Research Council. Crop protection research is supported by BASF and inoculant development work has been supported over the years by companies such as Novozymes. Canada is the largest global exporter of pea and lentil and has substantial exports of chickpea and dry bean.

Agronomy work is considered to be a part of breeding programs and strong agronomic packages exist for all crop kinds. Systems research continues to be carried out on how pulses fit into and benefit the rotation, including weed management, nitrogen management and rotation studies. Soils work is also conducted through AAFC and universities and new initiatives include considering the soil microbiome as a part of the larger picture. Environmental footprint studies are ongoing and there is increasing desire to develop good information here to inform further work on reducing footprint while maintaining and increasing profitability.

Technology transfer is strong in Canada. Extension services are handled by provincial governments and by the private sector and grower associations. Federal, provincial, university and private sector research and development personnel consider technology transfer to be a part of their mandate and are available for field days and annual information meetings.

Funding is provided by federal and provincial governments and via grower check-off. Funding is at a good level and is consistent. Excellent coordination and cooperation exists in the granting cycle and process among funding agencies.

4.2.7.2 United States

The United States has strong breeding programs in pea, lentil, chickpea, and dry bean. These programs are mainly focused in the Pacific Northwest, Northern Great Plains, and Midwest regions. Most breeding work in these crop kinds is carried out through the Agricultural Research Service at the United States Department of Agriculture in Pullman and East Lansing, with strong linkages to universities in those locations, as well as a relatively new breeding initiative at North Dakota State University. Cowpea breeding is carried out at universities in the primary production areas, such as Arkansas, Texas, California and the southeastern US.

In addition, a research initiative known as Legume Innovation Labs is in place through funding from USAID: Feed the Future, with focus on chickpea, cowpea, and beans, to develop improved climate resilience in countries of Central America and Africa.

Agronomy studies are in some cases linked to the breeding programs, particularly with respect to disease management; in addition, there are agronomy programs at various land grant universities, some of which include pulse crops as a part of systems research studies. Some work on carbon capture and environmental footprint may be carried out at the university level. Pulses are becoming increasingly popular as a component in cover crop blends seeded in rotations, to help improve soils which have been depleted of organic matter and nutrients.

The United States maintains an extension program mandate, carried out in various ways but usually by means of extension agents at county offices. This program has been reduced over the years, as farm size increases and numbers of farmers reduces. Extension services are also offered through private companies, eg. seed suppliers, crop input suppliers.

Funding is generally via public sector agencies and grower commissions. There is a private pea breeding company in Washington.

4.2.7.3 Mexico

Little information was obtained for Mexico. The following are points of interest:

- The major species of interest is common bean.
- INIFAP, Mexico. National, public (breeding for local adaptation and drought, especially pinto beans)
- Mexico has farmer associations who help to disseminate information and there are some non-governmental organizations (NGOs) as well.
- Mexico has a public science foundation called CONACYT which receives research proposals. Mexico also funds the CGIAR.

4.2.8 Central and South America

The major species of interest in this region is common bean. Cowpea is a species of interest in Brazil, as is Carioca bean. There is close to a century of research in pulse crops, and there is a good general understanding about pulse crops and their contribution to sustainable farming.

There are several major players in pulse crop breeding in the region:

- Zamorano University, Honduras. Regional, public (breeding for small red and black beans with disease resistance and drought tolerance; also high iron)
- ICTA, Guatemala. National, public (breeding black beans for disease resistance and high iron)
- INTA, Nicaragua, National, public
- EMBRAPA, Brazil: National, public (broad based breeding program for Brazil specializing in carioca beans; common beans and cowpeas in Santo Antonio de Goias and Teresina respectively)
- IAC, Brazil: State, public (broad based breeding program for Sao Paolo specializing in carioca beans)
- IAPAR, Brazil: State, public (broad based breeding program for Paraná specializing in carioca and black beans)
- Epamig – Empresa de Pesquisa Agropecuária de Minas Gerais (Belo Horizonte, PE). State organization, common bean
- Universidade Estadual de Maringá (Maringá, PR)
- UFV – Universidade Federal de Viçosa (Viçosa, MG)
- UFLA – Universidade Federal de Lavras (Lavras, MG)
- IPA – Instituto Agronômico de Pernambuco (Recife, PE), State organization (cowpeas)
- CIAT, Colombia. Global, public (broad based breeding program for biotic and abiotic stress tolerance and high iron, strength in molecular markers)

Breeding goals in Brazil include yield, quality, shelf life, disease resistance, drought tolerance, plant architecture. Genomics work in Brazil includes genomics, mapping, marker-assisted selection, genetic engineering; the first GM common bean has been approved, resistant to Bean golden mosaic virus.

Agronomy research is carried out on field management and integrated pest management, and there is some long term research on strains of inoculant. There is some work carried out in broader sustainability areas.

Research results are communicated to agronomists via regional meetings, a national bean congress, formal publications, and some extension programs, which are weak in some regions.

Funding comes from various sources: via CIAT, through national public funds, and in Mexico through farmer associations. Brazil's national budget is approximately US$10 million per year.

5. Research Funding Results

5.1 Funding Overview

Funding information was collected by means of email, voice and skype interview with key personnel in global, national and state/provincial organizations. Some estimation was used and is noted. Global funding for pulse crop productivity and sustainability is estimated to be at least US $175 million per year (Table 3). This does not include domestic funding in China. The major contributors to global funding for pulse crop productivity and sustainability research are CGIAR, USAID and the Bill and Melinda Gates Foundation. In addition, Australia and most countries in North America and Europe maintain international funding agencies. Virtually all countries involved in pulse productivity and sustainability research have national funding programs. In particular, the United States, Canada, Brazil, Australia, Europe, India and presumably China have substantial national funding programs at the federal and provincial/state levels; as well, some countries have grower check-off programs which help to fund research (eg. Canada, US, Mexico, and Australia). Little private sector investment exists, largely at the near commercial level and in related fields such as inoculant and crop protection product development (also see pages 14 and 15).

5.2 Global Funding

5.2.1 CGIAR

CGIAR's vision is a World Free of Poverty, Hunger and Environmental Degradation. Its mission is to advance agri-food science and innovation to enable poor people, especially poor women, to increase agricultural productivity and resilience, share in economic growth, feed

themselves and their families better, and conserve natural resources in the face of climate change and other threats.

Funding to CGIAR Research Programs comes from the governments of approximately 30 countries along with the World Bank, USAID and the Bill and Melinda Gates Foundation (BMGF). Funding is provided to CGIAR via three routes: funding to CGIAR without designation, funding to CGIAR with a designation to a specific CGIAR Research Programme (CRP), and funding to specific CGIAR centres for a contracted project.

CGIAR Research Program on Grain Legumes

CGIAR has focused on grain legumes, including the pulse crops chickpea, common bean, cowpea, faba bean, lentil and pigeonpea, together with groundnuts and soybeans, in its programs Tropical Legumes 1, 2 and 3, and its Research Program on Grain Legumes (CRP) 2013-2016. Research in pulse crops is delivered by four of its research centres, ICRISAT, ICARDA, IITA, and CIAT.

“The CGIAR Research Program on Grain Legumes focuses on improving chickpea, common bean, cowpea, groundnut (or peanut), faba bean, lentil, pigeonpea and soybean crops grown by poor smallholder families in five regions (in order of production area and numbers of poor): South and Southeast Asia, Western and Central Africa, Eastern and Southern Africa, Latin America and the Caribbean, and Central and Western Asia and North Africa. The Program aims to benefit 300 million poor by the end of its first 10-year cycle. It is a global research-for-development collaboration involving four members of the CGIAR Consortium (the International Center for Tropical Agriculture CIAT, the International Center for Agricultural Research in the Dry Areas ICARDA, the International Crops Research Institute for the Semi-Arid Tropics ICRISAT and the International Institute of Tropical Agriculture IITA, the CGIAR Generation Challenge Programme, four large national agricultural research systems (EIAR-Ethiopia, EMBRAPA-Brazil, GDAR-Turkey and ICAR-India), and two USAID-supported Feed the Future initiatives: the Dry Grain Pulses Innovation Lab, and the Peanut and Mycotoxin Innovation Lab (formerly known as Collaborative Research Support Programs).

The on-farm impacts of the CGIAR Research Program on Grain Legumes will be felt through eight Product Lines (PLs). The PLs are listed below, grouped into four key priority areas:

1. 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

2. Capturing unique legume ability to fix nitrogen
    - **PL 4.** High nitrogen-fixing chickpea, common bean, faba bean and soybean

3. Managing key biotic stresses
    - **PL 5.** Insect-smart chickpea, cowpea, and pigeonpea production systems

4. 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”* (http://www.cgiar.org/our-strategy/cgiar-research-programs/cgiar-research-program-on-grain-legumes/).

New CRPs are in process of development and are slated to begin in 2017. Grain Legumes will be a part of a new CRP entitled “CRP in Cereals and Grain Legumes”. The estimated total budget for the new CRP is USD$270 million over five years.

Table 3: Global Funding for Pulse Crop Productivity and Sustainability Research

Table 3. Global Funding for Pulse Crop Productivity and Sustainability Research.*

Country	Organization****	Project Name	Crop Kind	Per Year M USD	Recipient Organization or Region	Reference
Global	CGIAR	CGIAR Research Program Grain Legumes (CRP)***	chickpea, dry bean, cowpea, faba bean, lentil and pigeonpea	$ 46.7	CGIAR Centres	Ellis, pers.comm.
Global	USAID	Feed the Future (FTF)***	dry bean, chickpea, cowpea	$ 21.9	Africa	Long, pers.comm.
Global	IDRC	CIFSRF	lentil, chickpea	$ 1.8	Ethiopea	Wesley, pers.comm
Global	BMGF	Tropical Legumes III, CGIAR, N2Africa***	chickpea, dry bean, cowpea, pigeonpea	$ 12.0	Africa	Ehler, pers.comm. (with estimated reduction of groundnut allocation)
Global	ACIAR		lentil, pea, chickpea, mung bean	$ 1.4	South & SE Asia; E & S Africa	Huttner, pers.comm.
Global	Kirkhouse Trust		cowpea, dry bean, "orphan legumes"	$ 1.5	Africa; South Asia	estimate
Canada	AAFC	Cluster	pea, lentil, chickpea, dry bean, faba bean	$ 3.8	Canada	Pulse Canada news release July 29, 2013
Canada	AAFC	internal	pea, lentil, chickpea, dry bean, faba bean	$ 2.2	Canada	Clayton, pers.comm.
Canada	SPG	strategic plus grants	pea, lentil, chickpea, dry bean, faba bean	$ 5.6	Canada	Macarenhas, pers.comm.
Canada	ADF	strategic plus grants	pea, lentil, chickpea, dry bean, faba bean	$ 1.4	Canada	Jalil, pers.comm.
Canada	ACIDF	grants	pea, lentil, chickpea, dry bean, faba bean	$ 1.0	Canada	Hall, pers. Comm.
Canada	APG	grants	pea, lentil, chickpea, dry bean, faba bean	$ 1.0	Canada	APG annual report
Canada	Manitoba	grants	pea, lentil, chickpea, dry bean, faba bean	$ 0.5	Canada	MBG annual report
Canada	Ontario	grants	dry bean	$ 0.2	Canada	OBG annual report
US	USDA ARS		pea, lentil, chickpea, dry bean, cowpea	$ 3.5	Pullman, East Lansing, South Carolina, Maryland, Puerto Rico	Wisler, pers.comm.; Scholz, pers.comm.
US	USDA NIFA		pea, lentil, chickpea, dry bean, cowpea	$ 3.2	US domestic	Thro, pers.comm.; www.cris.nifa.usda.gov.estimate
US	Commissions		pea, lentil, chickpea	$ 1.1	US domestic	Lannoye, pers.comm.; Northern Pulse Growers Assn., Idaho and Washington Commissions websites
US	universities		pea, lentil, chickpea	$ 6.0	US domestic	estimate: 10 x $400k + project funds
US	state programs (eg cowpea breeding)		cowpea	$ 3.0	US domestic	estimate: 5 x $400k + project funds
Mexico	state programs		dry bean	$ 3.0	Mexico	estimate: 5 x $400k + project funds
Central & South America			dry bean	$ 12.0	South and Central America	estimate: 20 x $400k + project funds
Brazil			dry bean, cowpea	$ 10.0	Brazil	Brezeghello, pers.comm.
Europe	FP7	Legato	pea, lentil, chickpea, dry bean	$ 0.7	Europe	Legato website
Europe	FP7	Eurolegumes	pea, lentil, chickpea, dry bean	$ 0.7	Europe	estimate
Europe	FP7	Legume Futures	pea, lentil, chickpea, dry bean	$ 0.7	Europe	estimate
INRA			pea, lentil, chickpea, dry bean	$ 6.0	Europe	estimate: 10 x $400k + project funds
Other European countries			pea, lentil, chickpea, dry bean	$ 12.0	Europe	estimate: 20 x $400k + project funds
Africa: East and Southern			pigeonpea, cowpea, chickpea, lentil, dry bean	$ 4.0	ES Africa**	Kimurto, pers.comm.
Africa: North and West			pigeonpea, cowpea, chickpea, lentil, dry bean	unknown	Africa, North and West	n/a
Turkey			lentil, chickpea, dry bean	$ 0.8	Turkey	Aydogan, pers.comm.
India	IARI, IIPR		pea, lentil, chickpea, dry bean, pigeonpea, cowpea, "orphan legumes"	$ 15.0	India	Varshney, pers. comm.; Long, pers. comm.; Sharma, pers. comm.
Australia	GRDC		pea, lentil, chickpea, mung bean, dry bean, cicer milkvetch	$ 10.0	Australia	Kearns, pers.comm.
	CSIRO		pea, lentil, chickpea, mung bean, dry bean, cicer milkvetch	$ 5.0	Australia	estimate
China			unknown	unknown	China	n/a
				$ 197.8		
				$ 17.0	less portion of USAID in CRP***	
				$ 5.0	less portion of BMGF in CRP***	
				$ 175.8	**M USD per year**	

**includes genomics, breeding, agronomy, systems and sustainability research*

***funding in ESA ranges from $0.2-1 million per year in each country; it varies each year, making research budgeting difficult*

****note that funding from USAID and BMGF is double-reported in this table as both organizations donate to CGIAR. These amounts are backed out of the total at the bottom of the table.*

****** Acronyms:*

AAFC	Agriculture & AgriFood Canada	IARI	Indian Agriculture Research Institute
ACIAR	Australian Centre for International Agricultural Research	IDRC	International Development Research Centre
ACIDF	Alberta Crop Industry Development Fund	IIPR	Indian Institute for Pulse Research
ADF	Agriculture Development Fund, Saskatchewan Agriculture	INRA	Institut National de la Recherche Agronomique
APG	Alberta Pulse Growers	Legato	Legumes for the Agriculture of Tomorrow
BMGF	Bill and Melinda Gates Foundation	SPG	Saskatchewan Pulse Growers
CIFSRF	Canadian International Food Security Research Fund	USAID	United States Agency for International Development
CSIRO	Commonwealth Scientific and Industrial Research Organization	USDA ARS	United States Department of Agriculture Agriculture Research Service
GRDC	Grains Research and Development Corporation	USDA NIFA	United States Department of Agriculture National Institute of Food and Agriculture

5.2.2 USAID

United States Agency for International Development (USAID) is a substantive global funding agency for pulse crop improvement and sustainability research. Pulse crops fall under the USAID Feed the Future (FTF) initiative:

USAID is advancing global food security by helping to improve the most basic of human conditions: the need that families and individuals have for a reliable source of quality food and sufficient resources to purchase it. This, in turn, supports global stability and prosperity.

