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Pulse crops and sustainability:

A framework to evaluate multiple benefits

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Executive Summary

The potential of pulses—beans, peas, chickpeas, lentils, and other pulses—to help address future global food security, nutrition and environmental sustainability needs has been acknowledged through the UN declaration of the 2016 International Year of Pulses. However, the full set of benefits that pulse crops can offer has not been systematically characterized. This paper specifically seeks to develop a framework to evaluate the economic, social and environmental benefits and potential trade-offs of pulse production in different geographic, agro-ecological and economic contexts. The framework defines the sustainability elements to be evaluated in any given context, given the diversity across cropping systems and geographic contexts of suitable pulse growing areas. The framework will also provide a means to evaluate the potential sustainability contributions of pulses should they be brought into a cropping system, or integrated into crop rotations. The primary audience for this white paper is the food industry, but government policy makers, researchers and other stakeholders will find utility in it as well.

The methodology for developing the framework was to derive insights from a general global literature review and two geographic case studies—diverse contexts of production in Sub-Saharan Africa and Saskatchewan, Canada. Key insights and findings from the literature and case studies across the three pillars of sustainability—environmental, social and economic—are summarized below. Please refer to the full report for citations and references.

Environmental:

Nitrogen fixation: Pulse crops have a unique role to play in the global nitrogen cycle, as legumes and pulse fix atmospheric nitrogen in soils. The introduction of pulses into crop rotations actively helps fix nitrogen in the soil, thus reducing fertilizer requirements of the pulse crop itself, as well as the following crop. The nitrogen remaining in the soil also increases the grain yield in subsequent crops. How to maximize the environmental benefits of pulses added into crop rotations is an ever-evolving science, based on many factors best observed at the cropping system level.

- In Sub-Saharan Africa, altering the traditional planting methods of maize and bean are found to influence the nitrogen balance in cropping systems. Research in Central Kenya identified the nitrogen benefits of cowpea intercropping with maize and groundnut. Other research in the dry savannahs of Nigeria and Niger found modified strip-cropping of cowpea and sorghum, with the addition of livestock to boost manure nutrients, prevented the nutrient losses caused by traditional farming practices.
- Life cycle assessment findings in Saskatchewan, Canada indicate that the environmental benefits of pulse crops is strong, primarily due to their nitrogen fixation abilities, the reduction in nitrogen requirements of a cereal crop succeeding a pulse crop, and the increase in quantity and nutritive quality (protein content) of a cereal crop following a pulse crop. The assessment found that even when considering the practice of applying moderate amounts of pesticides to the crops, this did not generate sufficient differences in environmental effects to discount the overall positive environmental results. Related benefits of the reduced synthetic nitrogen fertilizers requirements in cropping systems, when pulses are added in rotations, include the reduced emissions and energy use associated with the production, use and disposal of fertilizers.

Conservation tillage: Changes in tillage practices have had a significant effect on shifting conventional cereal-based cropping systems to more diversified crop rotations that utilize pulses or oilseeds and that result in less soil disturbance. While increased use of herbicides has been utilized to address weed abundance under reduced or no-tillage, this appears to be moderated after a period of transition to conservation tillage.

- Saskatchewan: Long-standing patterns of monoculture cereal cropping resulted in pest and disease outbreaks and erosion, and fallowing led to increased soil salinity and loss of soil nitrogen and water. The conventional tillage practices in cereal monoculture resulted in increased soil erosion, despite the benefit of incorporating crop residues into the soil. These factors spurred farmers to seek alternative crops to include in rotations, usually replacing summer fallow. The greatest environmental benefit of adding pulse crops into cereal-fallow rotations was their nitrogen fixation capability, which reduced fertilizer nitrogen requirements in the current and succeeding crop, and improved the capacity of the soil to supply nitrogen.
- Changes in tillage requires adjustment, and farmers in Saskatchewan improved their herbicide and management practices over time, leading to reduced rates in use, and a significant reduction in repeat applications. Erosion has been found to increase during production of field pea, lentil, and chickpea in these areas, as

they often produce less crop residue than cereal crops, and the crop residue is more easily disintegrated by tillage than cereal residue. Therefore, farmers are advised to minimize pulse cropping on highly erodible soils and minimize or eliminate tillage, particularly in the fall.

- Few conservation tillage assessments are available for Sub-Saharan Africa.

Productivity improvements over area expansion: Adding more crops, such as pulses, into rotations can increase the efficiency of a production system, reducing the need to expand the production area to achieve overall yield increase.

- Finding ways to boost productivity in Sub-Saharan Africa, in order to meet expected food and feed demand will be crucial. Demand for pulses (mostly beans and cowpeas) in Sub-Saharan Africa is expected to increase 155% from 2015 to 2050. Yet, most Sub-Saharan pulse production occurs in rainfed areas, with low use of inputs and relatively low yields. Ghana's example of increasing the production and yields of cowpea at a greater proportion than hectares planted, indicates efficiency in production. These trends are attributed to the improvements in the supply, distribution and uptake of improved varieties and better quality seed, more demand by urban consumers and better markets, and both the profitability and existence of incentives for farmers to adopt productivity enhancing options.
- Though pulse production area has increased 23% since 2013 in Saskatchewan and Western Canada, the overall harvest area has slightly decreased over the same period.
- Integration of legumes into livestock production systems can be highly beneficial, with increased nitrogen supply and increased meat production.

Climate change mitigation and adaptation: Pulses in crop rotations can help lower GHG emissions due to lower fertilizer requirements, particularly given the large amount of energy used in fertilizer production.

- Up to 70% of the non-renewable energy used in Western Canadian cropping systems is due to the use of fertilizers, particularly nitrogen. Adding pulses into rotations commonly lowers GHG emissions. Research in Swift Current, SK assessing net GHG emissions from four cropping systems (fallow-flax-wheat, fallow- wheat-wheat, continuous wheat, and lentil-wheat), found the lentil-wheat system to clearly outperform the others. This was due to the lower rates of nitrogen fertilizer required by the wheat crop in this lentil-wheat rotation and the increased nitrogen availability, which enhanced plant biomass accumulation. Results indicated that spring wheat grown using improved practices of (a) fertilizing crops based on soil tests, (b) reducing summer- fallow frequencies and (c) rotating cereals with lentil can attain a net GHG balance regardless of water availability.

- In Sub-Saharan Africa, climate adaptation is more urgent that mitigation measures. In most of the Sub-Saharan countries reviewed, projected declines in bean production are significant, due to expected changes in rainfall patterns and temperature. The IPCC estimates that crop failure due to drought and water risk will be the highest in Africa due to climate change impacts. This indicates the vulnerability of agriculture in these contexts, and need for improved management practices, better adaptability and strength of seed systems, and technical and information support to farmers for improved practices.

Social:

Nutrition and disease: While per capita food consumption will level off in developed countries, significant increases in developing countries, based largely on increases in protein intake, are expected to 2024. Fairly recent changes in the global human diet favouring more energy-dense foods rich in total and saturated fats are increasing the rates of obesity, diet-related diseases such as diabetes, coronary heart disease and cancer. Helping to balance that trend, pulses and legumes are an important contributor of micronutrient-rich intake, along with fruits and vegetables, if consumers make healthy choices. Pulses have a role to play in combating cardiovascular disease, increasing gut health and healthy nutrition.

- The Canadian Diabetes Association Clinical Practice Guidelines recommend that a low-fat vegan diet (which would include pulses and legumes) improves glycemia and plasma lipids more than conventional diets. The role of pulses and legumes in dietary patterns of people with diabetes can be important to regulate blood sugar levels and moderate symptoms, and is also important in the prevention of cardiovascular disease.
- In Rwanda, which has the highest per capital consumption of common beans in the world, large-scale household surveys carried out in 2011 indicated that almost 90% of farm households cultivate beans as part of their cropping system, and yet 77% reported not growing enough beans for their needs. Other household survey research indicates that, as the share of improved bean seeds planted increased, household dietary diversity scores increased, showing a clear relationship between nutrition and improved seed variety adoption. In Kenya, Ghana, Eastern DRC, Nigeria and Tanzania, between 32 – 80% of cowpea and/or common bean crops goes toward subsistence production and consumption, highlighting their importance for food security and nutrition.

Nutrition and food security: Grain legumes added into the diet are found to contribute important energy, proteins, minerals, and B vitamins. When consumed with cereals, pulses contribute proteins, minerals and B vitamins, as well as the essential amino acid lysine, which increases the quality of protein. When added to root and fruit staples, they raise the protein content. Nitrogen-rich and protein-rich plant foods are necessary to supply dietary protein. New efforts are investigating the increased production and use of pulse protein fractions in manufactured food products.

- In Rwanda, adoption of improved pulse crop varieties appear to have a greater impact on food security than on bean farm income. Adoption of improved bean varieties influences food consumption in other ways than just through farm profitability. To address nutritional deficiencies in Rwanda that have resulted in one of the highest rates of child stunting in the world, quality seed of 'high iron' ('bio-fortified') bean varieties is being developed.
- The health aspects of including pulses in diets is an important contributor of the social benefits of pulses, as a micronutrient-rich food source, helps reduce inflammation in the gut, and has beneficial effect on serum cholesterol levels, thus reducing cardiovascular disease risk. North American and Canadian consumption of pulses appears to be far below the optimal level.

Gender: Gender aspect of pulse production relates primarily to women's involvement in pulse production commercially, to feed families, and to benefit from income derived from pulse sales.

- Across African countries for which gender research related to pulse production exists, pulse cultivation by women occurs at various and multiple stages in the supply chain. However, gender equity for women is more apparent when women can make decisions on quantities sold and those retained for household consumption. Gender differences in access to land, technologies and other strategic resources play a large role.

Anecdotal evidence from interviews conducted in this research suggests there are intertwined social and economic benefits of adding pulses to crop rotations, as many Saskatchewan farmers using rotations consisting of cereal-fallow or cereal-canola would have gone bankrupt without diversifying into lentils and other pulse crops. Thus, the addition of pulses helped keep farming communities intact and productive.

Economic:

Reduced reliance on fossil fuels and lower fuel costs: Where conservation tillage practices have been adopted, pulses and oilseeds have commonly been integrated into crop rotations. Reduced and altered tillage practices (commonly including pulse and oilseed crops) reduce reliance on fossil fuels and lower overall fuel bills. Farmers are likely to see the long-term economic benefits (and avoided costs) of less soil, air and water degradation by adopting no-till practices and including legumes in their operations.

- In Saskatchewan, when compared to conventional tillage, conservation tillage or no-tillage practices result in consistent yield advantages, less income variability and significant resource savings.

Economic benefits of adding pulses to crop rotations: Significant research and development has gone into improved pulse seed varieties. Less emphasis has been placed on the technical and financial support to help farmers navigate changes in practices and trade-offs associated with adding pulse crops into rotations (or different intercropping methods in Sub-Saharan Africa). Furthermore, though investments in pulse crop breeding have been made in in different regions, the extent of investment is still relatively small when compared to the scale of investments in corn, soybean and wheat. Investment in improved varieties will be key to improvements in the global pulse industry.

- Findings from Sub-Saharan Africa indicate that economic impacts of including pulses in rotations are influenced by a variety of factors, particularly farmer perception and knowledge. Farmers are more likely to adopt pulses in their cropping systems when they find a crop rotation sequence that produces higher return on investment over the long term. Low sales prices of beans contribute to low adoption rates of improved bean varieties, but other research indicates a complex set of factors, including lack of supply systems and lack of market coordination, limited post-harvest storage facilities, high opportunity cost of land, competition from crops that are more profitable, and limited technical and financial capacity of farmers to organize cooperatives. Findings from Tanzania indicate that access to finance and credit was not a limiting factor in adopting disease-resistant pigeonpea seed. Rather, informal seed networks, on-farm variety selection, farm size and ownership of household transport assets played a larger role in farmers adopting improved seed.
- In Saskatchewan, the economic benefits of adding lentil and pea into crop rotations has been significant, while chickpea has been less successful thus far due to disease (ascochyta blight), relatively long growing season requirement, and fluctuating export prices. Findings indicate that including oilseed and pulse crops in rotations with cereal grains contributed to higher and more stable net farm income between 1985 - 2002, in spite of higher input costs, across most soil zones. While the volume of lentil exports has increased 67% between 2009 and 2014, the value of those exports increased 37%. Pea exports show a different trend over the same period, with the volume of pea exports increasing 19%, while the value over the same time period increased 56%. Crop diversity is a hedge against fickle markets and changes in price. Farmer survey data from 2011 indicates that pulse producing farms grow a larger variety of crops than farms not growing pulses (up to seven or more field crop types). Estimates from the 2015 Saskatchewan Crop Planner indicate that lentils make an important relative

contribution to the financial returns of rotations in different soil types; returns from lentil are between 38% and 60% depending on soil zone.

Investments in pulse crop research: Investments in pulse crop research have led to important environmental, social and economic impacts in both case studies:

- The Saskatchewan Pulse Growers association institutes a mandatory, non‑refundable 1% levy to fund programs that develop the pulse industry, provides research and capacity for genetic improvement, agronomy, health and nutrition, and processing and utilization. In 2014/2015, the levy contributed 97% of the CD$10.1 million the organization invested in research and development, and another CD$2.8 million in market promotion, most of which was focused on domestic lentil markets.
- For 2012, the CGIAR Research Program on Grain Legumes estimates that the net present value of gross benefits of its legume research and extension was US$4.5 billion, equivalent to US$ 535 million per year, with significant food security benefits and environmental benefits through biological nitrogen fixation (a fertilizer cost saving of US$418 million). Fifty percent of the economic impacts accrue in South and South-East Asia and Sub-Saharan Africa.

Export versus domestic markets: Trade-offs between supplying domestic demand and serving export markets, or importing pulses, hinge on a variety of factors, including food security, market prices, post-harvest storage and processing, tariffs and import/export barriers, market efficiency, domestic food security, and effective sector policies. For example, India accounts for 26% of global pulse production, yet the average productivity of pulses is below the global average, and Indian production will not keep pace with domestic demand. Government subsidies and price controls in India's agricultural sector created distortions that affected domestic production, and minimum support prices for pulses have not demonstrated the same results as those for rice. Other countries have had success promoting export crops that do not compete with domestic food production. White pea beans (Navy beans) in Ethiopia and French beans in Rwanda are examples of export products that do not generally reduce domestic consumption, which is as crucial for food security as it is for realizing economic benefits.

Adding pulses into livestock diets also has economic benefit, but appears dependent on market pricing and labour use efficiencies.