Feed the Future is the U.S. Government's global hunger and food security initiative, which establishes a foundation for lasting progress against global hunger. With a focus on smallholder farmers, particularly women, Feed the Future supports partner countries in developing their agriculture sectors to spur economic growth that increases incomes and reduces hunger, poverty and undernutrition. Feed the Future efforts are driven by country-led priorities and rooted in partnership with governments, donor organizations, the private sector and civil society to enable long-term success (https://www.usaid.gov/what-we-do/agriculture-and-food-security/increasing-food-security-through-feed-future; also see http://feedthefuture.gov/article/feed-future-food-security-innovation-center).

Feed the Future is organized into seven program areas. Pulse crops fall under two of these areas: Legume Productivity and Sustainable Intensification.

Legume Productivity: Specific programs under Legume Productivity are aimed at breeding and crop improvement of dry bean, chickpea, and cowpea; basic agronomy and systems research; pest and disease management; and marketing, policy and impact assessment.

Country focus is as follows:

- Dry bean: Ethiopia, Haiti, Honduras, Malawi, Mozambique, Nepal, Rwanda, Uganda, Zambia
- Chickpea: Ethiopia, India, Turkey
- Cowpea: Senegal, Burkina Faso, Ghana, Nigeria

One of USAID's key initiatives is the establishment of the Legume Innovation Labs. Four of these labs specifically target pulse crops:

- The Feed the Future Innovation Lab for Climate Resilient Chickpea at UC Davis
- the FTF Innovation Lab for Climate Resilient Beans at Pennsylvania State University
- the FTF Innovation Lab for Climate Resilient Cowpea at UC Riverside
- the FTF Innovation Lab for Yield Enhancement of common bean and cowpea at Michigan State University

Approximately $5M is provided to each lab over a five-year period.

In addition, USAID is a key funder to CGIAR, providing approximately $17M annually to Grain Legumes research via Windows 1, 2 and 3.

Sustainable Intensification also has a pulse crop focus (http://feedthefuture.gov/sites/default/files/resource/files/ftf_factsheet_fsicsustainableint_may2015.pdf). The annual budget, including pulse projects and those with a pulse component, is about $2 million per year. Pulse crops are a part of several main projects / regions**:** Africa Rising in Ethiopia (faba bean, chickpea); East/Southern Africa (beans), West Africa (cowpea); in addition, some pulse sustainability research is a part of projects in the Indo-Gangetic Plains looking at crop diversification in wheat-rice systems.

5.2.3 Bill and Melinda Gates Foundation

The Bill and Melinda Gates Foundation (BMGF) is a relatively new entrant to global agriculture productivity and sustainability funding. The BMGF was formally established in 2000, after several years' engagement in funding health, disease eradication and education programs. In 2006 the BMGF, along with the Rockefeller Foundation, launched Alliance for a Green Revolution in Africa, an "Africa-based organization working to revitalize agriculture and help small farmers overcome poverty and hunger" (http://www.gatesfoundation.org/Who-We-Are/General-Information/History).

The BMGF Agriculture Development Goal is:

- With our partners, increase agricultural productivity as the driver to lift 75 million smallholder farmers in Sub-Saharan Africa and South Asia out of poverty.

Its Outcome Goals are:

- Increase potential productivity and realized productivity of staple crops and livestock commodities
- Transform surplus production into income, nutrition and empowerment of women.

BMGF has been funding agricultural research and development since 2006. At the start, funding allocation was somewhat opportunistic, and as time goes on a more strategic approach has been developed. Country strategies have been or are being developed. Most of BMGF's funding is allocated through its internal strategy. BMGF works with international funding agencies and national funding programs around the world to find synergies. BMGF strategy and partnerships account for 90% of its funding; 10% is through a Request for Proposals (RFP) process.

Pulse crops are core to the BMGF) agricultural development funding strategy, with approximately 12% of the agriculture portfolio focused on grain legumes. This equates to approximately US$15 million per annum, including groundnut research.

Crop by Country focus is:

- Dry beans – Tanzania, Ethiopia, Uganda
- Chickpeas – Uttar Pradesh, India; Ethiopia
- Cowpeas – Burkina Faso, Mali, Nigeria

BMGF has three large pulse crop investments:

- 1) Tropical Legumes: Historically TL 1 and 11 were part of a broader development strategy at BMGF, focusing on 12-13 crops with 3 pulse crops: dry bean, cowpea and chickpea, with some work on pigeonpea. TL 1 and 11 funding was allocated to Sub-Saharan Africa and to India, while TL 111 is focused on Africa. Tropical Legumes 1 and 2 were managed in parallel, with TL 1 focusing on upstream research and TL 11 on downstream research. TL III, led by ICRISAT, was begun in May, 2015 and is a part of the CGIAR CRP on Grain Legumes.

- 2) N2Africa (2009 – 2019): N2Africa has the mandate to develop rhizobial inoculants and agronomic packages including inoculants and fertilizers for grain legumes, including pulse crops, in Africa. The program is led by Wageningen University in Netherlands. The second phase began in January, 2014.

- 3) PICS Program (2007 - 2019): The PICS Program is led by Purdue University, originally with a grant from USAID. Its mandate was to improve storage of cowpeas in Cameroon (PICS1). PICS bags are hermetic storage bags, developed in the late 1980s at Purdue, which protect harvested grain from stored products pests. The program was then extended to other crops (PICS2). The bags have now been shown to be effective in storing crops such as corn, common beans, wheat, peanuts, pigeonpea, mung bean and sorghum. The BMGF also funded the initial PICS and PICS2 projects. Approximately $10 million is now being invested into development, manufacturing and distribution (PICS3).

BMGF also funds sustainability research in which pulse crops play a role.

5.2.4 ACIAR

Australian Council of International Agricultural Research (ACIAR) provides funds primarily to international projects in Southeastern and Southern Asia (http://aciar.gov.au/page/research-programs) as well as some projects in Eastern and Southern Africa. A list of current, new and recently finished projects follows, with USD budget numbers per annum for the pulse components of the current projects. Total funding per annum is approximately US$1.44 million.

Current Projects:

- CIM/2009/038: Introduction of short duration pulses into rice-based cropping systems in western Bangladesh. 2 M AUD. Suitable varieties and crop management to grow lentil and pea after monsoon rice, with a component on mungbean crop management. US$280k per year.
- CSE/2011/077: Sustainable and Resilient Farming System Intensification in the Eastern Gangetic Plains (Bangladesh, India, Nepal). 7 M AUD on topics of rice, wheat, maize, pulses, sustainability, resilience. About 15% of the project is about pulses crop management. US$30k per year.
- CSE/2013/008 (ex CSE/2009/024): Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa II (SIMLESA II). 40 M AUD over 8 years, on topics of maize, pulses, forages, sustainability, resilience. About 25% of the project is on pulses genetic and management, including capacity building in 6 countries of Eastern and Southern Africa. US$22k per year.
- SMCN/2011/046 Diversification and intensification of rice-based systems in the Ayeyarwady Delta (MyRice), Myanmar. 2.5M AUD. Significant component of pulses as a diversification option. US$340k per year.
- SMCN/2011/047 Increasing productivity of legume-based farming systems in the Central Dry Zone of Myanmar (MyPulses). 2M AUD. All about pulses crop management with a small genetic component. US$560k per year.
- SMCN/2012/071 Improving land, water and nutrient use efficiencies under irrigated and rainfed conditions in Cambodia and Lao PDR. 2M AUD. Minor component of pulses as a dry season crop. US$10k per year.
- Projects under design, starting in 2016 (not yet available on web site):
- CIM/2014/079 International Mungbean Improvement Network IMIN (Bangladesh, India, Myanmar, Australia, AVRDC). 2 M AUD. Support integrated mungbean pre-breeding efforts in 4 countries.
- CIM/2015/041 Increasing legume production and profitability in legume cropping systems in Pakistan. 2.2 M AUD. Variety testing and crop management research on chickpea, lentil and groundnut.
- SMCN/2012/105 Soil fertility in support of intensification of sweet potato cropping systems in Papua New Guinea. 1.5M AUD. Minor component of pulses crop management in a rotation with sweet potato.

Recently Concluded Projects:

- CIM/2007/122: Sustainable intensification of rice-maize production systems in Bangladesh. 1.8 M AUD. Minor mungbean crop establishment component in the context of limited tillage.
- CSE/2006/040: Diversification and intensification of rainfed lowland cropping systems in Cambodia. About 1 M AUD with a Pulses component of cropping system diversification
- CSE/2006/041: Increased productivity and profitability of rice-based lowland cropping systems in Lao PDR. About 1 M AUD with a Pulses component of cropping system diversification
- LWR/2005/001: Addressing constraints to pulses in cereals-based cropping systems, with particular reference to poverty alleviation in north-western Bangladesh. 1.1 M AUD. Focus on chickpea crop establishment and management and no-till farming.
- SMCN/2009/021: Climate change affecting land use in the Mekong Delta: adaptation of rice based cropping systems. 3.9M AUD. Minor component of pulse as a diversification option.

5.2.5 IDRC

Canada's International Development Research Centre delivers strategic long-term funding towards research and innovation in developing countries. IDRC works in partnership with other domestic and global agencies. Its agriculture funding is delivered through the Canada International Food Security Research Fund (CIFSRF), a partnership with Global Affairs Canada, with a total budget of $124 million over nine years. Of this, $2.6 million is directed towards pulse research, primarily in Ethiopia. In addition, IDRC provides $3.9 million towards its program "Scaling Up", whereby promising innovations which are deemed commercially feasible and ready to launch are taken from the lab to the field.

5.2.6 Kirkhouse Trust

The Kirkhouse Trust is a unique funding agency which works directly with National Agricultural Research Services in countries in Africa and Asia on pulse crops. It was founded in 2000, and is based in North Oxfordshire, UK (http://www.kirkhousetrust.org/):

"The Trust funds projects in Africa and India that make use of modern molecular methods for the improvement of legume crops. There are two consortia in Africa that are receiving support from the Kirkhouse Trust. They are the West African Cowpea Consortium (WACC) and the African Bean Consortium (ABC). The Trust also funds other individual projects in India that are working towards the improvement of orphan legume crops.

The consortia receive hands-on support from the Trust through annual meetings, training and student support. The Trust also funded the sequencing of the cowpea and common bean genomes and the creation of genomic databases for marker discovery. Each consortium has an academic consultant appointed to provide advice on the scientific research conducted.

The Trust's new programme on "Stress Tolerant Orphan Legumes" focuses on legumes that are heat and drought tolerant, as may be needed to provide a resilient response to a changing climate. A number of food legumes are grown in arid regions, often on marginal land unsuitable for major crop species. Most are neglected by the major funding agencies. The Trust is exploring the following crops because of their heat and drought tolerant qualities, nutritional value and use by subsistence farmers:

- horsegram (Macrotyloma uniflorum),
- moth bean (Vigna aconitifolia),
- Dolichos (Lablab purpureus),
- marama bean (Tylosema esculentum),
- and cowpea (Vigna unguiculata).

The Trust's research goals are to evaluate:

i. the potential benefits of these crops in hotter, drier climates,
ii. existing germplasm collections and their accessibility,
iii. the need to conserve the crop diversity, and
iv. the need for genetic improvement".

Although funding information is not available on its website, the Kirkhouse Trust appears worth mentioning because of its focus on pulse crop improvement in Africa and India, not only the main pulse crop species but also the "orphan legumes". Also, the Kirkhouse Trust appears to be autonomous from other global funding agencies.

5.3 National Funding

National funding for pulse crop productivity and sustainability research exists almost exclusively in the public domain. Most national governments have a national agriculture research institute, for example: Agricultural Research Service, United States Department of Agriculture (ARS-USDA); Agriculture and Agri-Food Canada (AAFC); Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; L'Institut national de la recherché agronomique (INRA), France; Department for Environment, Food and Rural Affairs (DEFRA), England; Turkish General Directorate of Agricultural Research (GDAR); Brazilian Agricultural Research Corporation (EMBRAPA); Ethiopian Institute of Agricultural Research (EIAR); Indian Council of Agricultural Research (ICAR). Information about national agricultural research funding is not readily available.

Some countries also have provincial or state funding agencies which may provide significant funding to pulse crops. Saskatchewan's Agriculture Development Fund, for example, has supported pulse crop research and development since 1972 and today provides approximately US$1.3 million annually to pulses. Some countries have grower check-off programs whereby funding is collected, generally at the first point of sale, and directed to national or provincial research programs. In Canada and the United States pulse crops are the subjects of provincial and state check-off respectively, at the level of 1% of the price paid to the farmer at the first point of sale. These programs have developed a strong and consistent base for funding of plant breeding, soils, agronomy, systems and nutrition research. The Saskatchewan Pulse Crop Development Commission, for example, began collecting funds in 1995, and today provides approximately US$8 million per year to pulse crop research. The Australian Grains Research and Development Corporation (GRDC) administers a national check-off on pulses. These funds are matched by the Australian government; GRDC provides approximately US$7.3 million per year to pulse crop research.

There is some private sector engagement in Europe and North America in pulse crop research. The private sector is generally involved in plant breeding and variety commercialization, as well as inoculant development and crop protection products. Systems for value capture encourage private sector plant breeding, for example a seed-based (pedigreed and farm-saved seed) or end-point royalty system.

6. Gaps and Opportunities

When the “Gaps and Opportunities” sections of surveys are scanned, overarching themes emerge as outlined below.

6.1 Breeding and Genetics

6.1.1 Genomics: New Tools and Technologies

It is generally noted that while pulse crop research has begun to encompass and embrace genomics tools, there is much room for improvement. The need for new and continuing work on bioinformatics, genomics tools, trait introgression, hybrids, doubled haploidy, herbicide resistance, and pyramiding resistance genes has been flagged. Global and national funding agencies generally appear aware and are engaged in funding these activities. Kirkhouse Trust makes genomics a priority.

6.1.2 Germplasm – Collection, Management, Analysis, Use

Several respondents note that wild type germplasm is being collected and preserved, and others noted the need to preserve this resource for analysis and possible sourcing of new genes for resistance to abiotic and biotic stress. There is awareness, funding and programming in place in several jurisdictions (United States through Legume Innovation Lab program, national programs in India and Turkey). One respondent points out that most commercial pulse crops are currently characterized by limited genetic and adaptive diversity, even though collections of their respective wild relatives or landraces may be widespread and genetically diverse. Renewed efforts are underway to collect and characterize new diverse germplasm, eg. chickpea through the Legume Innovation Lab at University of California at Davis, among others.

6.1.3 Yield

Yield improvement is the desired outcome in all breeding programs, and many respondents indicate that this needs to remain a primary focus for funding in the foreseeable future. Many of the other themes in this section are related to improving yield and resilience.

6.1.4 Functionality

Quality of pulse crops for human and animal consumption is part of all breeding programs. Functionality of pulse crops, including contribution to human and animal health, biofortification and fractionation, across crop kinds and at the varietal level, are a common theme across North and South America and Europe. This theme relates to understanding and improving pulses as a foodstuff, and also to the decommoditization of pulse crops by developing a diversity of products and an expanded value-added marketplace for pulse crops.

6.2 Agronomy

All respondents speak to the state of agronomic information in their region. Agronomy is seen as a necessary part of crop improvement programs, and must be considered hand-in-hand with new crop development.

6.3 Systems and Sustainability

6.3.1 Systems Research

Systems research is a part of most pulse crop research programs; however, there are new areas of research which need attention, including intercropping, winter cropping, water use efficiency, fertilizer use efficiency, and high- and low-input farming systems. One respondent suggested that development of joint methodologies across regions for data collection would facilitate the ability to compare results and share information.

6.3.2 Response to Climate Variability, Biotic and Abiotic Resistance, Reliability of Response to Climate Change and Weather Effects

Climate change and the need for genetic resiliency against abiotic and biotic stresses is a theme that resonates across all countries / regions, crop kinds and respondents, with a level of urgency implicit in respondent responses. Reliability of response to climate change and weather effects, an understanding of what limits current productivity, searching for new genetic diversity, and a better understanding of the genetic x environment interaction over the long term, are all a part of this theme, all with the undercurrent of a limited land base and a burgeoning global population and food requirement.

6.3.3 Quantification of the Role Pulses Play in the Cropping System

Several respondents indicated that there is a lack of economic quantification of the role pulses play in cropping systems.

6.3.4 Soils

The soil, its abiotic and biotic effects, the soil microbiome, including arbuscular mycorrhizal fungi, the belowground portion of the plant, and the plant's interaction with the soil microbiome, are mentioned by several respondents as an area where there is likely to be huge potential for increasing the understanding of plant-soil health, nutrient availability, and plant productivity, forming the basis of new understanding of pulse crop productivity and sustainability. The relationship between crop kind, rotation and the soil microbiome is considered by some respondents to be a frontier of new research. Global phosphorus deficiency is a concern on the horizon.

6.4 Supply Chain

6.4.1 Scaling up, Seed Delivery Systems, Technology Transfer, Value Chain

Moving research from the lab/field to the farmer, and commercializing research results, are themes mentioned directly by several respondents and indirectly through comments about the need for expanded extension services by others. One respondent makes the point that scaling up pulse crop for value-added opportunities can be problematic simply because production is relatively small and must compete with perceived higher-value or lower risk crops, so it may be difficult to see the opportunity, justify investment, or keep the project supplied with product. Critical mass along the value chain is important. Other respondents mention that appropriate technology at the farm level, with a minimal capital investment, can be a limiting factor, and that research is needed in both high- and low-input farming systems. The need for development of mechanical harvesting capability (from plant architecture through to appropriate harvesters) is mentioned by several respondents. Seed multiplication and systems for delivery of seed of new, improved varieties to farmers is fundamental to crop improvement at the farm level. Several funding agencies make it clear that a technology transfer component is critical to the success of a research application. Some funding agencies directly fund scaling up activities.

6.4.2 Why are Pulses Not Being Grown?

Several respondents asked the question: why pulses are not being grown, and suggested that analysis of this question may yield some factors affecting farmer choices which can be changed or ameliorated, such as risk factors, labour requirements, market opportunities, more or different machinery requirements. One respondent asked why peas, although produced and consumed world-wide, are not a part of the mandate of global funding agencies, while another suggested that peas provide net benefits to the rotation which are beyond other pulse crops and beyond what is currently clearly measurable.

6.5 General

6.5.1 Funding Uncertainties

Several respondents indicated that funding uncertainty makes the sustainability of pulse research difficult on a year-to-year basis. These uncertainties are found at the national level in Africa, and at the global funding level as well. One respondent made the comment that the electronic funding application process can be a barrier to entry for research scientists in countries where the internet is slow, not reliable, or not readily available. In addition, one respondent suggested that funding programs of five years' duration would allow for more robust results.

6.5.2 Development of a Forum for Communication with China

No direct information was obtained from China. There is undoubtedly a vast research network in China on various pulse species of global interest; however, it was not possible within the time available for the current survey to gain specific information.

It would seem to be beneficial to try to establish a forum for communication that includes Chinese pulse researchers for future mutual benefit.

6.5.3 Training of Future Research Personnel

One respondent indicated that there is a need to ensure that high quality research personnel are being trained and targeted for pulse crop research, as the current generation of research scientists reaches retirement age.

7. Summary

Responses from respondents in this survey uniformly present a passion for pulse crop research and a clear understanding of the value of pulse crops to society.

However, pulse crops are only one of many crop kinds available to farmers, and the planting decision, while taking many factors into account, is at the end an economic one. Pulse crop acreage has diminished remarkably in Europe over the past two decades, from 700,000 ha to 200,000 ha in France alone, and now represents only 1% of the total arable land in Europe. In contrast, pulse crop acreage has increased from 500,000 ha in 1991 to over 2 million ha in 2011 in Canada, driven by global market opportunity and not by any material increase in domestic consumption. This 2011 figure is still only 6% of the arable land base.

In developing nations:

- “Pulses are important local food crops in the developing world. They are an essential source of protein in the diets of the world’s poorest countries. In farming systems, pulses represent an input-saving and resource-conserving technology because their biological fixing of nitrogen reduces soil pathogens and the need for chemical fertilizer. For example, a substantial part of the historical growth in Australia’s cereal yields is attributed to the introduction of legumes in rotation systems. The nutritional and environmental benefits of pulses are being explored in sub-Saharan Africa, where production has increased over the last decade. At the global level, however, changes in consumer preferences and feed rations and the relegation of pulses to secondary crop status in the agricultural policies of other developing regions have led to stagnant production growth lagging behind population growth” (FAO Statistical Handbook 2013: World Food and Agriculture).

Respondents make it clear that it is important to continue to build momentum while staying very focused on the key goals of making pulse crops more productive and more competitive, providing information to farmers about production agronomy, being flexible in incorporating new breeding challenges, and continuing to advance the understanding of pulses in sustainable agriculture in developed and moreso in developing nations – all with a view to facilitating the farmer’s decision to include pulse crops in the rotation no matter where he or she lives. Market access issues, including those as basic as seed production and delivery systems, appropriate technology for harvesting, processing, storage, along with the bigger and very difficult challenge of market development, are a crucial part of the scaling up process.

There is a difference in focus of pulse research, with developed nations incorporating work on the broader aspects of sustainability and greenhouse gas mitigation, as well as on biofortification and functionality, while developing nations continue to develop their breeding programs and basic agronomy packages, recognizing the existence of broader issues and the need to incorporate them into research programs, but not making them a priority at this time.

Climate change has become part of the lexicon of agricultural research. All respondents in this survey mentioned issues surrounding climate change. Pulse crop plant breeding programs face the same challenges as all other crop kinds – continual yield improvement, a need for resilience of response to macro- and micro-climatic and weather changes, disease and pest resistance. Pulse crops bring a unique advantage to agricultural systems in their ability to “give back” nitrogen to the soil. This relationship between plant and soil microbiome has been studied, and is well-characterized, in most regions around the world with respect to nitrogen fixation. It now appears increasingly likely that the soil microbiome has more to offer, and respondents believe that an added research focus on the impact of crop kind and rotation on the soil microbiome and vice versa will yield valuable information on sustainable systems.

Funding levels and strategy appear to be stable in developed nations, especially in northern North America, and are particularly well-developed in Canada. Overall, though, funding appears to be low. The major pulse species, dry bean, faba bean, pea, lentil and chickpea, are most often mentioned, with cowpea, mung bean and pigeonpea also significant. There are several minor species which do not appear to receive much attention. Horsegram, moth bean, dolichos and marama bean are even referred to by Kirkhouse Trust as “orphan legumes”. Scientists in developing nations mention the lack of stability of funding and the difficulty of the application process, and these points appear to be important observations requiring attention going forward.

Appendix 1 - FAO Pulse Crops

Primary grain pulses recognized by the United Nations Food and Agriculture Organization (January 2011)

- Cajanus cajan (L.) Druce (pigeonpeas)
- Cicer arietinum L. (chickpeas)
- Lens esculenta Medik.(lentils)
- Lupinus spp. (lupins)
- Pisum sativum L. (peas)
- Phaseolus spp. (beans, including Phaseolus vulgaris L. (common bean) and Phaseolus acutifolius A. Gray (tepary bean))
- Vicia faba L. (including broad bean, faba bean, fava bean, horse bean)
- Vicia sativa L. (vetch)
- Vigna unguiculata (L.) Walp. (cowpeas)
- Vigna spp., including Vigna mungo (L.) Hepper (black gram), Vigna radiate (L.) R. Wilczek (mung bean), Vigna angularis (Willd.) Ohwi & H. Ohashi (adzuki bean)
- Other (eg. Lathyrus sativa – grass pea; Lablab purpureus – hyacinth bean, dolichos)

Pulses are the dry seeds of legumes eaten as food or the crops that produce these dry seeds. Pulse seeds are rich in protein and starch. Pulses are also grain legumes: legumes grown for their dry seeds, but although soybean and groundnut are grain legumes they are largely oil seeds and not generally considered as pulses. Many legumes are eaten as vegetables (e.g. green beans, mange tout peas, fenugreek) and some pulses are also grown for this use.

Legumes are a family of flowering plants, many of which are trees producing wood (eg rosewood *Dalbergia nigra*). Many (but not all) legumes have a symbiotic relationship with soil microbes that improve access to water, phosphorous and nitrogen.

Appendix 2 - Detailed Research Survey Results by Country or Region

Note that the following comprise survey responses and are not edited for content.

1. Australia (two responses)

1.1 Western Australia (WA):

Crop Kinds: lupin, pea, chickpea, faba bean

Research History: There is a strong history since the advent of the Centre for Legumes in Mediterranean Agriculture in 1992. Growers are well aware of the role legumes can play in sustainability but are also aware of the economic risks of over-committing to legumes. The general public is largely unaware of the role of legumes in farming.

Names of Major Research Organizations: CSIRO (national); DAFWA (Department of Agriculture and Food for Western Australia – state); University of Western Australia, Curtin University; Murdoch University.

Plant Breeding and Crop Improvement Only lupin breeding is headquartered in Western Australia, currently carried out by DAFWA, but in the process of privatization.

Genomics and Biotechnology: all of the research organizations above are involved.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies: DAFWA is doing agronomy to some extent as part of their Break Crops program. In recent years their interest in legumes has been supplanted by canola, which is expanding greatly in WA, having risen to a much larger area and production value than legumes have. However, from next year onwards DAFWA will rekindle their legume crop agronomy. CSIRO is interested in studying crop legumes from a holistic farming systems perspective to understand threats and opportunities to the system across regional yield potential gradients that are largely driven by rainfall, probably will be begun in 2016 or 17 onwards.

Pulse Crop Effects on Soil Quality: see above.

Nitrogen Fixation, Inoculants, and Fertilizer Use: Historically CLIMA and CSIRO did much of this work across the Australian production regions, with the applied aspects captured by the agriculture departments such as DAFWA. With the rise of canola and the advent of relatively cheap 'bag' N, this research has declined.

Pulse Crop Effects on Soil Water, Water Use: Not much done in WA.

Pulse Crop Effects on Biodiversity: Not particularly applicable since all the broad acre crops are introduced species, displacing the endemic species/ecosystems that used to reside there prior to land clearing.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: This is a focus of CSIRO in particular, who have run projects in WA looking at C sequestration in perennial and annual crops & pastures including legumes, and on methane emissions in livestock.

Technology Transfer: The honest answer is on an ad hoc basis unfortunately. Traditionally this was largely the preserve of departments of agriculture, all of which seem to have greatly reduced their role in this area as their budgets have become tighter, forcing them to lose staff. As

DAFWA declined regional grower groups became much more active. Funding bodies such as GRDC have taken up the slack, organizing industry forums, conferences such as Crop Updates, and funding grower group activities. Scientists who wish to strengthen their profile with the farming community and funding bodies make it their business to interact with grower groups, industry forums etc. and will extend their research both formally and informally at these events. Accordingly, this is mostly done by researchers focusing on agronomy and farming systems.

Conferences: International Lupin Conference, International Food Legumes Research Conference, Pulse Breeding Australia Conference, InterDrought-IV, Australasian Agronomy Conferences.

Journals: Functional Plant Biology, Critical Reviews in Plant Sciences, Journal of Experimental Botany, Crop & Pasture Science, Genetic Resources & Crop Evolution, Theoretical and Applied Genetics, Field Crops Research, Euphytica, Acta Physiologiae Plantarum, Agronomy for Sustainable Development, *Crop Science, Annals of Applied Biology, Australian Journal of Agricultural Research.*

Research Funding – Where, How Much: Funding is split between both public and private sector. CSIRO has funded much of the respondent's legume work in the last 10 years by covering salary and some operating costs. This is federally funded public money. In the last five years GRDC has been a primary funding agency. GRDC charges growers a levy on all grains sold officially (eg not traded on the black market over the fence), which is then matched by the federal government.