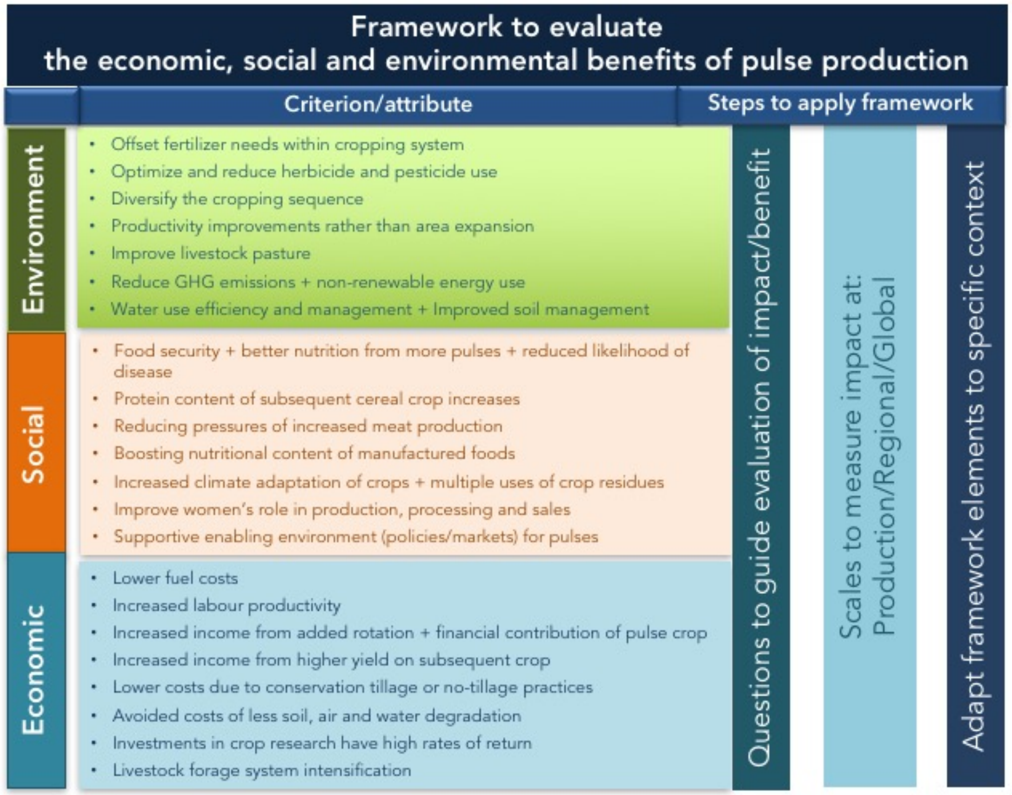
Pulse crop sustainability framework and application steps

Grounded in the literature review and the two case studies, this report proposes a framework for evaluating the sustainability of pulse crop production in specific contexts. Application of this framework is supported by criteria and guiding questions.

Figure 1 provides a diagrammatic overview of the framework elements. Section 4 of this report identifies the criteria and attributes, for each of the three sustainability pillars, to be measured or evaluated in any given production system, recognizing the highly diverse geographic, agro-ecological and economic contexts around the world that are suitable for growing pulses. The criteria and attributes of the framework can be used as a complement to a production standard or product certification scheme that growers could apply at the production level. Each criterion or key element contains a set of questions to guide evaluation of the sustainability of interventions, including commonly observed trade-offs.

Section 5 of the report applies the framework to hypothetical actions that could be take by the food industry, producers, and governments to increase pulse crop production and consumption. The criteria chosen, and questions to pursue should be adapted to local circumstances or to the appropriate scale, and are intended as a starting point, rather than a complete set of filters for testing the sustainability of cropping changes. These hypothetical applications provide initial guidance only, and present some overarching decision-support and questions for further investigation (e.g. qualitative and quantitative ways to test performance using key environmental, social and economic indicators). A real-world application of the framework would require adaptation to the unique production circumstances and interventions.

Figure 1: Summary of pulse crop sustainability framework and application steps



Framework to evaluate
the economic, social and environmental benefits of pulse production

Criterion/attribute

Steps to apply framework

Environment

- Offset fertilizer needs within cropping system
- Optimize and reduce herbicide and pesticide use
- Diversify the cropping sequence
- Productivity improvements rather than area expansion
- Improve livestock pasture
- Reduce GHG emissions + non-renewable energy use
- Water use efficiency and management + Improved soil management

Social

- Food security + better nutrition from more pulses + reduced likelihood of disease
- Protein content of subsequent cereal crop increases
- Reducing pressures of increased meat production
- Boosting nutritional content of manufactured foods
- Increased climate adaptation of crops + multiple uses of crop residues
- Improve women’s role in production, processing and sales
- Supportive enabling environment (policies/markets) for pulses

Economic

- Lower fuel costs
- Increased labour productivity
- Increased income from added rotation + financial contribution of pulse crop
- Increased income from higher yield on subsequent crop
- Lower costs due to conservation tillage or no-tillage practices
- Avoided costs of less soil, air and water degradation
- Investments in crop research have high rates of return
- Livestock forage system intensification

Questions to guide evaluation of impact/benefit

Scales to measure impact at:
Production/Regional/Global

Adapt framework elements to specific context

1. Introduction

Many of the benefits of pulses in diversifying diets and replenishing soil nutrients are well documented and understood. What has received less attention is the role of pulses in contributing to future food security and development goals. Our food systems face the challenge of needing to produce enough food to feed at least 9 billion people by 2050, with nearly all that additional food needed for developing countries and due to per capita increases in meat consumption (FAO, 2009; Foresight, 2011). But that challenge must be met in the context of increasing climate change impacts on food production; competition for energy, land, water and material resources; population growth and migration; poverty and food insecurity; and ecosystem degradation.

Climate change, resource depletion, and demographics have a strong impact on the availability and price of agricultural commodities (MSCI, 2012). Growing urban populations are increasingly purchasing their food rather than growing it, with substantial proportions of household expenditure going towards food. In South Asia and sub-Saharan Africa, 40–70% of all household expenditure is on food (World Bank and IMF, 2013). Increased urbanization means 96% of the developing world's additional 1.4 billion people by 2030 are expected to live in urban areas. Further, the global middle class is predicted to grow 172% between 2010 and 2030, and while agribusinesses will seek to serve this new middle class market, it will be at a time when resources are likely to be scarcer and more price-volatile (Kharas, 2010).

The potential of pulses—beans, peas, chickpeas, lentils, and other pulse crops—to help address future global food security, nutrition and environmental sustainability needs has been acknowledged through the UN declaration of the 2016 International Year of Pulses. However, the full set of benefits that pulse crops can offer has not been systematically characterized. For both large and small farmers, pulses represent important economic opportunities to boost income and reduce risk by diversifing their crop and income stream portfolio. The environmental benefits of adding pulses to crop rotations is well documented, however there is less documentation and evidence of the social and economic benefits of pulse production. Pulses could help address future needs for protein, help minimize soil degradation, and support diversification in food production and consumption. The livelihood and development impacts of increased pulse production and consumption must be better understood by the food sector, by pulse producers, and by governments, based on empirical evidence and known examples in both developed and developing countries.

1.1 Purpose

This paper is produced as part of the 2016 International Year of Pulses (IYP 2016), which bring an increasing awareness of the role of pulses in food production to a range of stakeholders, including governments, the food sector, farmers and producers, research organizations, development agencies, investors and donors. This research is part of a broader effort in IYP 2016 to deepen an understanding of the potential of pulses to contribute to sustainability and to motivate action to maximize the sustainable production and consumption of pulses.

This paper specifically seeks to develop a framework to evaluate the economic, social and environmental benefits of pulse production in different geographic, agro-ecological and economic contexts. Thus, the framework will define the elements of sustainability to be measured or evaluated in any given context, recognizing the highly diverse geographic, agro-ecological and economic contexts around the world that are suitable for growing pulses. The framework will also provide a means to evaluate the potential sustainability contributions of pulses should they be brought into a cropping system, or as a means to optimize crop rotations. The rationale for producing this white paper is to:

- Define the elements of pulse crop sustainability that can be applied in diverse contexts around the world (based on their contribution to cropping systems at the local scale as well as their contribution to global-scale sustainability goals).
- Help build the evidence base of the environmental, social and economic benefits of pulse production.

The intended primary audience for this white paper is the food industry, and secondary audience is government policy makers and private foundations.

1.2 Pulse production and sustainability

1.2.1 Environmental benefits

Nitrogen fixation

Nitrogen is the nutrient most commonly deficient in soils around the world, and is therefore the most commonly applied plant nutrient, often in the form of synthetic fertilizer. **Legume crops, including pulses, have a unique role to play in the global nitrogen cycle, as they fix atmospheric nitrogen in soils**. Pulses create a symbiotic association with rhizobia, a soil bacteria, enabling pulses to fix atmospheric nitrogen gas, which can make them self-sufficient in nitrogen, and enable them to grow in almost any soil without fertilizer inputs. Human impacts on the global nitrogen cycle from rapidly increasing fertilizer use and fossil fuel combustion starting in the 20th century have had strong negative effects, such as pollution into waterways and increased N_2O emissions. From 1960 to 2000, nitrogen fertilizer use increased by roughly 800%, with half of that being utilized for wheat, rice, and maize production (Canfield et al, 2010). Synthetic fertilizers provided close to half of all the nutrients received by crops globally during the mid-1990s, demonstrating both a large dependency on synthetic fertilizers, but also inefficient management of nitrogen in global agriculture (Smil, 2002). The IPCC estimates that nitrous oxide emissions contain roughly 300 times the global warming potential of carbon dioxide (CO_2), and application of fertilizer in agricultural production is a significant source of N_2O.[1] Cereal crops such as wheat, rice and maize typically only utilize 40% of fertilizer applied, leading to significant waste and environmental impacts such as eutrophication of coastal waters and creation of hypoxic zones (Canfield et al, 2010). A survey of various field studies of nitrogen fertilizer uptake by rice, corn and wheat shows typical nitrogen efficiency to be less than 50%, with Asian rice averaging as little as 30%. The study also found nitrogen losses along the food chain to be significant, with synthetic fertilizers causing significantly more nitrogen loss due to volatilization, erosion and leaching into water (Smil, 2002).

However, **introduction of pulses into crop rotations actively helps fix nitrogen in the soil, thus reducing the fertilizer requirements of the pulse crop itself, as well as the following grain crop**. One long-term study (2001 – 2013) on the nitrogen fixation of the pulse crop itself found field pea, lupin or faba bean derived about 70% of nitrogen requirements from atmospheric nitrogen, while an average of 19 kg of nitrogen was fixed per tonne of pulse shoot dry matter. The study covered the geographic range of southern and central New South Wales, Mallee and Wimmera in Victoria, and the high-rainfall zone of south-eastern South Australia (Peoples et al, 2015). Systematic crop rotation based on incorporating pulses/legumes into maize-based systems to reduce synthetic fertilizer use, and optimizing the timing and amounts of fertilizer applied to crops are recognized as the two most important interventions to decrease nitrogen application (Canfield et al, 2010). Biological nitrogen fixation is a crucial alternative source of nitrogen, and can be enhanced along with other integrated nutrient management strategies such as animal manure and other biosolids, and recycling the nutrients contained in crop residues (Lal, 2004).

The higher available nitrogen to subsequent cereal crops is generally assumed to **benefit yields of those cereal crops**, however this is not as well documented as the nitrogen fixation benefits. Findings in south-eastern Australia indicate strong evidence that the inclusion of legumes in cropping sequences results in higher available soil nitrogen for subsequent crops, with an additional 40 to 90 kg N/ha in the first year and 20 to 35 kg N/ha for the second year, as compared to continuous cereal sequences that do not include pulses (Peoples et al, 2015). Apart from the effects of additional fixed N that legume crops bring into systems, there are almost always beneficial yield effects from crop rotations with legumes. These positive effects on yield are probably related to disruption of the buildup of disease and pests that occurs when a particular crop is grown year after year, although this phenomenon is not yet well understood. Increases in grain yield in subsequent cereal crops have been documented in the Northern Great Plains of North America, and will be further explored in the Saskatchewan case study in

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[1] Agriculture emissions are 19-29% of all global GHG emissions. Nitrous oxide emissions are 39.3% of total agricultural emissions (FAO, 2015).

section 3.1. Evidence in a Mediterranean environment demonstrated that vetch, faba bean and chickpea all resulted in significant yield surpluses and provided nitrogen credit to the subsequent unfertilized wheat crop, though vetch outperformed the other (better researched) pulses (Dalias, 2015). Experiences in Australia show increased yield and protein content in cereal and oilseed crops that are planted following pulse crops. The wide variations in the amount of nitrogen fixation that pulses can provide depends on the amount of biomass produced by the pulse crop (often varying with water, soil quality and non-N nutrient availability), whether the harvest removes a significant amount of the biomass, and the effectiveness of the legume-rhizobium symbiosis in fixing nitrogen. Planting a legume into soils already having moderate to high levels of soil nitrogen can also depress biological nitrogen fixation.

Nuances and differences in successive cereal crops must be noted. Findings in Australia comparing legume and fertilizer nitrogen indicate that **recovery of legume nitrogen by a following cereal crop tends to be lower than top-dressed fertilizer** (a difference of 20% between high and low ranges), but is not too dissimilar from fertilizer applied at sowing. This is due to slower release of mineral nitrogen from legume and pulse crop residues as they decompose. However, **losses of nitrogen from the system are found to be usually lower from legume sources than from fertilizer**, indicating the contribution of legumes to the maintenance of the long-term organic fertility of soils (Peoples et al, 2015).

The successive planting of different crops on the same plot of land, through crop rotations, helps soil fertility, the transfer of nutrients from one crop to the next, and helps to control weeds, pests and diseases. **Crop rotations have been practiced by farmers for thousands of years,[2] yet maximizing the environmental, social and economic benefits of crop rotations is an ever-evolving science that must address many factors at the cropping system level**. The replenishment of nitrogen through the use of green manure, in sequence with cereals, is a common form of crop rotation. The Sakatchewan case study below explores further insights on crop rotation. Including pulses in cropping systems has high relevance for improving the overall use efficiency of available nitrogen at the farm system level rather than at just the crop level. Rather than emphasizing individual elements of a cropping system, a focus on overall growing conditions, the crop mix, and the sequence of crop rotations is central to achieving both sustainability and productivity objectives, such as increasing nitrogen fixation through improved rhizobia-host plant symbiosis (van Kessel and Hartley, 2000).

Conservation tillage

Changes in tillage practices have been an important part of shifts from conventional cropping systems, based on grain production, to more diversified crop rotations utilizing pulses or oilseeds. Conventional plow-based farming developed largely as a means for

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[2] The centres of origin of agriculture in South and East Asia, the Middle East, Sub-Saharan Africa, and Middle and South America all included the domestication of a legume.

farmers to control weeds in field-crop systems. Conventional tillage practices leave soil vulnerable to water and wind erosion, increases agricultural runoff, degrades soil productivity and releases GHG emissions both from soil disturbance and fossil fuel use. Conventional tillage in the US, Canada and Australia led to "dust bowl" storms due to wind erosion, and the loss of soil and farmland spurred policy makers and farmers to find solutions. No-till, or direct seeding under a mulch layer from the previous crop, is the most important technology in conservation agriculture and reverses this process by implementing a package of practices, including a) minimum mechanical soil disturbance, b) permanent organic soil cover, c) diversification of crop species grown in sequences and/or associations (FAO, 2013). Importantly, implementing conservation tillage practices has often involved introduction of pulses and oilseeds into grain-based crop rotations[3]. While increased use of herbicides, such as glyphosate, have been utilized to address weed abundance under reduced or no-tillage, this appears to be moderated after a period of transition to conservation tillage. Van Kessel and Hartley (2000) identified a range of studies that demonstrate the nitrogen fixation benefits of conservation- or no-tillage, with pulse and oilseed bean nodulation improving after multiple years of no-till and nitrogen fixation rates increasing (moderated by changes in rainfall patterns) (Van Kessel and Hartley, 2000). For more insight on how no-till and conservation agriculture has been adopted in Saskatchewan, refer to Section 3.

Productivity improvements over area expansion

An important goal in the sustainable use of land worldwide is to increase productivity on available croplands, while restricting agricultural expansion, which often occurs at the expense of forests and wetlands. Nine billion people will inhabit the planet by 2050. To avoid crop expansion and just meet projected 2050 crop needs by increasing production, it is predicted that crop yields would need to increase by an estimated 32% more from 2006 to 2050 than they did from 1962 to 2006 during the height of the 'green revolution (Searchinger et al, 2013).' However, reaching such increases in yields is highly unlikely. Pulses have a significant role to play in 'sustainable intensification,' yet, in developing countries, production increases have come primarily from expansion of cropping areas. The yield growth of pulses between 1980 and 2004 in developed countries was 2% per annum, while in developing countries, it languished at about 0.4% per annum (Nedumaran et al, 2015). Ethiopia's rise in chickpea production offers an example of productivity improvements that did not result in area expansion (Ethiopia, 2015b).