While the mandate for both funding sources has largely been Australian, both organizations are becoming much more global in their interests. This is well illustrated by the respondent's current wild Cicer project, in which we are collaborating with Turkish and American universities to widen the genetic and adaptive diversity of chickpea.

Granting Process: While funding bodies typically call for tenders on an annual basis, this does not imply that there is an annual call for more legume research. A more productive strategy is to develop good relationships with key stakeholders in the granting bodies so that they are aware of one's research interests and expertise, and therefore in a position to commission research directly. Annual reports are mandatory, demonstrating that agreed milestones are being met. This may or may not include publication.

Gaps and Opportunities: Most pulse crops are characterized by limited genetic & adaptive diversity even though collections of their respective wild relatives or landraces may be widespread and genetically diverse. Given the imminent need to produce more from a shrinking resource base it becomes essential that we make pulses more productive and reliable in our farming systems. To do this we need to understand what is limiting our current crops, and the extent to which these limitations can be addressed by accessing genetics from our resource collections. Put simply: which traits are limiting, do those traits exist in our current collections, and if so, can they be used in crop improvement. While this is a simple question, it takes expertise in physiology, genomics and plant breeding to put into action, and is a snap shot of the respondent's current collaborative Cicer work.

1.2 New South Wales

Crop Kinds: faba bean, lentil, chickpea, pea, vetch, lupin, mung bean

Research History: Breeding program for field peas, chickpea and faba bean have operated consistently since 1970s, lentil breeding program since the 1990s; lupin breeding commenced in the 1950s. Growers have a good understanding of knowledge and value of pulses in their farming systems. Different regions have adopted pulses more significantly than others. Pulse agronomy research has been funded consistently since the late 1990s.

Areas of Major Research Focus: There are a large number of projects. The majority of pulse research in Australia in funded by the Grains Research and Development Corporation (GRDC). These projects must provide outcomes to Australian growers either short or long term. Areas of research include; breeding, agronomy, quality, pathology, virology, genomics, nodulation, rhizobium, farming systems, genetic resources. Most projects are 3 – 5 years in length. A list of current GRDC projects (across all crops not just pulses) is available at http://www.grdc.com.au/Research-and-Development/2015-GRDC-research-investments-and-contacts.

Many of GRDC's pulse research investments are listed here: http://www.pulseaus.com.au/growing-pulses/pulse-research

Many of the GRDC projects are co-funded by State Government departments of Agriculture, Universities and the federal science organization (CSIRO), and a very small number of projects are solely funded by these organizations.

Some basic science projects and PhD projects are funded by the Australian Research Council (ARC) and international collaborations by Federal government relationships with other countries such as Australia India Strategic Research Fund (AISRF).

Names of Major Research Organizations:

National public – The largest is the Grains Research and Development Corporation – grower research and development levy matched with federal government funding. They contract research providers to deliver outcomes to Australian growers.

State government agencies public (Queensland (QLD DAF), New South Wales (NSW DPI), Victoria (VIC DEDJTR), South Australia (SARDI)and Western Australia (DAFWA) mainly conduct applied research.

Universities (Sydney University, Queensland University of Technology, Southern Queensland University, Charles Sturt University, Griffin University, Melbourne University, LaTrobe University, University of Adelaide, University of Western Australia, Curtin University).

Private funding in pulse breeding is emerging.

Plant Breeding and Crop Improvement:

Most pulse breeding is still in the public domain and co- funded between GRDC and the following state governments and universities:

- Chickpea – GRDC, NSW DPI, QLD DAF, SARDI, VIC DEDJTR, DAFWA
- Field Pea - GRDC, VIC DEDJTR, NSW DPI, SARDI, DAFWA
- Lentil - GRDC, VIC DEDJTR, NSW DPI, SARDI, DAFWA
- Faba Bean - GRDC, University of Adelaide, University of Sydney, NSW DPI
- These above crops are all part of Pulse Breeding Australia (PBA).

- Mung Bean – GRDC, QLD DAF
- Lupin – recently commercialized breeding program with Australian Grain Technologies (AGT), previously public funded by GRDC, DAFWA, SARDI, NSW DPI.

A large number of pre-breeding projects exist with a large number of different organizations involved – SARDI (herbicide tolerance, abiotic stress), VIC DEDJTR (breeding, pulse quality, biotic stress, abiotic stress, genomics), NSW DPI (breeding, biotic stress, pulse quality), University of Southern QLD (pathology), University of Adelaide (pathology, abiotic stress), Curtin University (pathology, genetic resources).

Genomics and Biotechnology: A number of different projects working on various crops and traits; the main organizations are VIC DEDJTR (lentil, field pea, chickpea, faba bean), University of Adelaide (chickpea), Curtin University (pathology focused), Queensland University of Technology (chickpea and mungbean).

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

Pulse Agronomy projects in target geographical regions:

- Northern pulse agronomy – winter pulses chickpea and faba bean, summer pulses – mungbean. GRDC, NSW DPI and QLD DA.
- South east pulse agronomy –GRDC, VIC DEDJTR, SARDI.
- Crop protection/pathology – GRDC, NSW DPI, QLD DAF, VIC DEDJTR, SARDI, University of Southern QLD, Curtin University, Griffin University.
- Rotational Studies/crop sequencing – GRDC, CSIRO, NSW DPI, Sydney University, QLD DAF.

Pulse Crop Effects on Soil Quality: Some work in pulse agronomy projects; soil N dynamics – CSIRO.

Nitrogen Fixation, Inoculants, Fertilizer Use: Nitrogen fixation and inoculants – GRDC, QLD DAF, University of Adelaide, SARDI; fertilizer use – some work in pulse agronomy projects.

Pulse Crop Effects on Soil Water, Water Use: Some work in pulse agronomy projects.

Pulse Crop Effects on Biodiversity: Pulse crop effects on weed diversity – weeds – University of Adelaide, insects – University of Melbourne.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: VIC DEDJTR – FACE research.

Technology Transfer:

Peer review scientific journals both national and international – discipline based.

GRDC grower and advisor updates, field days, GRDC Ground Cover magazine, Rural media, Social media, Pulse Australia (industry body) extends more specific pulse information to growers in collaboration with researchers.

Research Funding – Where From, How Much:

National public – The largest is the Grains Research and Development Corporation – grower research and development levy matched with federal government funding. They contract research providers to deliver outcomes to Australian growers. Investment in pulse breeding from GRDC is approximately 4.5 million per annum. Further co-investment by partnered state departments and universities.

Granting Process:

GRDC has clearly defined processes for identifying the priorities of grain growers, including consultation with local grain growers and discussion with the Department of Agriculture, Fisheries and Forestry.

Gaps and Opportunities:

Adaptation to climate variability, pathogen variability, herbicide tolerance, maximizing pulse benefits in farming systems, water use efficiency, tolerance to difficult soils, new tools and technologies to improve efficiency of breeding.

Many subjects are current but require greater focus.

Given the consistent funding source, GRDC, this will provide a link to existing research.

2. Southeast Asia – Mungbean Improvement Network (one response)

"The International Mungbean Improvement Network and its outcomes will help to unlock the potential of mungbean to improve system productivity and livelihoods.

The goal of the project is to build a successful network that will attract new members and investors in mungbean research and be sustainable beyond the timeframe of the project.

The network will coordinate and perform research resulting in the development and release of new mungbean varieties that are widely adopted and raise the profitability of smallholder farms and the sustainability of local production systems.

The objectives of the project are:

1) Establish and coordinate an International Mungbean Improvement Network: The network will strengthen local mungbean research, pre-breeding and variety development capacity to generate farmer-accepted improved varieties. The network will initially be coordinated by the mungbean breeding program of the Queensland Department of Agriculture and Fisheries (DAF) together with AVRDC – The World Vegetable Center. Once established, the network will be overseen by a Reference Group consisting of senior managers from mungbean research institutions in the target countries. The network will initially bring together organisations responsible for mungbean research and crop improvement in the target countries Myanmar, Bangladesh and India. It is envisaged that the network will eventually expand to include other South and Southeast Asian countries and further regions. The network will plan and execute mungbean variety improvement and implement training activities for researchers and extension services. The network will ensure ownership of the research by national scientists and will mobilise synergies between the research institutions in the participating countries.

2) Improve access to mungbean genetic diversity for researchers to source traits required for future elite varieties: The project will provide a genetically diverse mungbean mini-core collection to the project partners and coordinate multi-location evaluation of the collection to identify and characterise desired traits conferring biotic and abiotic stress resistance, agronomic *adaptation and grain quality for discerning markets. It will generate mungbean introgression lines from crosses with related species to give breeders access to novel traits that are currently missing in the mungbean genepool.*

3) Develop improved mungbean germplasm and elite lines: The International Mungbean Improvement Network (Objective 1) will coordinate and technically support improvement activities in the target countries. Mungbean lines combining key disease resistance traits with abiotic stress tolerance and desirable agronomic traits will be produced and submitted to farmers for participatory selection. Selected lines will be channelled into variety release pipelines by the project partners."

Sub-projects include research into resistance to Mungbean yellow mosaic virus and into inoculum which can withstand salinity conditions.

3. China

A report from the Agricultural University in Beijing indicates that the adzuki bean genome sequence has recently been accomplished by a team led by Dr. Wan Ping (October 14, 2015) (http://english.cas.cn/newsroom/news/201510/t20151014_153475.shtml).

4. India (three responses)

4.1 India 1

Crop Kinds: bean, faba bean, lentil, chickpea, pea, pigeonpea, cowpea, mung bean, grass pea

Research History:

- There is a very long history of research on pulse crops in the region, while modern R&D in pulses is >50 years old.
- Pulses contribute tremendously in productivity and contribute to the sustainability in this region. Being nitrogen fixing crops, these also have soil ameliorative properties and this fact is well recognized by researchers and cultivators across the region. Nevertheless, pulse productivity in the region fluctuates continuously owing to several reasons including weather conditions, market price and availability of inputs including quality seeds. Still the pulse growing farmers prefer to cultivate at least some area under pulses to meet their domestic demands.

Names of Major National Research Organizations:
The major research organization conducting research on pulses in the Indian region are:

- ICAR-Indian Institute of Pulses Research, Kanpur (National)
- ICAR-Indian Agricultural Research Institute, New Delhi (National)
- ICAR-National Agricultural Research System-State Agricultural Universities (Provincial)

Names of Major Global Research Organizations with offices in India:

- ICRISAT, Hyderabad (Global)
- ICARDA, Regional station, Bhopal (Global)
- AVRDC, India Centre, ICRISAT Campus, Hyderabad (International)

Plant Breeding and Crop Improvement:
Major Goals:

- High yielding and input-resistant cultivar development
- Introgression of resistance to diseases and insect-pests
- Development of suitable plant types
- Development of plants amenable to mechanical harvesting
- Quality improvement of pulse grains

Genomics and Biotechnology:
Goals:

- Development and use of genomic tools in crop improvement
- Development of transgenics for resistance to pod borer and tolerance to drought
- Marker assisted breeding for qualitative traits such as diseases

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Numerous such studies have been undertaken in the region by various national and international Institutes. Recommendations based on these results have been published, especially on crop geometry, plant population, crop protection measures, pre- and post-emergence herbicides, crop rotation studies and pulse-based cropping systems.

Pulse Crop Effects on Soil Quality:

- Long term (>10 year) experiments have been conducted on this aspect, funded by various agencies throughout the region, specific to local soils and conditions and numerous such results have been published.

Nitrogen Fixation, Inoculants, Fertilizer Use:

- Studies have been conducted on various aspects of nutritional requirement of pulses. Specific experiments have been conducted on micro- and macro nutrients, mode of application, residual effect on succeeding crops, seed treatment with Rhizobium, PSB, etc. Encouraging reports have been published on all these aspects.

Pulse Crop Effects on Soil Water, Water Use:

- Although some studies have been conducted on water use efficiency in pulse crops, their effect on soil water has been studied to a limited extent and requires more research.

Pulse Crop Effects on Biodiversity:

- This aspect has also been undertaken by researchers in this region, although to a limited extent. India is a hot spot for several pulse crops and a lot of biodiversity has been collected, evaluated, characterized and documented. Currently wild biodiversity is being used for introgression studies in several pulse crops.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

- Probably, this is the least studied aspect in relation to pulses in this region and requires substantial funding to carry out detailed studies.

Technology Transfer:

- To Scientists:
  - Publication in peer reviewed Journals
  - Publications in the form of popular articles, technical bulletins, monographs, books, etc.
  - Publications as conference proceedings, summaries, etc.
  - Participation in conferences, symposia, group meetings and exchange of ideas
- To farmers:
  - Organization of front line demonstrations
  - Organization of technological demonstrations, farmer fairs, etc.
  - Distribution of pamphlets, bulletins and handouts in vernaculars
  - Extension programmes in local media viz., radio, television, newspapers etc.

Research Funding:

- Mostly public sector organization with a very limited contribution of private sector
- Most of the funding agencies in this region have national/regional mandate while only a few have global mandate
- Amount is generally project based and is for a limited period, most of the times for 3 years for a project, amount of funding also varies depending upon the scope of the project although it is generally sufficient enough to meet protect targets successfully.

Granting Process:

- Application process: Open call
- Decision-making and granting process: Reviewed by few experts, sometimes modification required to suit the mandate as per expert comments, financial grants also rationalized, granting generally taken about 8-12 months after initial submission
- Reporting, publication requirements: Reporting is generally strict and very regular, mostly reviewed by high level committees; financial grants are generally released after annual/quarterly reviews; publications in the form of reports/articles are an essential criterion.

Gaps and Opportunities:
More research is required on the following areas in pulses:

- New disciplines:
  - Carbon sequestration
  - Herbicide tolerance
  - Water use efficiency in pulses
  - Conservation agriculture
- Existing disciplines:
  - Development of extra short duration cultivars
  - Breeding for biotic and abiotic resistance

Future research programmes need to be multi-disciplinary and multi-institutional.

Summary: Pulse research and development has a long history in the Indian region and very good success has been reported on several fronts such as cultivar development, crop dynamics, cropping system research, resource conservation and transgenic development. Nevertheless, a few aspects as mentioned above require additional efforts as well as adequate funding from national and international organizations. Market intelligence and use of information and communication technologies also require further impetus.

4.2 India 2

Crop Kinds: Bean, chickpea, pigeonpea, cowpea, urdbean (Vigna. mungo), mungbean (V.radiata), hyacinth bean (Lablab purpureus), horsegram (Macrotyloma uniflorum)

Research History:

- Since 1972.
- The pulses are excellent source of high quality protein, essential amino and fatty acids, fibers, minerals and vitamins. These crops improve soil health by enriching nitrogen status, long –term fertility and sustainability of cropping systems. Nearly 80 % to its nitrogen requirement will be met from symbiotic nitrogen fixation from air and leaves behind substantial amount of residual nitrogen and organic matter for the subsequent crops. Water requirement of pulses is about one –fifth of requirement of cereals thus effectively save available precious irrigation water.
- The production of pulses in India is presently about 15 million tonnes covering an area of about 20- 23 million hectare; majority of which falling under rainfed, resource poor and harsh environments frequently prone to drought and other abiotic stress condition. In Karnataka pulses are being grown an area of 25.06 lakh hectare with production of 17.03 lakh tonnes. The productivity during the year was 745 kg/ha.

Research Organizations:

- **Global:** International Crop Research Institute for Semi Arid Tropics, (ICRISAT) Hyderabad(India)
- **Regional:** ICAR institutes, State Agricultural Universities, Private companies with R&D

Plant Breeding and Crop Improvement:

- Major focus on crop improvement with development of resistant/tolerant varieties for diseases, insects and drought
- Development of suitable plant types with high yield, hybrid technology etc

Genomics and Biotechnology:

- Marker assisted selection, transgenic and gene pyramiding

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Considering the constraints and crop management/crop protection and requirements of the pigeonpea farmers, research is being carried out on the following important areas
    - Agronomic evaluations of pulses varieties.
    - Nutrient management and integrated Agro technologies.
    - Integrated weed/pest /disease management technologies
    - Cropping systems.
    - Transplanting of pigeonpea
    - Use of growth regulators and drought utilization studies

    - Identification of new bio-molecules and chemicals for disease and pest management

Pulse Crop Effects on Soil Quality:

- The leaf shedding by the pulses adds nutrients to the soil and going to help the subsequent crop.

Nitrogen Fixation, Inoculants, Fertilizer Use:

- Pulses meet up to 80% of nitrogen requirement from symbiotic nitrogen fixation from air and leaves behind substantial amount of residual nitrogen to subsequent crop. Seed treatment with Rhizobium + PSB+ PGPR increases grain yield of pulses over no seed treatment (control). Legumes possesses root nodules with nitrogen fixing ability to the extent of about 20-60 kg nitrogen per hectare per year and stores it in the root nodules which is going to help the succeeding crops.

Pulse Crop Effects on Soil Water, Water Use:

- The water requirement of pulses is about one-fifth of requirement of cereals, thus effective save available precious irrigation water. Pulses in general requires around 400-600 mm water per crop/season depending on the crops.

Pulse Crop Effects on Biodiversity:

- N/A

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

- N/A

Technology Transfer:

- To Scientists:
    - Communication through internet, publications, messages etc.
- To Farmers:
    - Scientist to farmers, Extension personnel to farmers, field visits, conduct of front line demonstration, large scale demonstrations, Radio and TV programmes, leaflets, bulletins, conduct of farmer melas, through commodity based associations etc,.

Research Funding:

- Funding: For pulses, major funding will be from public sector like ICAR and Govt. of India. In few cases, funding was provided from the private/ international organizations.
- Mandate: Mandate of state and state agriculture universities is to develop suitable crop technologies for higher productivity and sustainability.
- Amount: depends on research targets and persons employed in research projects

Granting Process:

- **Strategy:** Granting process will be as decided by the granting organizations based on the nature of research work
- **Periodicity :** Three to five years
- **Decision-making and granting process**: decided by the granting organizations

- **Reporting, publication requirements:** Reporting will be half yearly or Annually.
- **Publications** of research are compulsory.

Gaps and Opportunities:
Subject areas requiring research over the next decade

  - Development of multiple disease resistant varieties.
  - Development of climate resilient varieties having tolerance to temperature extremities and drought
  - Development of transgenic for pod borer and drought
  - Pyramiding resistant genes for various races of imp. diseases
  - Development of low cost and eco-friendly IWM, IPM and IDM modules
  - Expansion of pulses in new niches
  - Efficient conservation of rain water and its utilization
  - Integrated germplasm enhancement
  - Pre-breeding for broadening the genetic base
  - Introgression of molecular and conventional breeding technology
  - Exploitation of heterosis in pigeonpea
  - Development of varieties resistant to stored grain pest
  - Development of efficient harvest and threshing machines
  - Development of efficient dhal mills, modernization of existing mills and their popularization
- Development of improved technologies for storage

4.3 India 3

Crop Kinds: Chickpea, pigeonpea, mung bean, urdbean, lentil, pea, lathyrus, horse bean, moth bean

Research History:

- India has a strong history of research; Established Imperial Agricultural research Institute (IARI) in Pusa in 1905, followed by research on pulse crops in different states (1943-53), established All India Coordinated Pulse Improvement Program (AICPIP) in 1967, upgraded to Directorate of Pulses Research in Kanpur in 1984 and finally in 1993, India established Indian Institute of Pulses Research and four All India Research Programs one each on Chickpea (AICRP-Chickpea), pigeonpea (AICRP-Pigeonpea), MULLaRP (AICRP-Mungbean, Urdbean, Lentil, Lathyrus, common bean and Pea) and AICRP-Arid Legumes.
- Productivity is very low at 650-700 kg/ha. Since pulses are grown on 25 Million ha, they contribute substantially in sustainability of agriculture especially for cereal based cropping systems

Names of Major Research Organizations:

- An outlay of INR 1213.8 million during 2009-2014 from the Government of India besides various bilateral projects under National Food Security Mission and from various Government agencies like Department of Agricultural Research and Education, Department of Biotechnology invested.

- Scope: Main focus is on hybrid development in pigeonpea, transgenics against pod borer in chickpea and pigeonpea, high yielding varieties with tolerance to biotic and abiotic stresses, intensification of pulse-based cropping systems and resource conservation, mechanization and minimizing post-harvest yield loss, climate risk management and efficient extension models for dissemination of pulse-based technologies.
- Goals: Enhancing pulses production for food security and sustainability through technological innovations
- Outcomes: Self sufficiency in pulse production and improve competitiveness through knowledge based technological interventions for improving nutritional security and sustainability of the production base
- Brief description: IIPR is leading to intensify the breeding programme both conventional and genomic enabled crop improvement with strong basis of vast available germplasm including wild species. Improvement in pulse crops is needed through conservation and diversification of agriculture so as to increase the productivity of the system and improve soil health. Climate change associated with temperature rise and water scarcity adversely affecting the crop productivity, particularly under rainfed pulse growing regions, is one of the major challenges and concerns which needs to be addressed immediately. The Institute has made strategic planning to achieve the Goal fixed up to 2030 focusing on hybrid development in pigeonpea, transgenics against pod borer in chickpea and pigeonpea, high yielding varieties with tolerance to biotic and abiotic stresses, biointensification of pulse-based cropping systems and resource conservation, mechanization and minimizing post-harvest yield loss, climate risk management and efficient extension models for dissemination of pulse-based technologies for farmers to make the pulse cultivation in the country productive and remunerative.

Plant Breeding and Crop Improvement:

- Main focus is on genetic enhancement for yield, stress resistance, nutritional quality, hybrid pigeonpea through Cytoplasmic genetic male sterility, pre-breeding through mainstreaming local, exotic and wild germplasm, efficient plant type for machine harvest and extra early varieties for short season windows and rice fallows.

Genomics and Biotechnology:

- Deployment of genomics tools for the isolation of genes that underlie variability for genomic traits that determine crop performance in the field. These represent plant and crop architecture, the associated nutrient partitioning and response to biotic and abiotic stresses. Marker assisted breeding through development of molecular maps and mapping and tagging of genes/QTLs associated with important traits

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Agronomy and crop management and rotational studies: Development of efficient and remunerative cropping Systems *viz*. rice-wheat-mungbean, pigeonpea-wheat and maize/sorghum/pearl millet-chickpea/lentil; prrduction technology for rice fallow and relay planting; seed inoculation with *Rhizobium* and phosphate solubilising bacteria (PSB); Resource conservation practices including mulching, residue recycling, *etc*.; Raised bed planting for population management and ridge & furrow system to conserve and enhance water use efficiency; Seed priming (overnight soaking with water), Integrated nutrient management including foliar spray of Urea/DAP at flowering and podding stages and integrated weed management using pre- and post-emergence weedicide;

- Crop Protection: Integrated pest management involving varieties that are resistant / tolerant to pests and diseases, cultural practices like summer ploughing and destruction of stubbles / crop residues; trimming of bunds; proper preparation and leveling of fields; timely sowing; proper crop geometry; seed treatment; proper soil, water and weed management; rotation with non-host crops; harvesting of crop at right stage and under right conditions; raising trap crops as border / intercrop, etc, regular monitoring of pest situation vis-à-vis their natural enemies; Use of yellow sticky traps, pheromone traps, light traps to monitor pest population; mechanical control through collection and destruction of egg masses, larvae and adults; use of light traps for trapping adults of insects which are attracted towards light; biological control by conserving naturally occurring parasites, predators and pathogens; need based use of pesticides.

Pulse Crop Effects on Soil Quality:

- Inclusion of pulses in cropping systems has shown positive effect on physical, chemical and biological properties of soil. It is estimated that up to 70 kg/ha nitrogen saving is there when a cereal crop is taken after a pulse crop. A higher yield is reported from the succeeding cereal crop when grown after pulses. Similarly, intercropping of cereal crop with pulses have shown positive effect on cereal-equivalent yield.

Nitrogen Fixation, Inoculants, Fertilizer Use:

- The inbuilt mechanism of biological N fixation 2 enable pulse crops to meet 80–90 per cent of their nitrogen requirements, hence a small dose of 15–25 kg N/ha is sufficient to meet out the requirement of most of the pulse crops. However, in emerging cropping systems like Rice - Chickpea, a higher dose of nitrogen (30–40 kg/ha) had shown beneficial effect.
- Phosphorus deficiency in soils is wide spread and most of the pulse crops have shown good response to 20–60 kg phosphorus/ha depending upon nutrient status of soil, cropping system and moisture availability. In the recent years, use of sulphur (20–30 kg/ha) and some of the micronutrients such as Zn, B, Mo and Fe have improved productivity of pulse crops considerably in many pockets. Boron and placement of phosphatic fertilizers and use of biofertilizers enhance the efficiency of applied as well as native P. Foliar nutrition of some micronutrients proved quite effective. The amount and mode of application is determined by indigenous nutrient supply, moisture availability and genotypes. Balanced nutrition is indispensable for achieving higher productivity. At the same time, in view of increasing nutrients demand, there is immense need to exploit the alternate source of nutrients viz., organic materials and bio-fertilizers to sustain the productivity with more environment friendly nutrient management systems.
- Bacterial agents Rhizobium culture and phosphate solubilising bacteria (PSB) are bacteria that enable crops to fix crucial inputs from the soil. Rhizobium culture is one of the cheapest inputs in increasing production of pulses and other leguminous crops. The treatment of seed with this culture helps in fixation of atmospheric nitrogen through its symbiotic activity. The treatment is particularly beneficial in areas where groundnut and soybean are a new introduction. PSB has a capacity to release phosphorus and has been

recommended as one of the low cost inputs for all crops. It helps to reduce nearly 20 per cent of phosphatic fertilizer input to crops.

Pulse Crop Effects on Soil Water, Water Use:

- Kindly see in agronomy and Rhizobium section

Pulse Crop Effects on Biodiversity:

- India grows a large number of pulse crops. Inclusion of pulses and their >500 varieties at farm levels provide a positive effect on biodiversity. Pulses are used for diversification of cereal based cropping systems to reduce disease risk.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

- No data available except that it has positive effect on reducing greenhouse gas emissions and negative carbon footprint.

Technology Transfer:

- To Scientists:
  - Through Indian Society of Pulses Research and Development (ISPRD), it organizes national and international conferences at regular interval, publish a Journal of Food Legumes quarterly. In addition, there are a large number of national and international journals published by various agencies and societies for publication of research articles
- To Farmers:
  - Through large-scale frontline demonstrations through network of State universities, KVKs (Krishhak Vigyan Kendra), state extension machinery and farmers' fair, farmers and extension workers training, through print, audio and visual media and publication of pamphlets.

Research Funding:

- Public with national and state mandate.

Granting Process:

- Research funding is through a 5-year plan from Government funding besides invitation of research proposal under national agricultural science fund and national food security mission.

Gaps and Opportunities:

- More efforts are required for research on genomics enabled improvement, biological nitrogen fixation, mechanization, weed management, appropriate plant type, effect of climate change on productivity, nutrient use efficiency and rice fallow system.

5. Middle East – Turkey (one response)

Crop Kinds: common bean, chickpea and lentil

Research History: the first PhD thesis related to pulses was in 1938 at Ankara University. Since 1976 the state institutions have carried out research programs on chickpea and lentil.

Names of Major Research Organizations: Turkish General Directorate of Agriculture (GDAR); the Scientific and Technological Research Council of Turkey (TUBITAK); universities both state and private; state and private seed companies.

Plant Breeding and Crop Improvement: Current research institute focus is on chickpea, lentil, and dry bean. Subjects of plant breeding are biotic and abiotic stresses. Specific objectives for main pulse crops are germplasm development, disease management and quality criteria. State research institutes and private seed company are mainly focused on cultivar improvement and seed multiplication.

Genomics and Biotechnology: Tissue culture, marker-assisted selection, genetic characterization, genetic systematics, double haploidy

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies: seeding date, seed density, weed control, reduced tillage, organic production, sustainable rotations.

- Crop protection in chickpea: Ascochyta blight (Ascochyta rabie), Wilt (F. oxysporum f.sp. oxysporum).
- Crop protection in lentil: Wilt (F.oxysporum f.sp. lentis),Broom rapes (Orobanche spp.), Chalky spot (Dolycoris baccarum L. And Piezodorus liuratus F.)
- Crop protection in dry bean: White mold (*S. sclerotiorum*); Root rot (*R. solani*); Common bacterial blight (*X. campestris* pv. *phaseoli*); Halo blight (*P. syringae* pv. *phaseolicola*); Bean common mosaic virus.