This large yield gap between developing countries and developed countries is of concern, and cannot be addressed by improved pulse crop genetics alone, but rather requires a range of interventions, some of which are further explored in the Africa case

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[3] The oilseeds soybean and groundnut are also N-fixing legumes. Note that some of the brassicaceae lack root symbioses and so will have a very different consequence from legumes most of which have both bacterial and fungal root symbionts.

study in Section 3.2. Adding more crops into rotations can increase the efficiency in a production system, minimizing the pressure for cropland expansion to achieve yield improvements. However, in many contexts, regulations to restrict expansion, or encourage expansion on degraded lands, are necessary to send the right signals to producers.

Reduced greenhouse gas emissions

The role of pulse crops in mitigating greenhouse gas emissions in agriculture production can be significant, and this is explored further in the Saskatchewan case study below. The primary reason for the benefits from pulses in lowering GHG emissions is due to lower fertilizer requirements, particularly given the large amount of energy used in fertilizer production. Up to 70% of the non-renewable energy used in Western Canadian cropping systems is due to the use of fertilizers, particularly nitrogen, and the inclusion of pulses in cropping systems reduces the need for fertilizer inputs. Pulses supply their own nitrogen and contribute nitrogen to succeeding crops (Lemke et al, 2007). This is explored in greater detail in Section 3.1.

Pulses and livestock feed diversification

Integration of legumes into livestock production systems has been shown to deliver multiple benefits, such as increased nitrogen supply while also increasing meat production. Globally, meat demand is expected to increase by 200 million tonnes per annum by 2050, with corresponding demand for livestock feed (Alexandratos and Bruinsma, 2013). In the northern Great Plains of the US and Canada, field pea has been promoted as a means to boost protein and energy in cattle feed. Field pea grain has been found to be highly digestible to cattle, but the starch fermentation and ruminal protein degradation rates are slower than for other common feeds. Field pea has been shown to increase dry matter intake by cows when included in the livestock feed ration, and also produces benefits when used as a binding agent for pelleting formula feeds (Anderson, et al, 2007).

1.2.2 Social benefits

Nutrition

Without a concerted effort to boost the production of pulses in developing countries, consumption of pulses may stagnate or decline, due to changing consumer preferences, failure to promote production of pulses, and a greater focus on increasing production and self-sufficiency in cereals (Alexandratos and Bruinsma, 2012). Historically, when observed declines in protein-rich pulses were not accompanied by increases in the consumption of livestock products, the result has been deterioration in the overall quality of diets, even if per capita dietary energy increased (ibid).

Pulses have declined in consumption levels globally and in particular among developing countries, perhaps best illustrated by China's significant decrease in consumption, from 30 g per capita per day in 1963, to only 3 g per capita by 2003 (Kearney, 2010). Over the last decade, developing countries, particularly in large Asian economies, have seen steady population growth, rising per capita incomes and continuous urbanization, which has been accompanied by increased protein intake relative to the traditional starches. The OECD/FAO Agricultural Outlook to 2024 indicates stagnant growth in food consumption in developed countries, but significant increases in developing countries, reflecting this increase in protein intake in developing countries. At the global level, total caloric intake is expected to rise, but with regional differences. Cereals will remain the most consumed agricultural product, with consumption expected to increase by almost 390 Mt by 2024, most of which is coarse grains. The largest expected growth in coarse gain consumption will come from demand for feed, accounting for 70% of the growth in consumption. Global meat consumption is expected to grow 1.4% per year, resulting in additional consumption of 51 Mt of meat by 2024 (OECD-FAO, 2015).

India provides a counterpoint to China, as pulses there provide an increasing source of protein, now accounting for almost 13% of overall protein intake (OECD-FAO, 2014). Pulses are an important contribution to a vegetarian diet, given their protein content. India is the largest pulse producer and consumer, and the country grows the largest varieties of pulses in the world, accounting for about 32% of the area and 26% of world production. Indian pulse crops include chickpea, pigeonpea, urd bean, mung bean, lentil and field pea, and production reached a record level of 18.4 Mt in 2012-13, up from 15 Mt in 2007-08. Pulse crop yields have increased from 0.63 t/ha in 2007-08 to 0.79 t/ha in 2012-13, and annual yield growth is expected to outpace growth in production area, indicating better production efficiency. However, the average productivity of pulses in India still remains below the global average. It is expected that Indian production will not keep pace with demand and imports are anticipated to grow to 5.1 Mt by 2023 (OECD-FAO, 2014).

Fairly recent changes in the global human diet favouring more energy-dense foods rich in total and saturated fats are increasing rates of obesity, diet-related diseases such as diabetes, coronary heart disease and cancer. Public health and nutrition efforts seeking to promote healthier and more sustainable food production and consumption, must ensure a sufficient supply of staples and of micronutrient-rich foods without encouraging excessive consumption of energy-dense, nutrient-poor foods. Pulses and legumes are an important contributor of micronutrient-rich intake, along with fruits and vegetables (Kearney, 2010). Eighty-four percent of the protein in common bean is readily absorbed after consumption, and 94% of the protein from cowpea is available.

Pulses have a role to play in combating cardiovascular disease and increasing healthy nutrition. Worldwide, cardiovascular diseases are now the leading cause of death, and in the United States, is attributed to 1/3 of all deaths. While there is increasing awareness of this risk, and the role of balanced diets to decrease the risk, less than 1/3 of Americans consumes the 3 cups of legumes recommended per week by the Dietary Guidelines for Americans (Bazzano et al, 2011). A meta-analysis of ten randomized controlled trials from 5 countries sought to quantify the impact that consumption of non-soy legumes (navy, pinto, kidney, garbanzo and lima beans and peas such as split green peas or lentils) has on total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), very low-density lipoprotein (VLDL), and triglycerides. Findings indicate the **non-soy legume diet had a significant beneficial effect on serum cholesterol levels, thus reducing cardiovascular disease risk**. Both total and LDL cholesterol decreased, while HDL cholesterol did not change significantly, when non-soy legumes were supplemented. Further, findings indicate that the non-soy legume diet allowed for higher intakes of dietary total and soluble fiber (which lowers risk of coronary heart disease) and contained phytosterols, a component of plant cell membranes, which reduces blood cholesterol levels (*ibid*). The anti-inflammatory effects of beans and their contribution to the intestinal microbiome in the gut is increasingly being understood, particularly in among children in Malawi where findings indicate cowpea and common bean can reduce environmental enteric dysfunction (Manary, 2015).

Nitrogen and protein in global diets

More dietary protein will be needed to eliminate disparities in diets between developed and developing economies. However, the nitrogen budget in global food and feed demonstrates **the importance of nitrogen-rich and protein-rich plant foods**. About 70% of nitrogen in harvested food crops become available (after processing and losses) for human consumption, whereas meat and dairy production use large amounts of nitrogen. Nearly 7 kg of feed nitrogen is needed to produce 1 kg of edible nitrogen in meat, eggs, and dairy products. Thus, finding solutions to more efficient production of animal foods and damping the projected upward trend line of animal based foods is crucial to supply adequate nutrition to the world's growing population without any massive increases of nitrogen inputs (Smil, 2002).

In Canada, the US, and Europe, researchers, ingredient companies and food manufacturers are investigating **increased production and use of pulse protein fractions in manufactured food products,** in order to boost the nutritional quality of foods, and dietary fibre and starch, which can be used for food fortification and texture enhancement. In these processes, parts are derived from the whole seed, such as a split seed, hull or fibre, down to isolated starch and protein factions. These products are promoted as plant-based, sustainable, non-genetically modified and gluten-free.[4] Companies such as Ingredion, AGT Foods, Burcon, Cosucra, and Nutri-Pea and others are creating fraction products, and finding ways to incorporate them into manufactured food products. Researchers note that wet fractionation uses large amounts of water and energy, and the functionality of the protein is compromised during processing. Dry

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[4] Mark Olsen, Alberta Dept of Agriculture and Forestry, verbal communication.

fractionation is found to be more water and energy efficient, and retains functionality of the pulse protein (Schutyser and van der Goot, 2015).

Efforts to manufacture meat-like protein products is improving, with a recent soy-based meat analogue product being produced, with a thickness of 30 mm (Krintiras et al, 2016). Efforts are underway to further identify how pea protein and other vegetable fibers can be used for this purpose.

Balancing livestock production and food security through pulses

Livestock production benefits without food security conflicts are demonstrated via the integration of herbaceous legumes into the maize and upland rice systems in West Timor, Indonesia. After six years of participatory research, findings indicate significant benefits for local farmers. Farmers usually rely on low-quality native forages, sometimes supplemented, to feed their livestock. High rainfall levels in the monsoon season and climate variability provides risks that often result in feed demands outstripping supply and low rates of production, with up to 60% of the weight gained by livestock during the wet season lost during the late dry and early wet seasons. Herbaceous legumes were added either in annual rotation with a cereal or after wet-season cereal production has been completed, when land is traditionally left fallow. As cowpea, peanut, and mungbean are already occasionally intercropped with maize in the wet season, researchers chose to promote herbaceous legumes as a green manure or in rotation, so legumes would not further compete with the cereal crops for nutrients and thereby produce less forage. Research outcomes indicate that a) it is possible to add an additional crop into a traditional farming system without affecting existing food security, b) that feeding forage legumes to cattle during the late dry or early wet season resulted in increases in livestock weight, and c) that nitrogen provided by legumes improved maize production in subsequent crops. Critical to the success of integrating herbaceous legumes into an annual crop cycle was the recognition that water remaining in the soil as the main wet-season cereal crop matures is a resource that can be available for the subsequent dry-season production of herbaceous legumes, which is a period in which food crops are not traditionally grown (Nulik et al, 2013).

Gender

Gender aspects of pulse production are particularly important in contexts where women can be involved in various stages of production and throughout the value chain. This is further explored in the Africa case study, in section 3.2. No relevant findings related to gender were identified in the Saskatchewan case study.

1.2.3 Economic benefits

Farmers in grain and oilseed production have found economic benefits from lower input costs and increased profits by including a pulse crop in their rotation. These benefits accrue mainly through enhancing the efficiency of nitrogen fertilizer use, reducing tillage and, in some cases reducing pesticide use. **Reduced and altered tillage practices reduce reliance on fossil fuels and lowers overall fuel bills**. No-till systems with pulses provide a basis for sustainable agricultural intensification, including integrated crop approaches. It is estimated that farmers save between 30-40% of time, labour and fossil fuels using no-till, compared to conventional tillage (FAO, 2001; Lorenzatti, 2006). In Argentina, a review of farmer practices found that with one liter of fuel it is possible to produce 50 kg of grain under conventional tillage, whereas under no-till it is possible to yield 123 kg of grain (Lorenzatti, 2006). Better nitrogen management requires less fertilizer inputs. There are variations, of course, in the economic returns experienced in different geographies and farm-types, and these are explored further in the case studies. Farmers likely also see the **long-term economic benefits (and avoided costs) of less soil, air and water degradation by adopting no-till practices and including legumes in their operations**.

In Saskatchewan, Canada, including oilseed and pulse crops in rotations with cereal grains contributed to **higher and more stable net farm income, in spite of higher input costs, across most soil types**. The case study in Section 3.1 summarizes key findings regarding the significant benefits to farmers and the provincial economy. Significant findings exist and high potential for further economic benefits also exists in Africa, and this is further explored in Section 3.2.

Beyond the case study geographies, relevant insights should be noted, particularly related to India, which is the largest consumer of pulses globally. India sought to increase pulse production by 2 million tonnes by the end of the Eleventh Five Year Development Plan (2011-12), through implementation of the National Food Security Mission for Pulse Crops (NFSM). One study assessing the impact of the NFSM, based on interviews with farmers over two districts in the state of Maharashtra, identified significant economic returns at the farm-level from the programme's improved technologies (improved pulse seed, integrated nutrient management and integrated pest management practices, resource conservation technologies, and capacity building of farmers). **Farmers in a district participating in the programme saw double the net returns from pulses crop cultivation in 2008-09 over the previous year** as compared to the non-NFSM district. Further, the **profit from pulses exceeded net profit margins of all other crops cultivated in the district**, despite this occurring in rainfed conditions (Shah, 2011). However, economic gains from pulse production could be far greater in India, and import tariffs, minimum price supports, and government support has largely underserved the needs of India producing enough pulses to meet domestic demand and diversify farm incomes (Refer to Box 1).

Box 1: Economic challenges for pulses in India

India is the largest consumer of pulses, but government subsidies and price controls in the agricultural sector created distortions that affected domestic production. Government subsidies for fertilizer and water promoted grains and oilseeds rather than the mix of support necessary to promote pulses. Protectionist policies in the 1970s and 1980s were reversed in the 1990s, when government reforms sought to remove import restrictions and lower tariffs on agricultural products. However, with the exception of Basmati rice and durum wheat, external trade in all major crops was regulated, and imports of most crops occurred only through government agencies. Pulses were treated differently, with import tariffs on pulses reduced gradually and abolished by 1996. The hope that domestic pulse market liberalization would increase imports did not materialize. Rather, the share of total pulse imports in total merchandise trade declined after market liberalization (Agbola, 2004).

Further, in India, minimum support prices have been established as one of the policy instruments used to improve the economic viability of farming, stablize commodity prices, and enhance food security by diversification into oilseeds, pulses, livestock and fish. However, **minimum support prices for pulses have not demonstrated the same results as those for rice**. Prices for pulses were increased between 2008-09, at a rate higher than that for food grains, but that did not translate into larger areas planted under pulses, and this is attributed to the risks associated with pulse cultivation. In comparison, paddy cultivation does not carry such risks, and farmers are assured of procurement by government agencies, whereas this is not the case for pulses (OECD-FAO, 2014).

Adding pulses to rotations in economically deprived areas in India could bring much needed nourishment and income to millions of poor small landholders solely dependent on agriculture for their livelihoods. About 12 million hectares that are under rice production during the rainy season in India remain fallow in the subsequent post-rainy (rabi) season. Efforts to introduce pulses (primarily chickpea) in these rabi conditions could have significant economic and poverty alleviation benefits (Joshi et al, 2002).
Yet challenges remain. There has been a progressive decline in per capita availability of pulses in India, falling from 69 grams in 1961 to 32 grams in 2005. The requirement was estimated to be 21.3 million tonnes by 2012. The Economic Survey 2012-2013 reports the estimated production of pulses in 2011-2012 as 17.09 million tonnes, indicating a wide gap in demand and supply (Swaminathan, 2013).

Investments in pulse crop research is shown to have significant economic benefit. The CGIAR Research Program on Grain Legumes, a global alliance coordinating efforts across four CGIAR centers, estimated in 2012 that the net present value of gross benefits of its legume research and extension is estimated at US$ 4.5 billion, equivalent to US$ 535 million per year. Based on proposed activities to be undertaken by this CGIAR program, between 2014—2020, legume research was also projected to contribute to food security through increased availability of food (over 8 million tons), nutrition security from more availability of protein, and environmental benefits through biological nitrogen fixation (a fertilizer cost saving of US$ 418 million). The CGIAR estimated that over 50% of the projected economic benefits of legume research and extension would accrue in South and South-East Asia and Sub-Saharan Africa, where most of the world's poorest communities are located (CGIAR, 2012).