Pulse Crop Effects on Soil Quality: Amount of organic matter after pulses and other crops, Nutrition level on soil after difference crops.

Nitrogen Fixation, Inoculants, Fertilizer Use: Nitrogen fixation, inoculants, fertilizer: Effect of use with or without inoculant on yield, Effect of nitrogen fixation in difference pulses crops on yield, The effect of fertilizer in different level on yield.

Pulse Crop Effects on Soil Water, Water Use: Residual soil water level after pulse crops, the effect of irrigation time and period on yield of pulses, water use in different pulse crops

Pulse Crop Effects on Biodiversity: Turkey is a centre of genetic diversity for several pulse crops. For this reason:

- Collection and characterization (morphologic and molecular) of wild species and land races; conservation in national gene bank (Ankara and Izmir)
- Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: none at this time.

Technology Transfer:

General:

- Media (National/regional radio and TV)
- Social networking sites (facebook, twiter,wep page and youTube)
- Journals (National and regional)

To scientists:

- National and international agricultural journals

- National and international congress, symposia

To farmers:

- Demonstration programs,
- Provincial extension centers,
- Provincial governorships,
- Private seed company
- National technology transfer programs

Research Funding – Where From, How Much:

- Turkish General Directorate of agricultural Research (GDAR- State)
- The Scientific and Technological Research Council of Turkey (TÜBİTAK- State)
- Research programs of Universities
- Private sector
- Europe Union
- ICARDA

Granting Process:

- Research projects should be on main crops and priorities of Turkey, based on research objectives.
- Call for proposals by agricultural donors (For example. TÜBİTAK)
- The preparation of research project proposals to be given to donors
- Evaluation of projects by donors
- Selection of projects by donors
- This period varies from 6 months to 1 year.

Gaps and Opportunities:

Grain legumes are model crops for the other crops.

New research areas for pulse crops:

- Quality
- Genetic information on Grain legumes
- Understanding of genetic mechanism on nitration fixation
- And transfer to other crops (such as cereal)
- Multi-disciplinary approach on research projects
- Primary research should be supported by national or international funder
- Secondary research and extension work to farmers should be by national or regional or private sectors

6. Africa (three responses)

6.1 Eastern and Southern Africa (ESA)

Crop Kinds: Bean, lentil, chickpea, and pigeonpea are the major crops.

Research History:

- There has been a long history of legume research in the Region. It dates back to more than 10-30 years in many National Research programs in the countries of Kenya, Ethiopia, Tanzania, Uganda and Sudan. There is a wide general knowledge about pulse productivity (yields are generally low) and its high contribution to cropping system sustainability. That is why many farmers intercrop legumes and cereals in over 60% of crop lands. However, yields are generally low and in most cases mainly for subsistence and nutritional protein source in diets.

Names of Major Research Organizations:

- National and Regional - Universities in Region like Egerton, University of Nairobi-Kenya, Makerere in Uganda, Dar es Salaam in Tanzania etc.
- National Research Institutes like Kenya agricultural Research Institute (KALRO), Kenya, The Ethiopian Institute of Agricultural Research-EAIAR, Ethiopia, Malawi Research Institute and other NARS in Tanzania, Eritrea, Southern Sudan, NARO in Uganda
- International and Global Include-Global-CIAT Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), EMBRAPA Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation), ICRISAT - International Crops Research Institute for the Semi-Arid Tropics, IITA International Institute of Tropical Agriculture, The International Center for Agricultural Research in the Dry Areas (ICARDA)
- Collaborators with NARS: NCGR National Center for Genome Resources, USA; University of California–Davis, USA; University of California–Riverside, USA; GCP; Kirkhouse Trust; IAEA,Vienna

Plant Breeding and Crop Improvement:

- Not all legumes are given equal breeding focus in ESA but you will find beans as dominant in all countries and given significant focus in breeding since they are widely distributed and consumed in all 14 countries in ESA.
- Then each country has leading legume, eg Ethiopia is leading in chickpeas, followed by Tanzania, Sudan and Malawi. Kenya has strong breeding program for chickpeas though not a major legume there. Kenya is leading in pigeonpeas followed by Tanzania and Malawi. Some legumes are minor like Vigna unguiculata (cowpeas), Vigna spp., Lupinus spp. and Lablab purpureus; they do not have dedicated breeding programs and may not be existing, hence introductions of germplasm and evaluation for adaption from CGIAR and given to farmers.
- Generally, a few strong breeding programs exist eg beans, chickpeas, groundnuts.

Genomics and Biotechnology: No response.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies, Pulse Crop Effects on Soil Quality, Nitrogen Fixation, Inoculants, Fertilizer Use, Pulse Crop Effects on Soil Water, Water Use, and Biodiversity: Most national programs and universities as well as the CGIAR centres touch on some aspect of these subjects. Fertilizer companies are also involved in some collaborative research.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: None, and not given any priority.

Technology Transfer:

- To scientists: Internet, conferences, publications, Journal articles, national and international publications, symposia like the upcoming Conference in International Year of Pulse 2016.
- To farmers: Mainly extension work, technology transfer programs like pamphlets and publications, National open days and shows, farmer coops and associations, provincial/state county government agents, national Radio and Magazines like Seeds of Gold by Egerton University.

Research Funding:

- Bill and Melinda Gates Foundation has been the leading donor in pulse crop research in the region.
- AGRA, Generation Challenge program (GCP), USAID, DFID, EU, ACIAR, IDRC, CRP of CGIAR (ICRISAT, CIAT, ICARDA, IITA), IAEA, EU, World Bank, GTZ, DAAD, Chinese Government, JICA (Japan), etc.
- Up to several milions of Dollars but each country gets <1 million dollars
- Private Foundations - limited <100,000 dollars rare
- Regional - ASARECA, RUFORUM, African Union etc. 20,000-250,000 USD
- National Governments of Region, African Union, National Funding Agency, state University Research Grants 10,000-200,000 USD.

Granting Process:

- Many through competitive proposal calls, which is a flawed process because they are biased towards developed institutes and more well-known scientists in developed nations or CGIAR.
- Most are annual calls but some after 3years.
- Application process is fairly easy through internet, but this is also flawed, as many scientists in region do not access the internet and/or usually do not apply since either they may not be aware or internet access is low in offices or home. Also some may have low network and hence application may be frustrating through website of donors.
- Decision making is usually biased in not favouring ESA regional scientists, even though we have capacity and problems to address in the region.
- Reporting and publication may be weak among regional scientists, but situation is improving with networks, capacity building and linkages with CGIAR, AGRA, IDRC, DAAD etc.

Gaps and Opportunities:

- We need improvement in germplasm and productivity linked to nutritional and health needs of regional population.
- We need seed health, seed systems and drought and pest tolerance.
- There is declining soil fertility and legumes have a big role - research need to be done.
- There is a long history of intercropping which has been existing body of knowledge which should be linked to better sustainability of cropping systems--this has been neglected in last decade by NARS and CGIAR.

- There is general acceptance and proven technology in biotechnology and breeding contribution to legume productivity by TL1 and TL2 projects that need to be applied in large scale including outsourcing of genotyping.
- Donors, National Governments and all friends of pulses need to put more resources in legumes for increased incomes.
- National and international partnerships need to be strengthened for ease of communication especially in 2016 that has been designated the International Year of Pulses (IYP).
- There is need to have programs in regions supported for at least five years.

6.2 West Africa

Crop Kinds: Cowpea, pigeonpea, common bean

Research History:

- IITA and partner national programs have been collaborating in cowpea improvement over the last ~40 years. For cowpea, there is a wealth of knowledge which has been generated and captured in the literature, mainly with regard to crop improvement, but also including elements of productivity and sustainability (e.g. value of cowpea in crop rotations, N fixation and its availability in the soil through crop residues).

Names of Major Research Organizations:

- International: IITA (cowpea), ICRISAT (pigeonpea)
- Regional: African Agricultural Technology Foundation (AATF)
- National Agricultural Research Systems (NARS) in each of the West African countries, which include universities.

Plant Breeding and Crop Improvement:

- In cowpea, the IITA focus is in currently on development of varieties with high grain and fodder yield, improved resistance to selected pests and diseases (aphids and aphid-transmitted diseases), as well as drought and low-P tolerance. In the past, we have been breeding for resistance to most biotic stresses, with good success in developing varieties resistant to the parasitic weed Striga gesnerioides. More than 50 countries have released at least two varieties from IITA.

Genomics and Biotechnology:

- Colleagues at the University of California, Riverside (UCR) are finalizing the cowpea genome assembly, while IITA will focus on re-sequencing and RNA-seq (transcriptomes) for better targeting marker assisted selection.
- Colleagues at AATF, in collaboration with CSIRO (Australia) and Monsanto, have developed a transgenic cowpea which includes the Cry1Ab gene conferring resistance to the legume pod borer Maruca vitrata. This line is currently under evaluation in confined field trials in Nigeria, Ghana and Burkina Faso.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies: No response

Pulse Crop Effects on Soil Quality: No response

Nitrogen Fixation, Inoculants, Fertilizer Use: No response

Pulse Crop Effects on Soil Water, Water Use: No response

Pulse Crop Effects on Biodiversity: No response

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: No response

Technology Transfer:

- To Scientists: Mainly through scientific reports (publications, project reports), workshops, seminars and conferences
- To Farmers: Various approaches including Participatory Variety Selection, Farmer Field Fora, rural radio and TV programs, written training materials, cellphone animation videos in local languages

Research Funding:

- IITA is funded through the CGIAR system through the CRP on Grain Legumes; the funding level for 2015 was 2.5M.
- Bilateral donors include USAID (Legume Innovation Lab 150k, Seed scaling project 400k, direct contribution to cowpea research 500k, BMGF precision-IPM for cowpea 230k, IITA/Tropical Legume III 5M, Climate resilient cowpea varieties (USAID through the University of California, Riverside) $300k.

Granting Process:

- IITA granting process is organized through a Project Development Office at our HQ in Ibadan, which coordinates forwarding RFPs/calls to scientists, preparing good quality concept notes and proposals, and submitting to funding agencies on behalf of the principal investigators. We respond to calls from donors.

Gaps and Opportunities:

- In breeding, the target is to increase cowpea productivity by 60% in the next 5 years through the development of improved lines with: High stable yield potential, resistance/tolerance to both biotic and abiotic stresses, good adaptation to mono-cropping and intercropping systems, Grain characteristics preferred by consumers and processors. Opportunities are mainly the implementation of molecular breeding approaches, genetic gains strategies and increasing number of active breeding programs in West and Central Africa. Challenges will remain the stability and level of funding.
- In Integrated Pest Management, the focus for the next years will be to develop a precision-IPM approach which will both be affordable and implementable by low-literacy farmers. Recommendations for pest management will be tailored to individual farmers' needs, thanks to a simple-to-use Farmer Interface Application running on cheap phones which are predicted to be more and more available in rural areas together with internet coverage.

6.3. North Africa

Crop Kinds:

- The major legumes crop in the region in terms of area occupied and consumptions is faba bean followed by cowpea, chickpea and lentils. See below some indicators:
- **Cultivated Areas** Faba bean (0.43 mha), Cowpea and Chickpea (0.18 mHa), lentils (0.6 mH)
- **Importation of pulses:**
  - North African countries imports around 862000 tons
  - Egypt is the first importer followed by Morocco and Sudan. Around 608017 tons (63%) for its needs on pulses mainly faba bean (450000 tons, chickpea, lentils and beans

Research History:

- Yes, there is strong research program on cool season food legumes in the region leaded by the International Centre for Agricultural Research in Dry Areas (ICARDA), since 1977 in partnership with Agriculture Research Centre (ARC) Egypt, Agricultural Research corporation (ARC) Sudan and National Institute for agricultural Research in Tunisia (INRAT) and National Institute for Agricultural Research (INRA) Morocco.
- Pulses were neglected over the years by food security policies in different North African countries that subsidizing wheats by providing fertilizers and others inputs, while food could contribute to reduce soil erosion, enrich the soil with nitrogen, breakdown the weeds and disease cycles in cereals crops.
- The following fund for improvement of food legumes in the regions:
  - CRP grain legumes ongoing research (2012-2017)
  - OCP Morocco-India project for upscaling food legumes in Morocco,
  - EU-IFAD from 2012 to 2015 for upscaling food legumes in different target regions
  - ARC-Egypt on going for controlling orobanche and faba bean necrotic yellow virus
  - GRDC-chickpea program from 2014 to 2019 for gene mining of biotic and abiotic stresses
  - AFESD fund for capacity building.
  - China restricted fund to CGIAR programs

Names of Major Research Organizations:

- ICARDA for global research on faba bean and lentils and for regional research in drylands on none tropical areas
- ARC-Egypt, INRA morocco, ARC-Sudan and INRAT Tunisia are at national levels. Agriculture University in Egypt (also see above)

Plant Breeding and Crop Improvement:

- ICARDA has international breeding program for faba bean, chickpea and lentils. The majors traits were resistance to biotic and abiotic stress, weed management and nitrogen fixation and NARS partners work closely on development and testing new varieties for in faba bean, lentils and chickpea.
- Outcomes:
  - 22 faba bean varieties in Egypt, 6 varieties in Sudan and 6 varieties in Tunisia
  - 4 lentils varieties released in Sudan and 3 in Morocco

Genomics and Biotechnology:

- Ongoing research on genotyping by sequencing of faba bean in collaboration with China.
- Polymorphism on 855 SNP markers identified in faba bean
- Genome sequencing of lentils is ongoing.
- Chickpea research
- Development of magic population
- RILS populations in faba bean, chickpea and lentils available at ICARDA

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Herbicide tolerant faba bean, chickpea and lentils is currently under development at ICARDA
- Technologies for controlling orobanche by glyphosate has been developed and widely used by farmers in Egypt

Pulse Crop Effects on Soil Quality: N/a

Nitrogen Fixation, Inoculants, Fertilizer Use:

- ICARDA provides 1400 rhizobia collections at its genebank in Lebanon/
- Identification of faba bean and chickpea lines carried out at ICARDA in collaboration ARC-Egypt and INRA-Morocco

Pulse Crop Effects on Soil Water, Water Use:

- The following researches are ongoing in the region:
    - Chickpea and lentils drought tolerance
    - Raised-bed technology in Egypt is under evaluation

Pulse Crop Effects on Biodiversity:

- ICARDA provides in its the Genebank based currently in Lebanon and Morocco around 34000 accessions of cultivated lentils, faba bean and chickpea collected mainly from the centers of origin of this crops and in different environments were the crops grown traditionally. More over wild relatives of these crops are conserved ex-situ in the gene bank.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: N/A

Technology Transfer:

To Scientists:

- Capacity building program: short term training course was conducted at ICARDA
- Degree training for young research at different National research Institute
- Scientific publications in International food legume conference, publications in ISI journals (Genomics, Agronomy, Euphytica, Crop and pasture science, crop science, etc

To Farmers:

- Farmer's schools, field days and demonstration of new developed technologies.
- The new released varieties in Egypt increased the production from 136000 tons in 2012 to 186000 tons in 2014.

- The adoption of heat tolerance varieties in Sudan increased the production from 30000 tons in 1992 to 153000 tons in 2013.

Research Funding:

- The major fund organizations are:
    - Collaborative Research program (CRP) W1W2
    - United State Agency for International Development (USAID)
    - International Fund for Agricultural Development (IFAD)
    - Arab Fund for Economic and Social Development (AFESD)
    - NARS partners in Egypt, Tunisia, Morocco and Sudan

Granting Process: N/A

Gaps and Opportunities:

- There is need to focus on:
    - Development of orobanche resistance in lentils and faba bean for different north African countries.
    - Development of improved lines heat and drought tolerance as due to climate change frequencies and intensities of heat increased mainly during the reproductive stages
    - Development of herbicides and mechanical harvestable legume crops for NARS Africa, due the increase in labor cost farmers moved to mechanized crop for economical purposes.

7. European Union (three responses)

7.1 Spain

Crop Kinds: pea, dry bean, faba bean, chickpea, lentil

Research History:

- Long tradition of legume cultivation, consumption and research. Good knowledge of the crop and its benefits.

Names of Major Research Organizations:

- CSIC (Consejo Superior de Investigaciones Científicas) (this is the largest one, public, national, with several institutes all across the country): symbiosis (the institute at Granada), breeding (Cordoba, Pontevedra), genomics (Cordoba, Madrid), quality (Madrid); all legumes noted above are included in these programs
- INIA (Public, national): quality, genetic resources
- SERIDA (Public, regional): *Phaseolus*
- IFAPA (Public, regional): breeding
- ITACYL (Public, regional): breeding, agronomy
- University Leon: lentil genetics
- Univ. Cordoba: breeding and agronomy

Plant Breeding and Crop Improvement:

- Pea breeding at CSIC and ITACYL

- Faba bean breeding at CSIC and IFAPA
- Lentil breeding at ITACYL
- *Phaseolus* breeding at CSIC and SERIDA
- Chickpea breeding at IFAPA and UCO

Genomics and Biotechnology: CSIC, Univ. Leon, Univ. Cordoba

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies: CSIC, Univ. Cordoba

Pulse Crop Effects on Soil Quality: CSIC, Univ. Cordoba

Nitrogen Fixation, Inoculants, Fertilizer Use: CSIC

Pulse Crop Effects on Soil Water, Water Use: CSIC

Pulse Crop Effects on Biodiversity: CSIC and INIA

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: CSIC, Univ. Cordoba

Technology Transfer:

- to scientists via Spanish Legume Society meetings, journals
- extension programs for farmers also exist

Research Funding – Where From, How Much:

- Most program are nationally (public) funded, with additional support at some teams by European Union programs (FP7 and H2020). Only a few have other international projects.
- Mandate usually national. Funds usually limited.

Granting Process:

- Open competitive calls are made at regional (usually restricted to regional agencies), national, European, depending on the project. For clarity, there are no specific topics or priority for legumes at national or regional levels; researchers simply formulate their proposals (1 every 3 years) and if lucky they are funded. There are no guidelines or guarantee for support of a long term program. To be granted proposals ought to be "scientifically innovative" making it difficult to get funds for applied research.

Gaps and Opportunities:

- Legume improvement for Mediterranean farming systems. The fact is that legumes acreage is declining due to the lack of adapted cultivars and competition from other crop kinds. Research programs are insufficiently connected with stakeholders' needs because they are not active in the process of requesting and funding research.

7.2 France

Crop Kinds: mainly pea and faba bean

Research History:

- In the 1980s there were 700,000 ha peas in France, while today there are less than 200,000 ha. However, there are changes in policy and in food use which are leading to renewed interest in pulse crops. Two separate but related policy initiatives are creating a push-pull situation: the need for a reduced environmental footprint in agriculture, and food and feed industry demand for protein.

Names of Major Research Organizations:

- INRA is the major institute in France looking at pulse crops; there is some linkage with universities. Pulses are becoming of greater interest to INRA and the French Ministry of Agriculture and at the political level as a source of plant protein. There is increasing demand for more legumes as food, feed and forage. It is not easy to change orientation of research, at least not quickly.

Plant Breeding and Crop Improvement:

- Breeding programs in pea and faba bean; some work in chickpea

Genomics and Biotechnology:

- There is an international collaboration (Canada, France and Australia) to sequence the pea genome.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

Generally, there is a very strong focus on sustainability, driven by increasingly strong policies at the government level. Agriculture is one area of interest, including new agricultural methodologies with lower environmental impact. INRA is developing its program in agro-ecology. There are two meta-programs in cropping systems and food production.

Systems approaches are becoming increasingly important, especially in the last five years. There are now three major labs in France looking at cropping systems and intercropping.

Pulse Crop Effects on Soil Quality:

Two labs, Toulouse and Dijon, are looking at symbiosis, carbon and sulfur; one in Montpelier is looking at interactions between pulse crops and the micro-biome. Eurolegume is an organization funded by FP7 which is very focused on the plant-microbe relationship (http://www.eurolegume.eu/).

Nitrogen Fixation, Inoculants, Fertilizer Use:

- see above

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

Two labs in France are focusing on this area of research. The EU collaborations are good – there is work being done in France, Scandinavia and Switzerland. LEGATO, funded by FP7, promotes strong working level collaborations (http://www.legato-fp7.eu/).

Technology Transfer:

The policy of government is to promote technology transfer. The rule now is to involve private companies. Linkage to technology transfer must be included in all project applications now. Extension service is publically funded, all pulses were transferred to this service last year. A new organization called “Terre Sinovia” has been formed, and Agronomy guides for peas and faba beans have been written and are available for download or shipment: http://www.terresinovia.fr/ .

Research Funding:

Budgets are generally not expanding. Some programs are closing, and funds are being re-allocated.

There is private sector involvement – 6 companies in pea, 2 in faba bean, 1 in lupin. When private sector initiatives are small the public sector tries to fill in.

Generally, salaries and infrastructure come from public sources and operating money comes from a number of public and private sources, such as Ministry of Agriculture, INRA, Ministry of Research, professional structures, eg. GIA, private companies, regional economic development organizations. There is some international funding for large collaborative projects such as the pea genome sequence.

Granting Process:

Nothing to add.

Gaps and Opportunities:

- Economic analysis at the farm level. The idea to perform these calculations is new. It would be extremely useful to do some metanalysis; it would help to define and promote a joint global methodology which would be used globally, as often results are difficult to compare.
- More reference to environment, human and animal health at the academic level
- Better long term monitoring of varieties, the climate is changing, new winter legumes may have potential, need to stabilize yield and quality, have a better understanding of g x e to better understand resilience at crop and variety level.
- Strong need now and even stronger in the future for trained personnel; seeing this in France and in Europe and believe it will be very strong in Africa.

7.3 Sweden – sustainability research

Crop Kinds:

Research History: There is no strong previous history on research on pulse sustainability in the region (within the last 30-40 years). Research has been developed during the last seven years.

Scania is the part of Sweden with the best soils and conventional farming with a short rotation of cereals, sugarbeet and oilseed rape in the main cropping system. Peas are grown now and then as a break-crop, but due to the intensity of the arable systems, there is probably no interest in the other services which pulse crops provide.

Names of Major Research Organizations: Swedish University of Agricultural Sciences, Uppsala (SLU).

Plant Breeding and Crop Improvement: Until about seven years ago SW Seeds AB conducted a pea breeding program. Demand for peas in the EU diminished throughout the 90s and early part of the 2000s, and SW along with several other European breeding companies closed its breeding program in the middle of the last decade. There are still pea varieties sold in Sweden and they are generally used in the rotation as a break crop.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

Research on pulses in organic farming and development of sustainable systems are ongoing currently for more than 4 years.

Focus is a multicriteria sustainability assessment of rotations, intercropping with cereals and cultivar mixtures for yield stability, mainly in organic farming systems.

http://www.slu.se/en/departments/biosystems-technology/research/cropping-systems-ecology/legumes-for-sustainable-food-systems/

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

See: Jensen ES, Peoples MB, Boddey RM, Gresshoff PM, Hauggaard-Nielsen H, Alves BJR and Morrison MJ. 2012. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries – a review. Agronomy for Sustainable Development. 32, 329-364.

Technology Transfer:

So far mainly by publication in international journals and farmer magazines, and seminars.

Research Funding:

- National Research Council
- EU Commission
- University (SLU)

Gaps and Opportunities:

More research:

- on pulses in organic farming for food and/or feed
- intercropping with other species
- resilience of crops to climate change
- how to eliminate barriers and lock-in. Changing cropping systems and including more pulse crops is not only a decision of farmers but also the whole food system. If retailer/buyers of crops are used to buying grain as a sole crop, they may not have interest in buying a mixed grain, eg. pea and barley. The feed industry and advisory service may want to stick to producing concentrate from soybean because they can receive a certain quality in unlimited amounts. Thirdly, even if we have knowledge of the many advantages of grain legumes in cropping systems, farmers may, due to tradition, conservatism and/or risk management continue with what they have been doing over the last 25 years. These are barriers and lock-ins. Lock-in comes from economy and is related to the reluctance of change – eg. farmers may want to produce new crops, but no one wants to buy them.

8. North America (four responses)

8.1. United States (one response)

Crop Kinds: Chickpeas, dry beans, peas, lentil; no faba bean; cowpea mostly Texas, Arkansas, the southeastern states and California; ND and MT commissions include lupins (it is always pointed out in demonstration plots at field days at Carrington).

Research History:

- began in Palouse region of Washington in early 1900s with lentils
- 1960s commissions in WA and ID - > today's Dry Pea and Lentil Council
- research began in 1960s, mostly about processing, then insects and weeds in 1972. Pea insect pests in WA: pea weevil, pea aphid, associated viruses. ND and MT no insect pests to speak of.

Names of Research Organizations:

- Primarily universities and the Agricultural Research Service of USDA

Plant Breeding and Crop Improvement:

- WSU and ARS-USDA Pullman – primary location; 50 years of pea, lentil and chickpea breeding
- NDSU – pea and lentil breeding for seven years
- dry bean – several States at state – grower commission level – NDSU, MI, WI, CA, NE, CO, ; southern ID is seed production area; breeding is carried out at AFR-USDA at East Lansing.
- cowpea – research programs at universities in primary production areas (eg AK, CA, TX).
- the formal programs are on genetics and breeding

Genomics and Biotechnology:

- bean – moved forward most, collaborated on a CAP grant
- lentil and pea – collaboration with INRA, Canada
- chickpea – has been mapped through CDC/PBI (Canada) in collaboration with UC Davis, India
- Legume Innovation Labs – a USAID project supporting genomics work on multiple pulse crop kinds at multiple locations in the US, with the goal to improve the climate resilience of pulse crops in other countries in Central America and Africa (http://feedthefuture.gov/lp/feed-future-innovation-labs) (http://legumelab.msu.edu/strategic_objectives)

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies, and other Sustainability subjects:

- these programs largely resided in the land grant universities; there is a strong program in pathology and weed management at USDA ARS at WSU
- diseases – Aphanomyces and Sclerotinia research programs in pea and lentil at Madison
- larger issues – cover crops, pulses fit well; economic tool- enrich the soil; cropping systems research and carbon footprint primarily at universities; for example, REACCH at U of Idaho is a project in cropping systems and soil erosion, funded by USDA National

Institute of Food and Agriculture (NIFA) $25 million over 5 years – tristate; there are also other focused grants on cropping systems.

Technology Transfer:

- the US still has an extension service, but it is diminishing as farm size grows and numbers of farmers reduces; it is hard to keep agents in each county, the pressure is to reduce; some extension work is managed through industry.

Research Funding – Where From, How Much:

- public
- commission - Assessment level is 1% for US dry pea and lentil
- private – one breeding company in peas in WA

Gaps and Opportunities:

- The US spends 90% of funds on breeding, genomics, crop management, 10% on functionality and nutrition. We need to focus more funding on these aspects. WSU is looking at varietal analysis of fractionates. Note that soy comes in 22 formulations and pea in only three. We need to move away from commodity and into value added; there is an education component to farmers and processors regarding production and handling.
- There is also a new initiative at ARS at Pullman on autumn seeded pulses. Material is being selected showing cold tolerance. The productivity gain is 2.5x. This new timing will provide a diversification and a break crop in the winter wheat rotation in the Great Plains region.

8.2 Canada (three responses amalgamated)

Crop Kinds: pea, lentil, chickpea, faba bean, dry bean

Research History:

- Plant breeding in dry beans and peas began in mid-century in eastern and western Canada. The western Canadian lentil industry began development in the early 1970s with the hiring of Dr. Al Slinkard at the University of Saskatchewan's then newly-established Crop Development Centre. Dr. Slinkard established breeding programs in pea and lentil. Chickpea, dry bean and faba bean were added to the program at the U of S in the 1990s. Dry bean (eastern and western Canada) and pea breeding (western Canada) programs have also been carried out by Agriculture and Agri-Food Canada (AAFC); dry bean breeding is also carried out at the University of Guelph in eastern Canada. Pea varieties have also been developed for western Canada by European companies including SW Seeds and DL Seeds.

Names of Major Research and Funding Organizations:

- Crop Development Centre (CDC), Departments of Plant Science and Soil Science, at the University of Saskatchewan
- Agriculture and Agri-Food Canada (AAFC)
- University of Guelph
- Saskatchewan Agriculture and Agriculture Development Fund
- Saskatchewan Pulse Growers and other provincial pulse associations

- BASF
- Inoculant and crop protection companies

Plant Breeding and Crop Improvement:

- Robust programs in all crops in western Canada and in dry beans in eastern Canada.