Adding pulses into livestock diets also has economic benefit, but appears dependent on market pricing and labour use efficiencies. Findings in Western China indicate that livestock forage system intensification by incorporating a forage crop into grain-cropping systems increased average profits without increasing downside risks such as negative profit, crop failure, or livestock mortality. Forage vetch was the leguminous pulse crop, but forage oats and grain soybean were also incorporated. In contrast, replacing a grain crop with a forage crop in grain-cropping systems had a negative effect on profits, downside risk, and labour-use efficiency. Trade-offs between labour-use efficiency and profit were observed as forage intensification increased labour demands, however these effects were context specific (Komarek et al, 2014). Findings in Western Canada, based on a life cycle assessment of two swine diets—one using soybean meal in a wheat-based feed, and the other substituting the soybean portion with dry pea—indicates the dry pea diet to be a substantial economic improvement over the soybean meal diet. The rate of return on assets for a swine farm substituting the soybean portion of feed with dry pea in swine diets was 4.4%, an improvement of 3.6% over the 0.9% estimated when the swine farm was using the soybean diet. Only when hog prices were lower and feed costs increased were the benefits of incorporating dry pea in the diet not apparent (McWilliam et al, 2011).

2. Methodology

This research was guided by a neutral investigation approach to understanding the key features of pulse crop production associated with the three pillars of sustainability. Attention was given to socio-economic development and environmental benefits, across both developed and developing countries, and ranging from smallholder farms to large-scale agriculture production systems. A broad literature review was conducted, and interviews conducted with pulse researchers and members of the IYP Productivity and Sustainability Committee. Insights from the literature review, two in-depth case studies – Saskatchewan, Canada and pulse producing regions of Sub-Saharan Africa—and interviews guided the formation of the sustainability framework by the author.

3. Case studies

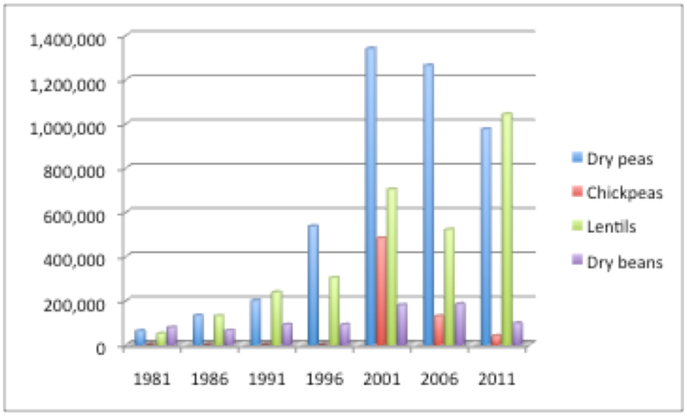
3.1 Saskatchewan

Saskatchewan covers 651,900 km^2 and contains 44% of Canada's cultivated farmland. According to the Saskatchewan Pulse Growers association, the province produced more than 95% of Canada's lentil and chickpea crop, and nearly two thirds of its pea crop, 80% of which is exported. Canada is the world's largest exporter of pulses, supplying 33% of the world trade in pulses, mostly in sales to India, China, Turkey, Bangladesh, and the United States. This has been a fairly recent development over the last twenty years, with hectares seeded to pulses increasing 1,000%, from 193,000 ha in 1981 to 2.1 million ha by 2011 (refer to Figure 1).

3.1.1 Context

Pulse crops grown in Saskatchewan include chickpeas, dry beans, dry peas and lentils. The Saskatchewan Pulse Growers, created after growers in 1983 chose to institute a mandatory, non−refundable 1% levy to fund programs that would develop the pulse industry, provides research and capacity for genetic improvement, agronomy, health and nutrition, and processing and utilization. The levy is applied to gross sales at the first point of sale or distribution. The Saskatchewan Pulse Growers allocates about 60% of its annual budget into research and development, benefitting 15,000 Saskatchewan pulse growers. In 2014/2015, the levy contributed 97% of the CD$10.1 million the organization invested in research and development, and another $2.8 million in market promotion, most of which was focused on domestic lentil markets (Saskatchewan Pulse Growers, 2015).

Figure 2: Hectares seeded with pulses by variety in Canada (1981 to 2011)



Source: Bekkering, 2014, based on Statistics Canada, Census of Agriculture, 1981 to 2011

For the 2015-16 crop year, across Canada, production of pulses and specialty crops is estimated at 6.3 Mt, 5% lower than 2014, as lower average yields more than offset the higher area seeded. Dry pea production decreased in the 2015-16 period by 16%, to 3.2 Mt due to lower yields and lower harvested area, particularly in Saskatchewan. Yellow and green pea types are expected to account for about 2.5 Mt and 0.7 Mt, with the remainder being other varieties. Supply has decreased by only 12%, to 3.7 Mt, due to large carry-in stocks. Exports are forecast at 2.95 Mt, with India, Bangladesh and China remaining Canada's top three markets for dry pea. Yields per hectare have decreased over last three growing seasons. In contrast, lentil production increased by 19% to nearly 2.4 Mt, as lower yields partly offset record harvested area and lower abandonment; the largest gains were made in red lentil production. Prices are at record levels, and India, Turkey and Egypt are the top export markets for lentil. Production of dry beans fell by 10% across Canada, though the US and the EU-27 will remain the main export markets. Though chickpea production fell by 31% to 90 kilotonnes, due to lower area and yield estimates, carry-in stocks help offset the supply decrease, and exports are expected to increase, with the US and Pakistan being the largest buyers (Agriculture and Agri-Food Canada, 2015).

3.1.2 Environmental

Cereal-fallow rotations have been the predominant cropping system in the semiarid Canadian Prairies, however patterns of monoculture cereal cropping resulted in pest and disease outbreaks and erosion, which spurred farmers to seek alternate crops to include in rotation. Fallowing has resulted in increased soil salinity and loss of soil nitrogen and water. Pulse crops were introduced to replace summer fallow in the past few decades. Conventional tillage has led to increased soil erosion, despite the benefit of incorporating crop residues into the soil. The introduction of pulses into the Saskatchewan grain crop rotations was found to have a number of environmental benefits beyond erosion control. Pulses are more drought tolerant and efficient in water use than most grain crops, and therefore could withstand summer cropping in the drier Brown and Dark Brown soil zones (Cutforth et al, 2009). Farmers sought more diversified and intensive cropping systems, increasingly abandoning the practice of summer fallow, and preferring to crop through four seasons. Thus, pulse crops were added into predominantly cereal and oilseed rotations, and most often replace a cereal crop, such as wheat, rather than replace an oilseed crop, such as canola. No-till seeding practices eliminates the need to plow by placing seed directly into undisturbed stubble or sod.

The greatest environmental benefit of adding pulse crops into cereal-fallow rotations was their nitrogen fixation capability, which reduced fertilizer nitrogen requirements in the current and succeeding crop, and capacity of the soil to supply nitrogen. This overcame a limitation in conservation tillage systems where minimal soil disturbance slowed cycling or release of nitrogen from crop residues (Brandt, 2010).

A challenge in shifting from conventional tillage to conservation tillage practices is in managing weeds. The price and abundance of herbicides such as glyphosate had a major role to play in farmer adoption of conservation tillage in Australian, Latin American and North American regions that have experienced dramatic changes in farmer uptake of conservation tillage practices. Farmers in Saskatchewan faced weed control challenges from diversified rotations as the herbicide treatments for pulse and oilseed crops were generally less effective than for cereals. Over time, farmers improved their herbicide and management practices, leading to reduced rates in use, and a significant reduction in repeat applications (Brandt, 2010).

Pulse cropping in rotation with cereals without effective tillage and crop residue management presents erosion problems, particularly on the Brown and Dark Brown soils of Saskatchewan, in areas where strong winds are common. Erosion has been found to increase during production of field pea, lentil, and chickpea in these areas, as they often produce less crop residue than cereal crops, and the crop residue is more easily disintegrated by tillage than cereal residue. Farmers are advised to **minimize pulse cropping on highly erodible soils; minimize or eliminate tillage**, particularly in the fall, while also applying low-disturbance direct seeding when possible; maximize carryover of crop residue from one year to the next; slow tractor speeds; and avoid harvesting pulse straw for feed on land prone to erosion (McConkey and Panchuk, 2000).

Based on farmer surveys across Canada, the proportion of farms with pulses reporting no-till seeding practices increased from 6.7% using no-till and 24.4% using conservation tillage in 1991 to 56.4% using no-till and 24.6% using conservation tillage in 2011. Conventional tillage has dropped in use from 69% in 1991 to 19% by 2011, across Canada (Statistics Canada, 2011). This coincided with the increase in pulse production over the same time period.

A life cycle and socio-economic analysis of pulse crop production and pulse grain use in Western Canada provides important insights. The goal of the research was to determine the difference in environmental and socio- economic effects of including pulse crops in rotation as well as using pulse crops for human consumption (system #1 in Box 2 below), and as swine feed (systems #2 in Box 3 below). Environmental benefits were found to be strong, primarily due to the nitrogen fixation abilities of pulse crops, the reduction in nitrogen requirements of a cereal crop succeeding a pulse crop, and the increase in quantity and nutritive quality (protein content) of a cereal crop following a pulse crop. Even when considering the practice of applying pesticides to the crops, this did not generate sufficient differences in environmental effects to discount the overall positive environmental results (McWilliam et al, 2011).

Greenhouse gas emission reduction

The greenhouse gas emission reduction benefits of adding pulses into rotations with grain is attributed to a range of interventions, not just the added nitrogen fixation capacity of pulses. Research was conducted on a wheat rotation system, utilizing the 25-year (1985–2009) field study conducted in Swift Current, Saskatchewan by the Agriculture and Agri-Food Canada Research Centre. Findings indicate that an improved farming system, based on fertilizing crops based on soil tests, reducing summer fallow frequencies and rotating cereals with pulses (lentil, in this case) lowers the wheat carbon footprint considerably (an average of 256 kg CO_2eq ha $^{-1}$ per year). Among the four cropping systems tested, which included fallow-flax-wheat, fallow-wheat-wheat, continuous wheat, and lentil-wheat, the lentil-wheat system clearly outperformed the others. This was due to the lower rates of nitrogen fertilizer required by the wheat crop

Box 2: Summary of system 1- Life Cycle and Socio-Economic Analysis of Pulse Crop Production and Pulse Grain Use in Western Canada

System #1. Pulse in crop rotations:
Oilseed/cereal rotation: canola, wheat after canola, wheat
Lentil rotation: canola, wheat after canola, lentil, wheat
Dry pea rotation: canola, wheat after canola, dry pea, wheat

Key findings in the lentil and dry pea rotations modeled, compared to the oilseed-cereal rotations:

Human Health: Reductions in human health impacts are noted related to reduced carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion and respiratory organics. Human health effects are related to the amounts of inputs required for production, hence decreased inputs equates to less use of fertilizers, fewer field operations such as harvesting equipment, and less toxic emissions released to the air.

Ecosystem quality: Reductions in effects on the quality of the ecosystem such as aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrification, land occupation, aquatic acidification and aquatic eutrophication due to fertilizer use and mechanized harvesting were noted, based on reductions in the amount of applied chemicals and fertilizers, while wheat yields increased.

GHG emissions: Reductions of GHG emissions by 25% in the dry pea rotation and 22% in the lentil rotation are noted, while non-renewable energy was decreased 25% in the dry pea

in this lentil-wheat rotation, and the increased nitrogen availability, which enhanced plant biomass accumulation. Results indicate that spring wheat grown using this suite of improved farming practices can attain a net carbon balance regardless of water availability (Gan et al, 2014).

Research shows that **crop rotations containing a pulse crop have lower overall greenhouse gas emissions than those that do not include a pulse crop**. This is because up to 70% of the non-renewable energy used in Western Canadian cropping systems is due to the use of fertilizers, particularly nitrogen. Pulses supply their own nitrogen, reducing the need for added nitrogen fertilizer. Research on nitrous oxide emissions specifically is limited, but shows that emissions tend to be lower for pulse crops compared to fertilized cereal crops. **Indications are that the more often a pulse crop is grown in rotation, the more greenhouse gas emissions are reduced.** One 17-year study at Swift Current, Saskatchewan, indicates a reduction in GHG emissions of 31% annually when lentils were included in rotation with spring wheat. A similar study at Indian Head, Saskatchewan showed an 18% reduction in yearly GHG emissions when peas were included in rotation with spring wheat, winter wheat, and flax. The site with the greatest magnitude difference included a pulse crop once every two years, whereas at the other locations a pulse crop was included only once every four years (Lemke et al, 2007). A similar study at Indian Head, Saskatchewan showed an 18% reduction in yearly greenhouse gas emissions when peas were included in rotation with spring wheat, winter wheat, and flax (Lemke et al, 2007).

Using a carbon footprint method of analysis, a review of available literature found that durum wheat preceded by a nitrogen-fixing pulse crop emitted total greenhouse gases of 673 kg CO_2eq, which is 24% lower than if the crop was preceded by a cereal crop. In this same analysis, it was determined that canola and wheat had significantly greater carbon footprint than pulse crops (such as chickpea, dry pea, lentil) (Gan et al, 2011).

In controlled circumstances, biological nitrogen fixation by lentil and pea was determined not to be a direct source of nitrogen emissions (Zhong et al, 2009).

A life cycle analysis found that by reducing the requirement for synthetic nitrogen fertilizers, pulse crops inherently reduce the emissions and energy use associated with the production, use and disposal of fertilizers (McWilliam et al, 2011).

Box 3: Summary of system 2- Life Cycle and Socio-Economic Analysis of Pulse Crop Production and Pulse Grain Use in Western Canada

System # 2. Pulses for Swine Feed: Replacing the imported (from the US) soybean meal in swine feed with dry pea

Starter swine diets examined in the study had a 15% rate of dry pea inclusion, whereas the more mature grower and finisher swine diets contained 42.5% and 30% inclusion rates of dry pea in the feed mix. Feed production accounted for the majority of the environmental effects associated with swine production in all impact categories (50 - 100%). However, the majority of the GHG emissions from swine production were associated with animal husbandry (53-55%), not feed. Additional environmental benefits would occur if wheat grown after a pulse crop was included in the swine diets.

Human health: Findings indicate that replacing soybean meal with dry pea resulted in a marked decrease (-30%) in life cycle respiratory organics, although other impact categories were comparable.

Ecosystem quality: Findings indicate comparable effects on ecosystem quality in the categories of aquatic ecotoxicity, terrestrial ecotoxicity and land occupation. However, the soybean meal diet had greater terrestrial acidification/nutrification (17%), aquatic acidification (13%) impacts, while the dry pea diet had greater aquatic eutrophication (63%) impacts. Decreased fertilizer requirements in the dry pea diet resulted in aquatic and terrestrial acidification.

GHG emissions: The two production systems had similar GHG emissions. The dry pea diet decreased non-renewable energy use by 11%, based largely on the reduction of wheat in the diet.

Source: MacWilliam et al, 2011.

3.1.3 Social

The social benefits of pulse production in Saskatchewan are not well documented, however anecdotal evidence suggests the shift to no-till, reduction in summer fallow, and introduction of new crops such as canola in the 1970s and more recently pulses, has **provided the means to keep farmers on the farm, and keep rural communities relatively intact**. At its peak in 1936, Saskatchewan had 142,000 farms, by 2011 that number had dropped to just over 37,000 (Bitner, 2010; Statistics Canada, 2011). Farm size has increased over the years, and Saskatchewan has the largest average farm size in Canada, at 1,668 acres (675 ha), and farm sizes are increasing at a higher rate than in other regions of Canada. The average age of farm operators in the province is 54.2, which is fairly consistent with the national average. However, the rural population is decreasing, down to 33% of the population, compared to 50% in 1966 and 84% in 1901 (Statistics Canada, 2011). Anecdotal evidence from interviews suggests that many Saskatchewan farmers growing cereal-fallow and cereal-canola would have gone bankrupt without diversifying into lentils and other pulse products. Chickpea was pursued as a pulse diversification crop, but the ascochyta blight and long growing season requirements have diminished plantings of this pulse. The next section provides more insight into the economic benefits, as recent economic returns from pulse production show significant benefits to farmers and the provincial economy, and this has ripple social effects within rural communities.