Genomics and Biotechnology:

- Strong genomics initiatives in all crops. Part of international collaborations in sequencing the chickpea (completed), lentil and pea (in progress) genomes. Doubled haploidy techniques have been worked on. Molecular markers for some key traits have been developed and are being utilized, and many more are under development.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Dr. Slinkard believed that one cannot introduce a new crop without a robust agronomic package to aid its adoption by farmers. Thus, basic agronomy was a part of his research. This approach has continued to be fundamental to Canadian research programs, as new crops are added to the breeding programs. Basic agronomy work has been conducted on chickpea, for example, including nitrogen and phosphorus requirements, inoculum development (there was no native inoculum in the soil), and more recently the contribution of chickpea to the soil nitrogen component.
- Development of crop protection strategies has also been and continues to be managed at all research institutes, through collaborative research and through private-public sector partnerships.
- Agronomy can be categorized into three large stages:
    - Basic agronomy packages to help farmers, including seeding rate, date, row spacing, adapting the crops to the region.
    - Cropping systems, benefiting the whole farm; how do pulses fit into the system, diseases, weed, N-fixation, rotation studies; 3-4 year studies on productivity and sustainability; lots of land required and longer term studies are in progress.
    - Recently begun: Soil microbial communities, and their biodiversity, show a very strong feedback to the crops grown in the next year; effect of pulse crops on the microbiome (also see below).

Pulse Crop Effects on Soil Quality, Nitrogen Fixation, Inoculants, Fertilizer Use:

- Much inoculant research has been carried out over the years through the Department of Soil Science at the University of Saskatchewan, at AAFC, and by private sector inoculant manufacturers. Soil fertility requirements and the benefits to the rotation have also been subjects of research. The benefits to the soil, to subsequent crops and to the rotation are well-known and understood by the research, extension and farm communities.
- One area of research which is coming to the forefront is that of the soil microbiome (also see above). There is a dawning realization that understanding the soil microbiome is a critical part of understanding crop production. Arbuscular mycorrhizal fungi are a group of soil fungi which probably play a huge role in the success of a crop; as new research techniques are developed we can re-examine agronomy packages, current understanding of crop benefits to the soil, nutrient and micronutrient cycles, and even biofortification research, and their inter-relationships with the soil microbiome.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

- There is a strong concern at the policy level to consider the carbon footprint of agriculture, particularly with respect to nitrogen use. The good news is that in regions with dry climates the carbon footprint is inherently lower per acre. In addition, low and no-till is crucial to maintaining a reduced carbon footprint.
- We need to increase profitability while reducing environmental footprint. Reducing the carbon footprint is equivalent to reducing greenhouse gas emissions by both CO_2 and N_2O. (One unit of N_2O is equal to 298 units of CO_2). Pulses are lower than other crops in their carbon footprint, and this carries over to the next crop in the rotation with respect to the consequent reduction in N application.
- Comparing pulses – pea is better than chickpea and lentil for nitrogen fixation but, while it is probable that peas are more valuable in the larger rotation, they may be less profitable in value of the grain to the farmer; chickpea can be lower in profitability because of a higher fungicide requirement in some years; however, more disease-resistant cultivars are becoming available.
- We need to consider the life cycle assessment.

Technology Transfer:

- Canada has a strong technology transfer mandate and extension services exist at the provincial government level, often in conjunction with grower associations. Federal, provincial and university personnel consider tech transfer to be a part of their mandate. Grower field days and winter meetings are held annually.

Research Funding:

- Research funding is strong at both federal and provincial levels. Grower check-off programs exist in each province. The check-off is currently 1% of the purchase price at the first point of sale. Excellent coordination exists in the granting cycle and process among the funding agencies.

Gaps and Opportunities:

- Phosphorus is becoming depleted globally and we need to understand the roles that crops, rotations, and soil microbiomes play in the phosphorus cycle in order to manage this nutrient efficiently.
- It appears that the soil microbiome contributes far more than just nodulation to pulse crops. This could be considered a new frontier of research.
- Aphanomyces root rot is a disease with long term ramifications on pea and lentil production. Genetic resistance, chemical control and biocontrol studies are beginning. In New Zealand there is an Aphanomyces-suppressive soil region – we need to understand why.
- The economics of the rotation should be analyzed and published.
- Biofortification. The continuum from soil through the crop to human health.
- Bioinformatics: The recent huge expansion in available genomic resources for plant breeding has focused a need for more expertise in bioinformatics.

9. Mexico, Central and South America (two responses)

9.1 CIAT

Crop Kinds: common bean

Research History: Since 1920s; a good understanding and knowledge base about the crop, its productivity and contribution to sustainability.

Names of Major Research Organizations, and Plant Breeding Programs:

There are several major players in dry bean breeding in the region:

- INIFAP, Mexico. National, public (breeding for local adaptation and drought, especially pinto beans)
- Zamorano University, Honduras. Regional, public (breeding for small red and black beans with disease resistance and drought tolerance; also high iron)
- ICTA, Guatemala. National, public (breeding black beans for disease resistance and high iron)
- INTA, Nicaragua, National, public (selection for tolerance to low soil fertility in beans, identifying drought tolerant lines, implementing high iron (biofortified) beans)
- EMBRAPA, Brazil. National, public (broad based breeding program for Brazil specializing in carioca beans)
- IAC, Brazil: State, public (broad based breeding program for Sao Paolo specializing in carioca beans)
- IAPAR, Brazil: State, public (broad based breeding program for Paraná specializing in carioca and black beans)
- CIAT, Colombia. Global, public (broad based breeding program for biotic and abiotic stress tolerance and high iron, strength in molecular markers)

Plant Breeding and Crop Improvement: see above.

Genomics and Biotechnology: see above.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies: various institutions in Brazil, employing high level technology.

Pulse Crop Effects on Soil Quality: minimal, perhaps CATIE in Costa Rica.

Nitrogen Fixation, Inoculants, Fertilizer Use: EMBRAPA – long term research on inoculant strains

Pulse Crop Effects on Soil Water, Water Use: minimal

Pulse Crop Effects on Biodiversity: minimal

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture: minimal

Technology Transfer:

To other scientists

- In Central America through a regional annual meeting of agronomists
- In Brazil through a triennial national bean congress and formal publications
- From CIAT, through formal publications and personal contacts

To farmers

- In a few countries through extensionists but this is now very weak
- Some NGOs
- In Mexico through farmer associations

Research Funding – Where From, How Much:

- Largely through public funds
- In Mexico, through farmer organizations
- CIAT, through public funds and competitive grants

Granting Process:

- Mexico: proposals are presented to a public science foundation CONACYT
- CIAT: Most donors have been associated with the CGIAR for many years and receive grant proposals on a yearly basis; most grants are for 3 years. Data are publicly available.

Gaps and Opportunities:

- Stress physiology, especially multiple abiotic stress and tolerance to edaphic stress. There is an increasing body of knowledge around stress adaptation but much less on multiple stress (eg, heat and drought combined). In the tropics edaphic constraints are the most frequent cause of low yields, but genetic adaptation is largely unexplored.
- Economics: who will be competitive in what in the future under climate change? Competitiveness has been an age-old topic but changing climates will alter current advantages and relationships.
- Pathology/Entomology: Potential for new distributions of pathogens and insects under scenarios of climate change
- Breeding: exploitation of cross-species hybridization. While not a new topic, the application of genomic analyses has permitted a new focus and means to analyze successful introgression.
- Agronomy: novel practices that fit smallholder farming systems with minimal capital investment. Most problems can be fixed with capital, but we are waiting for the medium-scale solutions that require low capital investment.
- Product transformation: As populations urbanize, legumes (beans) are less attractive due to cooking time. Canned beans have been the traditional answer to this, but other options should be explored.

9.2 Brazil

Crop Kinds:

- Phaseolus vulgaris (common bean)
- Vigna unguiculata (cowpea)

Research History:

- Common bean research in Brazil began in the 1930's at IAC (Instituto Agronômico de Campinas, Campinas, SP), a State organization. Since this time, national research programs have been established and continuously funded. Plant breeding and pathology are the main fields focused by research, which are being developed almost exclusively by the public sector. Initiatives on plant sciences have been reported, but they are limited and intermittent.

- To date Brazil is the largest producer and consumer of common bean grains worldwide.
- Although there are reports dated over the last 40 years, the research on cowpea has increased in volume and importance in Brazil in the last two decades, when the crop became important in the Brazilian savannas ("cerrados"). To date, cowpea is still grown by smallholder farmers in the Northeast area of the country as a subsistence crop tolerant to heat and drought. However, it has also been grown by farm companies in the Brazilian savannas focused on grain exportation.
- There is a strong knowledge background in the public sector about bean breeding, genetics and crop management.
- Work in the private sector has been limited, mostly on chemical pesticides.
- Genetic resources conservation and characterization is strong and continuous.
- There is a polarization of cropping systems: low-input small farming versus high-input large farming.
- Sustainability concepts still incipient but high in the current agenda of research organizations.
- The most important grain type (Carioca beans, 60% - 70% of the market) is almost unique to Brazil as preferred type, thus importing/exporting is limited mostly to black beans.

Names of Major Research Organizations:

- Common beans:
  - Embrapa Rice and Beans (Santo Antônio de Goiás, GO). National organization.
  - IAC – Instituto Agronômico de Campinas (Campinas, SP), State organization.
  - Iapar – Instituto Agronômico do Paraná (Londrina, PR), State organization.
  - Epamig – Empresa de Pesquisa Agropecuária de Minas Gerais (Belo Horizonte, PE). State organization, common bean.
  - Universidade Estadual de Maringá (Maringá, PR)
  - UFV – Universidade Federal de Viçosa (Viçosa, MG)
  - UFLA – Universidade Federal de Lavras (Lavras, MG).
- Cowpeas:
  - Embrapa Meio-Norte (Teresina, PI). National organization.
  - IPA – Instituto Agronômico de Pernambuco (Recife, PE), State organization.

Plant Breeding and Crop Improvement:

- Important breeding goals are:
  - Yield (high, stable)
  - Grain quality (size, color, cooking properties)
  - Shelf life (non-darkening, no hard grain coat)
  - Disease resistance
  - Drought tolerance in reproductive stage
  - Plant architecture (standing, machine-harvestable)

Genomics and Biotechnology:

- Structural genomics, whole genome sequencing (in collaboration with international partners)
- Functional genomics for abiotic and biotic stresses.
- Genetic mapping and marker-assisted selection for traits of interest of breeding (mainly grain quality and disease resistance)
- Genetic engineering (RNA interference) – first GM common bean approved, cultivar registered in 2015 with possibility to be released in 2016, resistant to Bean golden mosaic virus.

Agronomy, Crop Management, Crop Protection, Systems/Rotational Studies:

- Integrated pest management is a large priority. Emphasis on whitefly (*Bemisia tabaci*) control.
- Identification of pest natural enemies and capacitation of extension agents for their identification.
- Some work done in crop rotation with maize, cotton and rice.

Pulse Crop Effects on Soil Quality:

- There is a research gap on this topic for pulse crops and, consequently, need and opportunity for initiatives in the near future.

Nitrogen Fixation, Inoculants, Fertilizer Use:

- BNF: *Rhizobium* spp. diversity and compatibility with bean germplasm; crop management with BNF; different levels of substitution of N input by BNF; breeding for BNF ability.
- Growth and resistance promoters.
- Different sources and rates of mineral fertilizers (N, P, K, micronutrients)

Pulse Crop Effects on Soil Water, Water Use:

- Reduction of irrigation requirement in dry-season production, extra-short crop duration.

Pulse Crop Effects on Biodiversity:

- No specific research
- Organic bean production has been studied for several years, viable in some types of farming systems.

Greenhouse Gas Emissions, Environmental Footprint, Carbon Capture:

- Quantification of GGE on cropping systems involving common beans and cowpea.
- Alternatives for reduction of GGE.
- Soil carbon balance, N input and GGE.

Technology Transfer:

- Technical publications, field days, farm technology fairs, lectures, short courses, etc.

To scientists:

- Publication of papers in scientific journals, both Brazilian and international. Most of them in English, still some in Portuguese.

- Talks, oral and poster presentations in scientific meetings in Brazil and other countries.
- Support and orientation of undergraduate and graduate students in research projects.

To farmers:

- In the large farming areas: collaboration with field agronomists in the private sector for identification of problems and validation of research results.
- In small farming areas: collaboration with public extension agents, mostly from state organizations.
- Participation in discussion workshops to subsidize public policies.
- Short training courses for public and private technology multipliers.
- Publications oriented to field technicians and farmers.
- Online information.
- Radio and TV programs produced by Embrapa and aired by communication partners.

Research Funding:

- Almost all of the funding for bean research in Brazil comes from the public sector. Embrapa makes the largest investment (ballpark estimate: USD 10 million/year, including salaries), followed by state level organizations and some universities.
- Private companies do seed multiplication and commercialization, some of them have proprietary materials of their own, but investment in breeding is modest as well as in other research fields.
- Multinationals have so far demonstrated little interest in beans, except in the agrochemical sector.
- (Accurate amount of funding not readily available. A meaningful figure would require defining a method of estimation.)

Granting Process:

- Embrapa has three rounds of proposal submission per year.
- Proposals are evaluated at the research center level (Embrapa Rice and Beans), then centralized (Embrapa headquarters).
- Approved projects have funding for 3-4 years.
- Only Embrapa scientists can apply as project leaders. Partners can collaborate and receive support with running costs.
- Reporting yearly and final.
- Results must be documented by publications or product registration (patent, PVP, etc.).
- State organizations (Iapar, IAC, IPA and Epamig) have their own funding sources and processes, but with modest and limited investments.
- Financial support for researches in universities comes mainly from wide scope calls from Brazilian government agencies. Some of these funds can also be accessed by scientists from Embrapa and State organizations.

Gaps and Opportunities:

- More research needed on agronomy, in two situations:
    - High input farming: rationalizing the use of agrochemicals and chemical fertilizers; reducing environmental impacts on soil, water, air, biodiversity.

    - Low input farming: closing the wide yield gap observed in some areas; adoption of improved materials and crop management; development of low-cost, yield-effective technologies.
- Functional food based on beans: high-quality protein, high-fiber, colon-cancer protection, etc.
- There are opportunities to improve and increase the collaborative research on beans among different groups in Brazil and among Brazil and other countries to address common problems and challenges.
- Brazil has a strong expertise on bean production in tropical areas.
- There is much room for improvement of average yield, considering the extreme low yields still observed in small farming (closing yield gaps).

Appendix 3 – Respondents

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Appendix 4 - Acknowledgements

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Opinions expressed in this document are those of the survey respondents and not those of the author.