The health aspects of including pulses in diets is an important indicator of the social benefits of pulses, although North American and Canadian consumption of pulses appears to be far below the optimal level. The role of pulses and legumes in dietary patterns of people with diabetes can be important to regulate blood sugar levels and moderate symptoms. The Canadian Diabetes Association Clinical Practice Guidelines recommend that a low-fat vegan diet (which would include pulse and legumes) improves glycemia and plasma lipids more than the conventional diets. Research testing diabetes patient response to a calorie-restricted vegetarian diet versus a conventional diet demonstrated a significant decrease in diabetes medication use in the vegetarian compared to those on a conventional diet (a 38% difference). Similarly, a “Mediterranean diet” which is predominantly a plant-based diet (including fruits, vegetables, legumes, nuts, seeds, cereals, whole grains, a moderate-to-high consumption of olive oil, and low consumption of fish and meat) is confirmed to improve glycemic control and cardiovascular risk factors, including systolic blood pressure. The metabolic advantages of a Mediterranean diet improve primary prevention of cardiovascular disease in people with type 2 diabetes (Dworatzek et al, 2013). The Saskatchewan Pulse Growers and Pulse Canada are supporting research on the glycemic response of pulse flour and fraction ingredients, in order to better understand health benefits and inform future development of pulse ingredients and food product matrices (Saskatchewan Pulse Growers, 2015).

3.1.4 Economic

Grain producers in Saskatchewan experienced a convergence of factors that contributed to the uptake of pulse production. The environmental aspects such as reduced erosion and nitrogen fixation benefits to the current and subsequent crops, and social reasons such as the ability of farmers to stay in the agriculture sector, are described above. But the economic reasons for diversifying into pulse crops were significant. One influence was Canada's commitment in 1994 to cut grain export subsidies by 21% in volume and by 36% in dollar terms over a period of years as part of its agreement to the Global Agreement in Trade and Tariffs, and also the 15% cut in subsidies to grain under the Western Grain Transportation Act (Dakers and Fréchette, 2001). This had a direct effect on grain prices and export market dynamics. Another factor was that the economic benefits of adding pulses in cropping systems in Saskatchewan were recognized over time, as farmers increasingly eliminated summer fallow periods.

A long-term crop rotation experiment, first established in 1967 on Brown soils in Swift Current, Saskatchewan, and running up to the 2002 season, evaluated the economic performance of conventional tillage management practices in this semiarid region. Research investigated the most optimal cropping frequency, value of applying nitrogen and phosphorous fertilizer at soil test rates, and the advantage of replacing monoculture wheat with pulse or oilseed crops grown in mixed rotations. Findings indicated that under the more favorable growing conditions between 1985–2002 (as compared to the previous study covering the 1967 – 1984 period), area producers could maximize economic returns by choosing a wheat-lentil (with nitrogen and phosphorous application) rotation, and eliminating summer fallow from the cropping system. Net returns from the next optimum mixes of fallow-wheat and continuous wheat rotations were 44% less than for the wheat-lentil rotation. Researchers found that only if producers were highly risk averse, did not subscribe to all-risk crop insurance, or if the price for wheat was high or price for lentil low, would the monocropped wheat systems be preferred to wheat-lentil (Zentner et al, 2007). Similarly, evidence from a review of empirical studies prior to 2002 suggested that **including oilseed and pulse crops in rotations with cereal grains contributed to higher and more stable net farm income, in spite of higher input costs**, across most soil types (Zentner et al, 2002).

Recent economic returns from pulse production show **significant benefits to farmers and the provincial economy**. Saskatchewan's agri-food export sales in 2014 were CD$13.9 billion, CD$2.7 billion of which were lentils and peas. While the volume of lentil exports has increased 67% between 2009 and 2014, the value of those exports increased 37%. Pea exports show a different trend over the same period, with the volume of pea exports increasing 19%, while the value over the same time period increased 56% (Saskatchewan, 2015).

The crop types that are put in rotation can be a strong determinant on economic returns. McWilliam et al reference one study in the Black soil zone, the net return for dry pea after barley was 39% lower than that for wheat after dry pea. Whereas in another study, a legume-based rotation of winter wheat and vetch was found to produce a 16% higher return over a continuous winter barley rotation. However, McWilliam et al caution against such results, particularly for the net returns, as the market price has more significant effect than costs, in terms of net returns, and market pricing can be quite variable. McWilliam et al note that many studies on including dry pea or lentil in a grain or grain-oilseed rotations observe the costs of production increasing, but that increased costs are offset by increased returns, leading to higher net returns to producers (McWilliam et al, 2011). Crop diversity is a hedge against fickle markets and changes in price. Farmer surveys in 2011 indicate that farms growing pulses produce a larger variety of crops than farms not growing pulses. Twenty-six percent of all pulse-producing farms report four field crop types, and one in ten farms growing pulses grow seven or more field crop types, indicating significant on-farm diversity (Bekkering, 2012).

Another aspect to diversification in crop types and pricing that is likely significant: **diversifying the cropping mix with crops that do not have correlated prices helps spread market risk.** Lentil has the lowest correlation effects of crops commonly put in rotation in Saskatchewan. By including lentil in rotation with other crops (refer to the values in Table 1 below) farm level risks are reduced, as the prices of these commodities are not as strongly correlated as grains such as wheat and barley. Dry pea also has lower correlation effects, but not to the same degree as lentil, and therefore may not offer the same risk reduction as lentil (McWilliam et al, 2011).

Lentils in rotation add considerable value to economic returns in cropping systems over multiple years. The Saskatchewan Crop Planner is available to farmers to help estimate the potential income and costs of production for different crops in the various soil zones in the province. The Planner factors in crop prices, yields, inputs such as fertilizer, other variable and fixed costs such as machinery and labour costs, land investment costs, and crop insurance premiums. Estimates from the 2015 Saskatchewan Crop Planner indicate that lentils make an important relative contribution to the financial returns of rotations in different soil types found in the Province (refer to Table 1). In the black soil zone, returns over variable expenses from lentil are 38% of total returns from both rotations over 4 years. The Brown soil zone shows highest returns, with returns over variable expenses from lentil exceeding 60% of total returns from both rotations over 4 years. Returns from lentil over total rotation expenses on a per acre basis are almost CD$100, compared to deficits for most wheat, barley, oat and corn crops, and marginally better returns for red lentil, edible yellow, edible green peas, soybean and canola (Saskatchewan, 2015). These ranges are largely corroborated by the findings of McWilliams et al, which applied a partial equilibrium simulation model based on 2006 prices to assess the economic desirability of pulse crops in rotations. Findings indicate that dry pea and lentil rotations are better economic choices than the oilseed-cereal rotation. Including pulses in rotation is found to be positive except when pulse prices are low and grain and oilseed prices are high (McWilliams et al, 2011).

Average total expenses for pulse crops are roughly the same as other stubble crops, with variable costs for pulse crops being CD$180/acre, compared to CD$185/acre for all other crops considered (ten crops included, ranging from wheat, barley, oats, corn, soybean, flax and canola). Other expenses, including machinery, buildings, land are similarly comparable, with pulse crops (including large green lentil, red lentil, edible yellow, edible green peas) costing CD$115/acre compared to CD$116/acre for the ten other major crops. When adding labour and management into production costs, pulses are slightly more economical, bringing total costs to an average of CD$296/acre for pulse crops, compared to an average of $302/acre for other crops (Saskatchewan, 2015).

A review of empirical studies found **consistent yield advantages, less income variability and resource savings in conservation tillage or no-tillage practices when including oilseed and pulse crops in the rotation with cereal grains**, compared to conventional tillage, and therefore to be highly **profitable in the Black and Gray soil zones** of the Canadian Prairies, due to substituting herbicides for more mechanized tillage. In the Brown soil zone and parts of the Dark Brown soil zone, the short-term economic benefits of using conservation tillage practices are more marginal and less profitable than comparable conventional tillage practices (Zentner et al, 2002).

Table 1: Economic returns of lentils in rotations, based on different soils in Saskatchewan

Black Soil Zone

	Rotation 1			Rotation 2		
	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)
Year 1	Oats (on stubble)	-27.60	87.79	Spring Wheat (on stubble)	3.26	118.65
Year 2	Spring Wheat (on stubble)	3.26	118.65	Large Green Lentil (on stubble)	96.35	211.74
Year 3	Large Green Lentil (on stubble)	96.35	211.74	CPS Wheat (on stubble)	-14.96	100.43
Year 4	Canola (on stubble)	10.15	125.54	Canola (on stubble)	10.15	125.54

Dark Brown Soil Zone

	Rotation 1			Rotation 2		
	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)
Year 1	Chem fallow			Spring Wheat (on stubble)	0.67	107.83
Year 2	Spring Wheat (on fallow)	-67.96	104.03	Large Green Lentil (on stubble)	199.12	306.28
Year 3	Large Green Lentil (on stubble)	199.12	306.28	Durum (on stubble)	-6.02	101.14
Year 4	Durum (on stubble)	-6.02	101.14	Canola (on stubble)	18.43	125.59

Brown Soil Zone

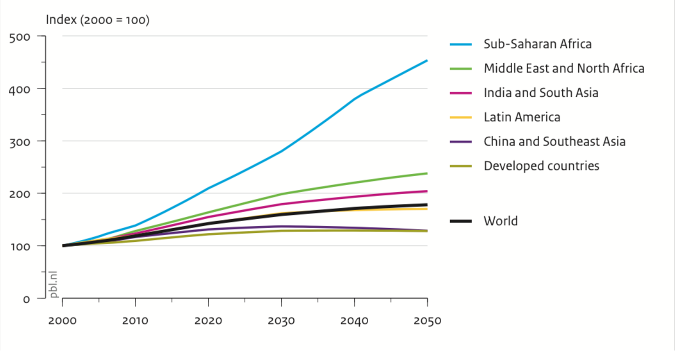
	Rotation 1			Rotation 2		
	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)	Crop	Return over Total Expenses ($/ac)	Return over Variable Expenses ($/ac)
Year 1	Chem fallow			Spring Wheat (on stubble)	-31.87	60.93
Year 2	Spring Wheat (on fallow)	-63.65	83.21	Large Green Lentil (on stubble)	184.33	277.13
Year 3	Large Green Lentil (on stubble)	184.33	277.13	Durum (on stubble)	-19.18	73.62
Year 4	Durum (on stubble)	-19.18	73.62	Canola (on stubble)	-25.42	67.38

Source: Crop Planning Guide, Saskatchewan Ministry of Agriculture, 2015

3.2 Sub-Saharan Africa

3.2.1 Context

Figure 3: Projected global food demand



Source: Hilderink, et al, 2012.

Food demand is expected to increase dramatically in Sub-Saharan Africa. Around 40% of the global total population growth between 2010 and 2050 will take place in sub-Saharan Africa, with its population projected to more than double from 814 million people in 2010 to 1.7 billion by 2050 (Hilderink et al, 2012). The corresponding food demands by this growing population is striking (refer to figure 2). Yet indications are that Africa will not produce enough staple foods such as cereal to feed its population. The largest trade deficits globally in 2023 will occur in Africa and Asia, and indications are that African food production, particularly of staples such as cereals, will not keep pace with demand (OECD/FAO, 2014). Demand for pulses in Sub-Saharan Africa are expected to increase from 14.6 million MT in 2015 to 22.7 million MT in 2030 and 37.3 million MT by 2050, with the majority being beans and cowpeas (Robinson, et al, forthcoming). The vast majority of pulses are grown in rainfed areas in Sub-Saharan Africa, with 19.5 million ha of production being in rainfed conditions in 2015 compared to only 339,000 ha irrigated, and that ratio is largely predicted to endure out to 2030 and 2050 (ibid).

3.2.2 Environmental

The environmental benefits of pulse production in Africa are not documented to the same degree as in Saskatchewan. Most pulse production occurs in rainfed areas (97% of total cropland is rainfed), with low use of inputs and relatively low yields. In Ethiopia, while pulses covered 12.4% of the grain crop area in 2014-15, their reliance on fertilizers is almost negligible. On private smallholdings, cereal crops demanded 89% of inorganic fertilizers applied, while farmers only applied roughly 4% of inorganic fertilizers to pulse crops (Ethiopia, 2015b). In Ghana, smallholders cultivating pulses use basic technologies without mechanization, mostly use recycled seed and apply insufficient fertilizers and agrochemicals. In addition, there are significant biotic yield-reducing pests and diseases, especially in the case of cowpea. Note that in Ghana, all fertilizers used in the country are imported, mostly by Yara and distributed by Wienco. Use has increased by over 500% since 2000, according to Ghana's Ministry of Food and Agriculture, Crops Services Directorate (Rusike et al, 2013).

Similarly, in eastern DRC, all fertilizers, agrochemicals and inoculants are imported. Seed quality is poor, despite decades of higher-quality seed production, distribution and assistance with farmers to improve uptake, with the civil war exerting significant negative effect. Farmer access to certified seed of improved varieties remains low due to the lack of formal seed multiplication and marketing systems. Yields of common bean have fluctuated over the past decade with no upward trend (Rusike et al, 2013). In the future, improved management practices such as optimal crop rotations using pulse crops, could be an important means to promote appropriate application and judicious use of synthetic fertilizers, boost soil fertility and yields of subsequent crops.

The challenge is for African pulse production to not only make huge gains in realized (on-farm) yields, but to also adapt to a changing climate, with increased water and temperature stress. Improved access to improved seed and agro-chemicals and complementary farm practices are needed to close yield gaps. Government policies are needed to reduce production costs (e.g. through support for small-scale mechanization), lower production risk (e.g. crop insurance) and stabilize markets (e.g. commodity exchanges, price supports). The Africa Adaptation Gap Report finds that warming projections under medium scenarios indicate that extensive areas of Africa will exceed 2°C by the last two decades of this century relative to the late 20th century mean annual temperature. Under a high warming scenario (over 4°C), that threshold would be crossed by mid-century across much of Africa and reach between 3°C and 6°C by the end of the century. In the 2ºC warming scenario, all crop yields across sub-Saharan Africa will decrease by 10% by the 2050s, but if temperatures exceed 3ºC, all present-day cropping areas for maize, millet and sorghum will be unsuitable for those crops (UNEP, 2015). It is unclear how future climate stress will impact disease outbreaks. Fusarium wilt, a fungal soil-borne disease that infests all pigeonpea growing areas in east and southern Africa, requires either improved seed varieties of seeds resistant to this disease, or use of extended rotations or expensive chemicals (Shiferaw et al, 2008).

The Intergovernmental Panel on Climate Change estimates that the negative impacts of climate change on crop yields will be more common than positive ones, with changes in crop yields due to climate change, with the bulk of yield changes exceeding 5 – 25% after 2030 (IPCC, 2014). Drought mortality and water risk will be the highest in Africa due to climate change impacts, and African countries are increasingly recognizing the need to address agricultural adaptation pressures, and promote climate-smart agriculture. In a simulation of how Sub-Saharan African agriculture would adjust to a 5ºC increase up the year 2090, projections indicate 24% declines in the mean average yields for maize and a 71% decline in bean production, indicating how vulnerable African agriculture is to significant changes in rainfall patterns and temperature (Thornton et al, 2011). **Changes in management practices and improving the adaptability and strength of seed systems will be crucial to build resilience and adaptation in African agricultural systems**.

In Africa, **climate and environment benefits can derive from multiple uses of pulse crops**. In Tanzania, pigeonpea biomass can be used for feeding livestock or as source of firewood, thereby reducing firewood collection needs carried by women and children and reducing deforestation and loss of biodiversity (Shiferaw et al, 2008).

Altering the traditional planting methods of maize and beans can influence the nitrogen balance in cropping systems. A study in Central Kenya which assessed the effect of smallholders shifting from a single one-by-one row system of alternating maize and legumes, to a modified two-by-two row staggered arrangement found nitrogen balances were negative in the maize/bean and groundnut scenarios, but neutral with cowpea as the intercrop, indicating the nitrogen benefits of cowpea intercropping (Mucheru-Muna, 2010). Interventions in the dry savannah's of Nigeria and Niger also found modified strip-cropping of cowpea and sorghum, with the addition of livestock to boost manure nutrients, prevented the nutrient losses caused by the region's traditional farming systems, and increased farmer incomes (Gatsby Charitable Foundation, 2014).

A sustainability challenge in global agricultural production is how to increase efficiency on existing agricultural lands, rather than extensive practices which push production into forests and wetlands. In Ghana, production and yields of cowpea have increased with greater proportion than hectares planted, indicating increased efficiency in production. These trends are being driven by the development, release, availability and adoption of quality seed of improved varieties; availability of markets and increasing market demand by urban consumers; increased prices, profitability and incentives for farmers to adopt productivity enhancing options, especially to grow and protect their crops from insect pest attack. The Ghana Grains Development Project had considerable impact over the 1980s and 1990s, helping to improve yields through better varieties (19 were developed), agronomic, grain storage and seed production technologies, better seed distribution, and extension services (Rusike et al, 2013). Given the current low rates of fertilizer use, climate change mitigation can be maximized with sustainable intensification (e.g., better productivity and reducing deforestation pressure) and improved soil condition (e.g., carbon sequestration). Improvements in seeds and agronomic management are foundational to capturing these opportunities.

3.2.3 Social

The social dimensions of pulse production in Africa includes food security and livelihoods, household benefits, diversified diets and nutrition, and gender aspects.

Nutrition and food security

Nutrition is closely linked to income in Sub-Saharan Africa, and in many rural areas, a large portion of family income can be directed towards food. Food security, livelihoods, household benefits and nutrition are often quite interlinked. In Sub-Saharan Africa the cowpea is the most consumed pulse, followed by chickpea and pigeonpea, on a per capita basis, but there are regional variations.

Rwanda has the highest per capita consumption of common beans in the world, along with Burundi, Uganda and Eastern Democratic Republic of Congo (Rusike et al, 2013). In Rwanda, beans provide 32% of caloric intake and 65% of protein intake in the average diet, while protein from animal sources only accounts for 4% (Asare-Marfo et al, 2011). Rwandans consume roughly 29 kg of beans per year, more than double that of neighboring Uganda (SPIA, 2014). Other data indicates that 80% of the population consumes beans daily, making Rwanda one of the highest bean consumers in the world (Berti et al, 2011). Results from a large-scale household survey[5] in 2011 indicates that 87.9% of farm households in Rwanda cultivate beans as part of their cropping system, and yet of the 708 households surveyed, 77% reported not growing enough beans for their needs, and often ran out a few months after harvest (*ibid*). Other household survey research indicates that as the share of improved bean seeds planted increased, household dietary diversity scores increased, showing a clear relationship between nutrition and improved seed adoption (Larochelle and Alwang, 2014).

In Ethiopia, pulses are culturally essential to the diet, based on religious practices of fasting, which depend on alternative sources of protein when almost half the population does not consume meat. As chickpea has an average of 22% protein, they are a more sustainable alternative to meat. Thus, USAID/Feed the Future and PepsiCo are working with the United Nations World Food Programme (WFP) on a pilot program in Ethiopia to improve the production of chickpeas by building the capacity of local farmers, establishing drip irrigation systems, and supporting local millers, processors, and packers. Called Enterprise EthioPEA, this effort supports the Ethiopian government's agriculture sector development plans and aims to dramatically increase chickpea production by improving yields, production and availability. While Ethiopia is Africa's largest producer of chickpeas, there remains high potential to increase yields and improve quality. The project intends to enable nearly 10,000 Ethiopian farmers to see a two-fold increase in chickpea yield with improved practices and irrigation, and to develop a locally sourced, nutrient-rich, ready-to-use supplementary food to address malnutrition. The project also seeks to scale up and strengthen the Ethiopian chickpea supply chain, for both domestic and export markets.

In Tanzania, nutritional aspects of dryland legumes such as pigeonpea, chickpea, and groundnut, are noted for their contribution to help overcome nutritional deficiencies due to diets lacking proteins and oils, particularly among poor families unable to afford more expensive animal-based foods. Pigeonpeas provide a vital source of protein for poor families and provide cash for marginal farmers in semi-arid Tanzania (Shiferaw et al, 2008).

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[5] 708 households in Rwanda's Northern and Southern Provinces, and 743 women and 674 children.

In Kenya, the share of subsistence production and consumption ranges from 60-70% for beans and cowpeas, as compared to only 20% for commercial grain legumes such as soybean. In Kenya, cowpea is important for food security both as a major leaf vegetable (it contains more minerals and nutrients than most other vegetables) and as a grain, and is sold in both forms to urban markets. Similarly, in Ghana, cowpea is valued for food security and a cash crop, with 32% of cowpea produced for subsistence production and consumption. The cowpea dry grain is a daily staple for the majority of the population and the green leaves of cowpea are eaten as vegetables. The dried haulms are used as livestock feed. In Eastern DRC, common bean is the second most important staple food after cassava, and 50-80% of common bean production is cultivated by smallholders, usually intercropped with cassava and maize. In Rwanda, common bean is the first major crop prioritized on 35% of plots, and is the most important legume for household consumption and for earning cash income. In fact, it is one of the most important cash crops for many rural households. In Nigeria, 56% of cowpea produced is subsistence production and consumption (Rusike et al, 2013).

Food security and diversity

Grain legumes added into the diet are found to contribute important energy, proteins, minerals, and B vitamins. When consumed with cereals, pulses contribute proteins, minerals and B vitamins, as well as the essential amino acid lysine, which increases the quality of protein. When added to root and fruit staples, they raise the protein content. When energy and protein are both deficient, leguminous oilseeds can play an important role in improving diets. Legume leaves are also important, as they provide sources of B-carotene and vitamin C, as well as more folic acid, calcium and iron to a meal (de Jager, 2013).

The diversity in types of production systems will influence yield rates or farmer adoption of technologies, such as improved varieties or rotations. In Rwanda, intercropping reduces productivity, whereas in Uganda, no statistically significant yield impact is seen with intercropping. In Uganda, beans are frequently grown with bananas, whereas in Rwanda, beans are more likely to be intercropped with crops such as maize, tomatoes, eggplants, and peas (Larochelle et al, 2014).

Despite the variation in whether farmers fully adopted or only partially adopted improved bean varieties, roughly 22% of Rwandan households would be food insecure in the absence of improved beans compared to only 13% after adopting improved varieties (Larochelle and Alwang, 2014). The research findings indicate **that the impact of improved seed varieties on food security are believed be more pronounced than those on bean farm income**. This is because adoption of improved varieties influences food consumption in other ways than just through farm profitability. Authors note that, frequently, improved varieties have shorter production cycles, which can free up labour and allow household members to be engaged in additional income-generating activities.

Further, higher productivity can also allow households to focus on other crops, increasing diversity in agricultural production food consumption (*ibid*).

Research applying **econometric approaches to estimate profitability** at the household level and at the market level, accounting for the difference from the counterfactual, was used to **estimate the impact of improved bean varieties released since 1998 on food security** in Rwanda and Uganda. Research findings are that food insecurity would have been 16% higher in Rwanda without the introduction of improved bean varieties. Food insecurity would have been a negligible 2% higher in Uganda (Larochelle et al, 2014). Improvements in bean varieties on both countries have occurred through genetic enhancements or seed selection processes. The International Center for Tropical Agriculture (CIAT), Research Agriculture Bureau (RAB) in Rwanda and Uganda National Agricultural Research Organization (NARO) have worked to create 46 improved varieties in Rwanda and a significant number in Uganda. In Rwanda, CIAT-improved varieties accounted for 15% of the area planted to beans by 2003 (Larochelle and Alwang, 2014). Poverty would have been about 0.4% and 0.1% higher in Rwanda and Uganda respectively, in the absence of varietal improvements to this vital subsistence crop (SPIA, 2014). In Uganda, the adoption of improved bean varieties by the National Agricultural Research Organization (NARO) and partners over ten years was found to be less than 15% of households, primarily due to limited access to seed of improved varieties (Kalyebara, 2005). In contrast, Kenya has seen much higher rates of farmer adoption of improved seed, with 80-90% of the farmers growing common bean in Kenya using improved varieties developed under the Grain Legume Project implemented in the 1980s (Rusike et al, 2013).

Bio-fortified seed and food security

Bio-fortified seed has been largely promoted in Rwanda to improve nutrition and yields. Bio-fortification involves either breeding crops to increase their nutritional value, which can involve genetic engineering, or through conventional selective breeding. The bio-fortified bean seeds developed in Rwanda are non-GMO products, as the varieties were selected from natural variation in the bean collections.

As a result of food insecurity, households are also vulnerable to malnutrition, resulting in Rwanda's very high rate (43%) of stunting among children under the age of five. A cornerstone of Rwanda's Agriculture Sector Strategic Plan (PSTA III) is interventions to improve nutrition and household vulnerability, and one of the six strategic priorities is a programme to support bio-fortified food, focusing on beans fortified in iron, vitamin A rich maize, orange sweet potato, and fortified cassava and rice. The production and consumption of bio-fortified seeds is to be expanded (Rwanda, 2013). The PSTA III seeks to increase production of beans from 452,828 MT in 2013 to 749,381 MT by 2017-2018. The PSTA III also identifies the need to maintain a National Strategic Food Reserve, prioritizing maize and bean.

Five districts of Rwanda's Southern Province that were struck with cassava brown streak were prioritized by the government for interventions by HarvestPlus and partners to deliver 165,000 metric tones of quality seed of 'high iron' bean varieties to these farmers. By 2014, about 800,000 of Rwanda's two million bean farmers were using iron enriched biofortified bean varieties, which also have higher yields than local varieties (HarvestPlus, 2014). Rwandan Afro-pop stars released a song in late 2014, with support from HarvestPlus, to extol the virtues of planting and eating iron-fortified beans, for nutritional health (See: https://www.youtube.com/watch?v=fo6449Rd3I0).

Gender

Gender aspects of pulse production relates primarily to women's involvement in pulse production commercially, to feed families, and to benefit from income derived from pulse sales. In Kenya, cowpea is grown primarily by women. While women do not take part in the value chain beyond production in Kenya and Rwanda, in Ghana cowpeas are cultivated by both men and women, but dominated by women in post-harvest processing and marketing. Common bean is grown by most farmers throughout Rwanda, although traditionally common bean is cultivated by women. In Nigeria, cowpea is cultivated by women and men, and gender equity for women is more apparent when women can make decisions on quantities sold and those retained for household consumption (Rusike et al, 2013). A gender framework developed for pulse growing districts of Ethiopia indicates five gender-related pillars for improving pulse productivity/management and nutrition, including knowledge, skills and training acquisition, participation in production and decision-making, access to and control over resources, and policy development. Researchers identified the importance of considering gender differences in access to land, technologies and other strategic resources in pulse crop productivity/management and related interventions (Henry et al, 2016).

3.2.4 Economic

Agriculture is the economic mainstay of Sub-Saharan countries, employing about 60% of the workforce and providing an average of 30% of the region's gross domestic product.

Economic benefits of adding pulses into rotation

The **economic impacts of including pulses in rotations are influenced by a variety of factors, including farmer perception and knowledge**. In Uganda, the economic benefits of producing pulses is found to be overshadowed by farmer perceptions of marketability of certain products, unfamiliarity with pulses, concern over high labour costs to produce pulses, or other reasons. Findings from Eastern Uganda indicate that despite pigeonpea and mucuna (Velvet Bean) being profitable when grown in good soils and groundnut having the poorest economic performance of crops grown in rotation with millet, farmer evaluations indicated a stronger preference for growing groundnut, while there was disinterest in growing pigeonpea and mucuna. This is thought to be due to unfamiliarity of pigeonpea as a food or market crop and concerns over higher labour costs in growing mucuna, which is often grown as a green manure/cover crop (Ebanyat et al, 2010). In Central Kenya, the importance of improved methods of intercropping had significant effects on economic performance of both grain and legume crops. One study over seven growing seasons in Central Kenya with smallholders assessed the effect of shifting from a single one-by-one rows, alternating maize and legumes, to a modified two-by-two row staggered arrangement. Legume production was already occurring in this system, so farmers were already familiar with the crops. This modified intercropping arrangement did not increase the amount of legume planted, but did shift the intercropping patterns with maize, common beans, cowpea and groundnut. Findings were that smallholders producing maize were able to increase net profitability by 40% on fertile soils by applying the modified staggered arrangement with beans. On the less fertile soils, groundnut and cowpea were better adapted, and the staggered arrangement system increased net benefit by 12–37% (Mucheru-Muna, 2010).

Farmer survey results in Ethiopia indicate that smallholders grow various crops for their own consumption and/or economic benefits, and pulses contribute significantly for the 7.9 million farmers producing them, most of whom are smallholders. Faba bean, chickpeas, field peas, and red haricot beans comprise the largest production, and white haricot bean and lentil is also grown. Faba bean accounts for the largest production, at 8.3 million quintals, while chickpea is the next most produced pulse, at 4.6 million quintals. Pulses grown in Ethiopia's 2014-15 Meher season covered 12.41% of the grain crop area (Ethiopia, 2015a).

In Nigeria, farmers rank cowpea very high for cash farm incomes and allocate it a significant proportion of their cultivated area. Farmers sell cowpea to buy staple cereals, but also consume cowpea themselves. In addition, farmers rearing livestock use cowpea haulms as hay to feed animals. Cowpea processing is also dominated by household enterprises and SMEs, contributing to household income (Rusike et al, 2013)

Finding a crop rotation sequence that produces the highest return on investment can be an important indicator of whether farmer practices change to include pulses over the long term. In Benin, better labor productivity was maximized when legumes were intercropped with traditional smallholder yam production occurring in shifting cultivation systems. Thus, net revenue and return on investment were achieved in yam-based systems with legumes, with significant returns on investment (Maliki et al, 2012). While maize/cowpea, sorghum/cowpea, and maize/sorghum/cowpea crop combinations had the highest gross margins per hectare in the *fadamas* of Southern Guinea Savanna, Niger State, Nigeria, the return on investment was found to be highest with spinach, okra and sorghum/cowpea (Lawal et al, 2010).

Economic benefits from improved seed

The **economic impacts of CGIAR-supported improved bean varieties** in Rwanda and Uganda was assessed through the CGIAR-supported project 'Diffusion and Impact of Improved Crop Varieties in Sub-Saharan Africa' (DIIVA). Economic impacts were estimated based on the change in farm profit among adopters compared to non-adopters for improved versus traditional varieties, taking into account additional revenues and production costs, including seeds and increased labor requirements. Findings estimate that Rwandan households which planted improved varieties increased their production by 42 kg/yr, thereby increasing household revenue by US$74. Similarly, Ugandan households saw production increases of 40 kg/yr thereby increasing household revenue by US$63 (SPIA, 2014). The average yield gain over local varieties from adopting improved bean varieties was found to 53% in Rwanda and 60% in Uganda (*ibid*). Larochelle and Alwang reference a 2003 study that found the Rwandan yield gains over local varieties to be 900 kg/ha, which is also attributed to the shift from bush to climbing beans in the Northern region of Rwanda. Estimates identified this contributed an annual additional value of US$8.7 million to the economy, from the additional production of 28,888 tons (Larochelle and Alwang, 2014). Another analysis in Uganda, completed a decade earlier, estimating the net present value of total benefits to Uganda from public investments in bean research and development estimated it to be US$19 million dollars per year, with an internal rate of return on the investment of 41% (Kalyebara, 2005). In semi-arid Tanzania, average estimated yield gains from growing fusarium-resistant pigeonpea varieties was about 67%, with farm-level benefits resulting in 80% higher net income per ha compared to using non-disease resistant seeds (Shiferaw et al, 2008). The average marketed surplus of adopting farmers in 2003 was about 716 kg/yr, while those growing local varieties sold only 349 kg of pigeonpeas. This increase in yield and reduction in variable costs was also found to benefit the government through increased tax revenues received from producers and consumers, based on a total economic surplus of US$6.1 million, with an internal rate of return of 32.2%. Pigeonpea accounted for about 50% of the cash incomes of the sample farmers during the year, demonstrating the key role of this crop as source of cash. Adoption of new varieties may also generate other non-quantified benefits, though these were not quantified by the researchers (*ibid*).

The CGIAR estimated the **poverty impacts of improved varieties** in Rwanda and Uganda in 2011 by aggregating household level data to the market level and estimating the differences between the counterfactual and actual income distributions. While the magnitude of poverty impacts from improved varieties were found to be relatively small (between 0.4 and 0.1%), the study found that some households in both countries were able to escape poverty by adopting improved bean varieties (Larochelle et al, 2014). It is noted that the methods used to estimate poverty impacts are limited, as only the growing year of 2011 was considered, and a distinction was made in which release dates to include, such that the measured adoption rate dropped by half, thus reducing potential impacts of crop varietal technology (*ibid*).

The Malawi Seed Industry Development Project, focused on providing high-quality groundnut, pigeonpea and bean seeds, was carried out with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Malawi government, with support from IrishAid, to diversify predominantly maize and tobacco-based production systems and address food insecurity felt by farmers and boost farm income. Since 2008, direct engagement along the seed value chain has sought to develop the capacity of local seed companies and seed saving by farmers, improve the policy environment for the seed trade and commercial distribution network for improved seeds, and engage with farmer associations that reach smallholders and contract farmers. The success of the project in boosting legume production and thereby improving food security and farm income has resulted in legumes now being a key feature of the National Export Strategy and Malawi's Presidential Initiative on Poverty and Hunger Reduction, which has a special component on legumes (Sichal at al, 2013). The results directly reached at least 2.2 million households in providing legume seed. The projected impact of seed provision includes coverage of 128,000 ha of land, representing roughly 33% of cropped area under groundnut and pigeonpea in Malawi. Results also included estimated revenue increases of US$54 million from seed and grain sales into the cash economy, and US$30 million worth of grain from legumes consumed on-farm, according to a government spokesperson (ICRISAT, 2014).

Public-private partnerships have been instrumental to link market development and policy coherence for improved seed uptake. ICRISAT's Malawi Seed Industry Development Project created a partnership with the Malawi Government's Farm Inputs Subsidy Programme (FISP), to promote crop diversification and increase use of certified seed among farmers. During the 2010-2011 farm season, the FISP provided smallholder farmers with vouchers for 2kg of certified improved legume seeds from participating merchants, and reached 395,000 farmers after four years (Sichal et al, 2013). From 2000, Nigeria has experienced increased planted area and productivity of cowpea due to improved seed varieties, distribution of insecticides, storage systems including the Purdue Improved Cowpea Storage (PICS) bags, and strong markets and prices. Efforts to promote improved and new varieties, and several related development projects focusing on improved crop-livestock integration, including Purdue, BMZ, AGRA and Gatsby projects, had success. However, cowpea production still does not meet demand, and Nigeria imports cowpea during significant times of the year (Rusike et al, 2013).

The Alliance for a Green Revolution in Africa (AGRA), and the Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA), are facilitating positive changes in the regulatory regimes of individual countries and regions. This work enables global initiatives seeking sustained and inclusive agricultural growth through better alignment between government and private sector interests like the New Alliance for Food Security and Nutrition and Grow Africa to be successful. Further, ACTESA has been working to develop seed sector policy that is harmonized across the region.

Barriers to technology and improved seed uptake

Anecdotal evidence in Rwanda points to the value of providing farmers in Rwanda with low cost microbial inoculants to boost nitrogen fixation. One Acre Fund, working with with N2Africa, found this intervention cut fertilizer use by farmers in half while maintaining yields (which would carry significant environmental benefits as well). The inoculants only cost a modest USD$1 per farmer and resulted in a doubling of farmer profits and reduced reliance on chemical fertilizer. One Acre Fund is building on this Rwandan example to expand this program both within Rwanda and in other countries in East Africa (Guerena, 2015). Observations from the CGIAR DIIVA project points to evidence from Uganda that showed that poorer bean-producing households are less likely to adopt the new bean varieties, which the CGIAR suggests could be overcome that if poorer producers can gain access to better bean technologies. This assertion may be based on the experience in Rwanda of more available agricultural extension services in most regions of the country, which favors the spread of new varieties (SPIA, 2014). However, Larochelle et al also note that low sales prices of beans in Rwanda also attenuate the poverty impact of technology and improved bean variety adoption (Larochelle et al, 2014). Further constraints on Rwandan bean production include the lack of supply systems and lack of coordination in the markets (such as market information for farmers and lack of standard measures), limited post-harvest storage facilities, the high opportunity cost of land, competition from crops that are more profitable, and the limited technical and financial capacity of farmers to organize cooperatives (Rusike et al, 2013).

Despite the significant economic benefit of increased income from fusarium-resistant pigeonpea varieties grown in semi-arid Tanzania (income increases of 80%), many farmers in the growing areas did not adopt the disease-resistant varieties mainly due to inadequate local supply of seed and access to agronomic information. As seed requirements for pigeonpea are small and farmers reported being able to buy the required seed, **access to finance and credit was not a limiting factor in pursuing disease-resistant pigeonpea seed**. Findings indicated that **participation in informal seed networks, on-farm variety selection, farm size and ownership of household transport assets increased the likelihood of farmers to pursue improved seed** (Shiferaw et al, 2008).

Export dimensions

In Malawi, Mozambique and Zimbabwe, cowpea value chains are dominated by a subsistence production and consumption pathway. In Ghana, excess demand for cowpea, groundnut and soybean in Ghana drives cross border trade flows along export corridors from foodsheds in Togo (Northern part), Burkina Faso (Pouytenga and Bobo-Dioulasso), Benin, Niger and Cote D'Ivoire (Korhogo). Because most of the cowpeas entering commercial trade are directly consumed by households as a food staple, the bulk of cowpeas are moved from the surplus producing areas to consumption centers by traders via truck. There is no formal industrial processing of cowpea and large traders do not buy cowpea unless they are procuring for large scale processors when they get contracts to supply cowpea-maize blended flour to the World Food Program ‘Purchase for Progress’ which distributes it through school and refugee feeding programs (Rusike et al, 2013).

Uganda has been a consistent net exporter of dry beans to eastern and southern Africa, and yet adopted rates of improved seed is lower than in Rwanda. In contrast, Rwanda has only recently entered the bean export market in 2005, and continues to import dry beans as needed to meet domestic demand, fluctuating between being a net importer and a net exporter of beans (Larochelle et al, 2014). Tanzania is one of the major growers and exporters of pigeonpea in eastern Africa, exporting 30,000–40,000 tons/year to India (Shiferaw et al, 2008).

Promoting export crops that do not compete with domestic food production is as crucial for food security as it is for realizing economic benefits. Rwanda’s PSTA III prioritizes French bean for improved production for export markets (Rwanda, 2013), which may be strategically beneficial, as production of French bean is less likely to compete with food crops for domestic use, and also may command higher prices. However Rwanda may need to import more preferred pulse crops to meet domestic demand. Farmers in Rwanda are noted for having higher unit production costs compared to growers in DRC and Uganda, making Rwandan cowpea uncompetitive pricewise with growers in neighboring countries (Rusike et al, 2013). Rwanda may need to keep domestic cowpea production serving domestic demand, or entice farmers to move into export crops that can be sold at margins well above Rwanda’s import needs. The risk, however, is decreased food security if market dynamics or prices change.

A four-year project seeking to create new business models for sustainable trade relationships in white pea bean production in Ethiopia **demonstrated the feasibility of building production and economic returns for an export crop, without impacting local food production**. White pea beans are not widely consumed locally in Ethiopia, as they are not part of the traditional diet. Bean production is a short-duration crop, well-suited to the low rainfall conditions in the regions, and provides much-needed cash during the leaner time of the year, between September and March. Farmers received training on improved practices, including use of improved seed, planting rows at specific densities, timely weeding, harvesting and in-field drying, threshing on canvas and not on the ground, and cleaning seed. Farmers were also able to access micro-finance for buying improved seed, with payback provisions at the end of the growing season. Results were strong: farming families earned about twice as much selling white pea beans for export than they would have obtained from sorghum, the second most commonly grown crop in the region. A total of 4,746 family farms (and 24,000 family members) increased their profit by US$164-$227 per household, and more than doubled yields. The income from beans represented a significant portion of household income (15 – 20%) and provided families with a means of buying cheaper food in the local market. Their income from beans increased from US$160 to $230 on an average half-hectare plot. By the end of the four years, the project supplied 15,000 farmers with improved seed, productivity increased from 0.7 MT/ha to 1.4 MT/ha, disease pressures were reduced, and efforts with UK retailers for supply chain development and export market access were matured. However, the impact and outcomes of the supply chain and market access interventions of the project were weakened by drought, personnel changes within the UK purchasing company, economic recession, and changes to the Ethiopian bean supply chain with the creation of a new commodity exchange, which blocked direct trading relationships (Ferris et al, 2012).

4. A framework: evaluating multiple benefits of pulse production

The framework below is intended to define the elements of sustainability to be measured or evaluated in any given context, given the diversity between cropping areas and geographic contexts of suitable pulse growing areas. It is also intended to provide a means to evaluate the potential sustainability contributions of pulses should they be brought into a cropping system, or as a means to increase crop rotations. The development of the framework is based on the literature review and two case studies in this report. It is not intended to replace a production standard or product certification scheme[6] that producers could apply at the production level, but would certainly complement and add to such performance measures. Each criterion or key element contains a set of questions to guide evaluation of the sustainability of interventions, including common trade-offs that have been observed. The questions should be adapted to local circumstances or to the appropriate scale, and are intended as a starting point, rather than a complete set of filters to test interventions against.

This framework seeks to identify the scales at which sustainability attributes of a pulse crop, or adding pulses into rotations, can be understood and evaluated. The environmental, social and economic benefits (and risks or trade-offs) of pulse production occur at various scales (refer to Figure 3). Of course, sustainability attributes can occur at multiple scales, such as increased income benefitting farmers and regional/national economies, or nitrogen fixation increasing cereal crop yields and reducing a farmer's reliance on fertilizer which also carries global benefits through reduced N_2O emissions. Efforts to increase pulse production will be well served if accompanied by measures to evaluate environmental, social and economic benefits at all relevant scales.

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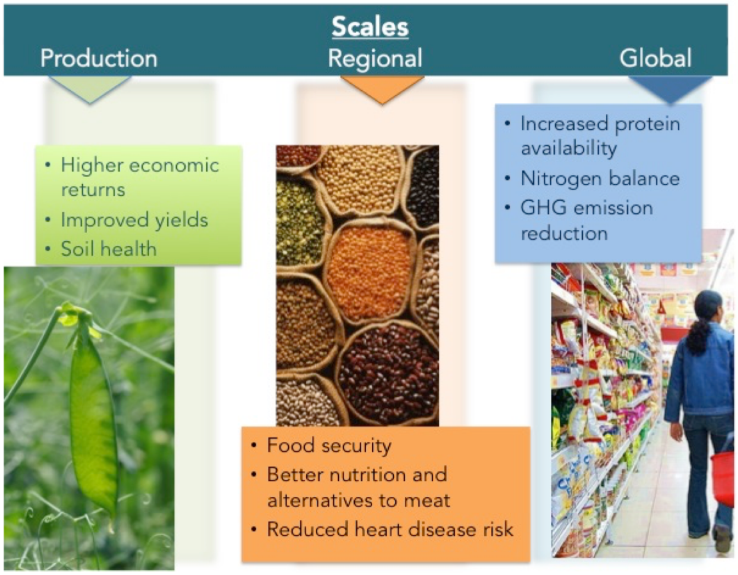
[6] Examples include the SAN's Sustainable Agriculture Standard, GLOBALG.A.P. and others.

Figure 4: Attributes of pulse crop sustainability at various scales



Source: Author generated

Table 2: Summary of criteria and guiding questions to evaluate the economic, social and environmental benefits of pulse production

Environment		
Criterion or key attribute	Question to guide evaluation of impact/benefit	Sources/case study elements + Trade-offs
Ability of pulse crop to offset fertilizer needs within cropping system	• Choice of the pulse crop – based on nitrogen fixation rates, market demand, farmer familiarity, etc. • Does the crop sequence in the rotation ensure maximum transfer of nitrogen to subsequent crop? • After pulses are added to the rotation, can timing and amounts of fertilizer be further optimized? • Other nutrient management strategies in place? • Are rhizobium innoculants sufficient to ensure maximum nodulation? • Can the treatment of crop residues be optimized for nitrogen benefits?	• Choice of pulse crop has economic and social dimensions • The global effects of overuse of synthetic fertilizers is of high concern (Canfield et al, 2010) • Nitrogen for subsequent field crop well documented in Saskatchewan and south-eastern Australia
Ability of pulse crop to offset or reduce herbicide and pesticide use	• Can management practices be moderated to optimize use of herbicides (noting that a transition period may be necessary)?	• Shifts in tillage requires transition time, herbicide use may increase before then decreasing over time (has been observed in Saskatchewan (Brandt, 2010))
Diversify the cropping sequence	• Will the addition of a pulse crop minimize competition with other crops for moisture and nutrients?	• Diversifying cropping sequences can be maximized to deliver social and economic outcomes, beyond environmental ones.

	• Does the addition of the pulse crop result in a reduction of tillage and soil disturbance?	
Productivity improvements rather than area expansion	• Can yield increases be realized without spatial expansion, in the short- and long-term?	• Ethiopia's rise in chickpea production (Ethiopia, 2015b) • Ghana cowpea production (Rusike et al, 2013).
Applications to improve livestock pasture	• Are there livestock feed applications to improve pasture? • How to maximize nitrogen benefits to soil? • Will it improve nutritional value for livestock?	• Balancing livestock production and food security through pulses: Nulik et al (2013); Anderson, et al (2007)
Ability of pulse crop to reduce GHG emissions	• Reduced tillage (soil carbon emissions) • Reduced fertilizer use (reduced energy input and reduced N_2O emissions) and increased yields • Can altered rotations or intercropping sequences and timing maximize nitrogen benefits? • If pulse fractions are being considered in manufactured foods, does the pulse fraction ensure lower GHG emissions?	• Indications are that the more often a pulse crop is grown in rotation, the more GHG emissions are reduced (Lemke et al, 2007). • Note that pea protein fraction production was modeled to have a 60% decrease in GHG emissions and a 52% decrease in non-renewable energy when compared to soy protein isolate production. However, pea starch does not carry such benefits; rather GHG emissions increase.
Reduced non-renewable energy use	• Reduced tillage requires less mechanized equipment use and fuel	• LCA analysis: McWilliam et al (2011) • Note that the LCA analysis identifies dry pea ethanol to not be comparable to wheat ethanol, so use in biofuels is limited
Water use efficiency and management	• Can the pulse crop take advantage of residual moisture and not compete with food crops for water and nutrients?	• Nulik et al (2013): growing pulses for forage in the shoulder season, when land is fallowed
Improved soil management	• Minimized pulse cropping on highly erodible soils; minimize or eliminate tillage	• Is dependent on ascertaining local conditions; pulses have been shown to perform well in poor soils, and can improve soils if managed well

Social

Criterion or key attribute	Question to guide evaluation of impact/benefit	Sources/case study elements + Trade-off's
Food security	• What further practice and yields improvements be made with existing pulse varieties? • Can the introduction of pulses into cropping systems benefit existing food crops? • If introducing a pulse crop for export, how to ensure it does not negatively impact local food security? • How can value chains be supported and developed for a solid balance between improved market access and increased on-farm pulse consumption?	• In Rwanda, household dietary diversity scores increased as improved seed rates increased (Larochelle and Alwang, 2014). • Malawi (ICRISAT, 2014)
The addition of pulses in the diet boosts nutrition	• Pulses provide greatest benefit to diets when combined with other foods. How to educate consumers on the best combinations? • How to promote pulses as a tasty and sustainable alternative to meat?	• de Jager, (2013); Rusike et al (2013) • Pulses regulates blood sugar levels, improves glycemia and plasma lipids. When eaten with cereals, adds proteins, minerals and B vitamins, and essential amino acid lysine. Legume leaves can also be eaten.
The addition of pulses in the diet reduces likelihood of disease	• What are the best ways (media, targets, message) to promote awareness of the health benefits of pulses?	• Dworatzek et al (2013) and Canadian Diabetes Association • Reduces blood cholesterol levels and cardiovascular disease risk, lowers blood pressure
Protein content of a cereal crop increases	• What are the specific conditions that can maximize the boosting of protein content of the subsequent (likely cereal) crop?	• Saskatchewan life-cycle analysis (McWilliam et al, 2011)

following a pulse crop		• This factor is not independent from water supply in the case of Saskatchewan lentil added to rotations (Gan et al, 2014)
Multiple uses of crop residues	• Can crop residues be used for alternative uses, without decreasing necessary biomass to restore soils and maintain nitrogen balance?	• Shiferaw et al (2008)
Reducing pressures of increased meat production	• How to promote consumer awareness of healthy alternatives to meat, and increase use of fractions? • Adding pulses to livestock diets improves pastures and quality of livestock	• Improved forage and pasture in the US Great Plains (Anderson, et al, 2007) and Indonesia (Nulik et al, 2013)
Boosting nutritional content of manufactured foods	• Can pulse factions be effectively incorporated into processed foods? • How can the food industry develop market legume products given the higher raw input prices of legumes vs cereals?	• Important to ensure pulse production for fractions and export markets does not risk local food security
Increase global and regional production of crops with climate adaptation capability	• How can adding pulses into rotations not compete with other crops for water and nutrients, while maximizing climate adaptability? • Can locally-adapted pulse varieties and varieties bred for adaptability be promoted?	
Women's role in production, processing and sales	• Women have a meaningful role in the value chain, as well as managing profits to feed families and/or support income-generating activities. How can their engagement be supported and promoted?	• In some countries, women's role in pulse value chains directly impacts food security, household income and livelihood dimensions

Getting the enabling environment right for pulses	• How to create the research, technical and extension support to improve production practices? • How to promote partnerships to link farmers to viable markets and promote trade, without risking food security or increasing dependency on imports? • Public-Private-Partnerships to make the policy and private sector connection • Are pulses prioritized in agriculture sector plans? How can benefits from pulses be understood by policy makers?	• Rwanda prioritizes pulses in Ag sector plan • Despite its significance to the Indian diet, production support, market price controls and import tariffs have not been maximized for environmental and societal benefits • Harmonized seed sector policy: Alliance for a Green Revolution in Africa (AGRA) + Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA)

Economic

Criterion or key attribute	Question to guide evaluation of impact/benefit	Sources/case study elements + Trade-off's
Lower fuel costs	• How can use of mechanized equipment be decreased or minimized?	• Argentina no-till (Lorenzatti, 2006) • Saskatchewan (McWilliam et al, 2011)
Labour productivity	• What is the most efficient way to introduce pulses into the existing rotation cycle, to maximize labour use? • How can changes in labour requirements maximize benefits to farmers (e.g. time to cultivate other crops, providing reliable sources of income)	• Argentina (Lorenzatti, 2006) • Rwanda (Larochelle and Alwang, 2014). • Benin (Maliki et al, 2012).
Increased income from added rotation + financial	• How to a crop mix and rotation sequence with the highest return on investment? • In regions where pulses are unfamiliar or known risks are high, how can farmers receive assistance (improved practices, improved seed, low-interest	• Increased input costs offset by increased profits (Zenter et al, 2002; McWilliam et al, 2011) • Farmers doubled income in India from improved management practices (Shah, 2011)

contribution of pulse crop	loans to offset risk) to increase likelihood of incorporating pulses into their rotations?	• Variability in market pricing and pulse crop type can strongly influence profitability (McWilliam et al, 2011) • Pulses increase income except when pulse prices are low and grain and oilseed prices are high (ibid)
Increased income from higher yield on subsequent crop	• How to decrease risk of nutrient competition or suppression, and maximize the nitrogen benefits from the pulse crop to the subsequent crop?	• Grains in Australia, US and Canada; yams in Ghana • There are differences in yield possibilities depending on whether pulses are intercropped or added to rotations
Lower costs due to conservation tillage or no-tillage practices	• If changes in tillage frequency, lower fuel and/or labour costs are present.	• Herbicides use may increase as mechanized tillage is reduced. • May depend on soil types and localized conditions
Avoided costs of less soil, air and water degradation	• How can long-term benefits of pulse production be best understood in economic terms? Avoided costs of soil and ecosystem degradation can be significant.	• Hard to estimate these. • Life-cycle analyses help frame scope and scale (McWilliam et al, 2011)
Investments in crop research have high rates of return	• How can research of improved practices and seed best be disseminated for maximum public and private benefit?	• 1% levy on Saskatchewan pulse sales and investments made by Saskatchewan Pulse Growers • CGIAR (SPIA, 2014)
Livestock forage system intensification	• How can livestock forage system intensification occur with least downside risk?	• Dependent on market pricing and labour use efficiencies

5. Applying the framework for decision support

The framework defines elements of sustainability that can guide evaluation of the economic, social and environmental benefits and/or trade-offs of pulse production, or adding pulses into crop rotations. In order to better understand how the framework can be applied, this section defines its application within the context of hypothetical decision cases. These are real-world decision points that the food sector, pulse producers, or governments, are likely to engage in the pulse production context. These hypothetical action steps (columns 1 and 2 in Table 3) are adapted from Negra's (2015) distillation of key messages from the scientific literature of relevance to key audience groups, which is a complementary knowledge product to this one, also commissioned under the auspices of the International Year of Pulses.

This application of the framework to the hypothetical action steps below is intended as initial guidance only, and presents some overarching decision-support and questions for further investigation related to qualitative and quantitative answers to test performance along key environmental, social and economic indicators. These must be designed to suit the unique circumstances in whatever production region is being evaluated, and suited to whatever management objectives might already be in place (e.g. adherence to a production standard, adherence to national laws, etc.). Again, the framework is not intended to replace a production standard or product certification scheme, but will add dimensions that are unique to the pulse production context. The overview of framework elements that apply to each action area in the tables below are not a comprehensive listing of all that would apply, but rather indicative of the general areas to cover. This application helps define how sustainability attributes must be tested at the three scales—production level, regional level and global level. This is intended as a rudimentary starting point, and applying this in real contexts would require a much finer and detailed assessment, with decision-support guidance for all criteria/attributes necessary for measuring performance against, and how those criteria/attributes should apply in each of the three scales. Effective evaluation of performance and how to balance trade-offs can only be made through more detailed assessment.

Table 3: Application of the framework to food sector actors (pulse manufacturers, suppliers and traders)

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Increase use of pulses in product lines	▪ Boost customer demand through awareness raising and diversification in product lines ▪ Increase the use of pulse flour blended into manufactured foods (fractions) ▪ Increase manufacturers' understanding of how to use pulses.	➢ **Environmental**: All environmental criteria and attributes in the framework should be evaluated to identify which ones are relevant, and at what levels in the supply chain they can be tracked or influenced (sourcing directly from a region will increase likelihood of influencing producers directly) ➢ **Social**: Same – almost all framework criteria and attributes should apply. Work with suppliers and producers to obtain performance measures. ➢ **Economic**: Same – almost all framework criteria and attributes should apply. Work with suppliers and producers to obtain performance measures.	➢ **Production**: Do practices in the producing region minimize environmental and social costs, while promoting environmental (e.g. good nutrient management strategies) and social benefits (e.g. food security)? Is a production standard in place or best practices being applied? ➢ **Regional**: What elements of regional value need can be accounted for, such as water use efficiency and management? Are food security benefits and economic trade-offs minimized at the regional scale? ➢ **Global**: Does the action promote use of nitrogen-rich and protein-rich plant foods, while displacing or diversifying from nitrogen-depleting and protein-rich animal foods? Net reduction in non-renewable energy use and GHG emissions at the production level, and emissions minimized throughout the supply chain?

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Source sustainably produced, high quality, traceable pulses	▪ (*company-level*) Develop sustainable sourcing criteria. ▪ Build monitoring into business operations (e.g., HACCP) ▪ (*sector-level*) Agree on credible sustainability indicators / standards and verification mechanisms through platforms for cooperative market action.	➢ **Environmental**: Do crop rotations maximize nitrogen and nutrient management options for maximum yield and maximum long-term soil health? Are production standards or best management practices in place? What criteria in addition to the standard should be measured (e.g. fuel use, diversification of the cropping sequence, integration of livestock, etc.)? ➢ **Social**: If a production standard is in place, what social criteria apply? What additional social criteria can be attained (e.g. measures for nutrition and food security, gender equity in the supply chain, consumer awareness of the range of sustainability benefits, etc.) ➢ **Economic**: Is labour productivity maximized, farmer income increased, fuel and associated costs decreased?	➢ **Production**: Is the provenance known and traceability clear? Can environmental, social and economic benefits be measured at the production scale? Are economic benefits maximized at the producer level from best management practices (technical assistance provided and premiums paid to farmers) ➢ **Regional**: Can environmental, social and economic benefits and trade-offs be measured in the supply chain? Are water use efficiency and management, and nutrient management optimized? Adequate investments made in post-harvest storage and market efficiency? ➢ **Global**: Increased consumer awareness of the environmental and social benefits of pulse consumption, including certified products? Net reduction in non-renewable energy use and GHG emissions? Increased plant-based protein availability?

Table 4: Application of the framework to pulse producers (both small and large-scale)

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Integrate pulses into farming systems	▪ Identify, acquire, and use appropriate pulse varieties, production practices, and mechanical options to optimize system productivity.	➢ **Environmental**: Can the crop sequence in the rotation ensure maximum transfer of nitrogen to subsequent crops? How can the treatment of crop residues be optimized for nitrogen benefits? Can yield increases be realized without spatial expansion? Can the pulse crop take advantage of residual moisture and not compete with food crops for water and nutrients? ➢ **Social**: Would pulses contribute to increased food security? How to best promote the protein contributions of the pulse crop to the subsequent cereal crop? How to optimize crop residue use (trade-off: use for livestock may mean less return to soils)? How can gender benefits be maximized (women have meaningful role in supply chain and management of profits)? ➢ **Economic**: How can changes in production costs be understood (pulse production may carry higher costs, but the net return on investment after the harvest is sold may be higher than for cereal crops)? Is there increased income from introduction of the pulse crop in rotation? How can labour productivity be maximized? Can the risk of nutrient competition or suppression between crops be minimized, in order to maximize the nitrogen benefits from the pulse crop to the subsequent crop?	➢ Production: Can herbicide and fertilizer use be optimized and overall use decreased? ➢ Regional: Are the social and economic impacts of adding pulses well understood, and positive benefits maximized? Efficient water use and management? Can locally-adapted pulse varieties and varieties bred for adaptability be promoted? ➢ Global: Does the increase in pulse production provide more plant-based protein and improved net nitrogen management? Net reduction in non-renewable energy use and GHG emissions?

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Adopt and report on sustainable production practices/certification	• Learn and apply recommended practices to optimize farm system and landscape sustainability. • Understand buyers' reporting expectations; build monitoring into farm operations. • Help to develop sustainability standards and feasible reporting processes; advocate for price premiums or preferred market access for verified sustainable products.	➢ **Environmental**: Are production standards and certification in place? Some certification systems promote the increased use of fallow areas, whereas increasing pulse crops in rotations usually means less fallow; are these trade-offs qualitatively understood, and will there be net benefits to soil health by introducing pulses? What other nuances of pulse production may not be best evaluated by the standard (e.g. GHG emissions, tillage and crop sequencing)? What aspects of sustainability beyond the production unit should be brought into key performance indicators (KPIs)? ➢ **Social**: Does the standard include a social component? Based on the framework, adopt those that fit the context. ➢ **Economic**: Some standards consider economic trade-offs (such as pesticide use versus crop losses or cost of mitigation). What are the economic attributes in the pulse framework that the standard omits?	➢ **Production**: Methods to optimize fertilizer and nutrient management, minimization of herbicide use and phased approach especially if tillage practices are altered. Social aspects addressed including fair distribution of profits (in supply chain), gender, labour use efficiency, decreased dependence on non-renewable fuels (relates to tillage), options for livestock integration and forest intensification. Can avoided costs due to less soil, air and water degradation be quantified? ➢ **Regional**: Avoided costs due to less soil, air and water degradation have regional implications. Is regional food security improved? Water use efficiency and nutrient management will have regional implications. ➢ **Global**: Improved practices results in longer-term soil integrity (a global resource) and improved nitrogen balance.

Table 5: Application of the framework to governments (policy makers in pulse producing (or suitable) jurisdictions)

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Invest in R&D and extension services	▪ Fund research on productivity, sustainability, and risk reduction. ▪ Provide training and resources to promote sustainable pulse production across diverse farming systems.	➢ **Environmental**: Can multi-year research on soils (nutrients and management), nitrogen, crop sequencing, tillage practices, crop-livestock integration, and yield improvement without crop expansion be supported? Given the focus on investment already in plant genetics and yield improvement, how can underfunded areas such as extension services, and new innovations in public-private partnerships be promoted? ➢ **Social**: How can investments in R&D help develop indicators and measures of the social benefits of pulses? How can extension services help rural producers evaluate benefits and trade-offs of crop residue use (affects soils, livestock, etc.) promote gender equity (or better understand gender inequity)? ➢ **Economic**: How can producer market price support, import or export tariffs, and other measures maximize domestic and international food security and economic returns simultaneously, without undue risk if volatility in market prices occurs?	➢ **Production**: Practices at production levels improve if already producing pulses and if integrating pulses into rotations, have research and support to optimize pulse crop and varieties without impacting other key crop yields; farmers are supported in transitions in crop residue management and tillage practices; more is documented and analytics are supplied to farmers to help troubleshoot trade-offs and recognize how to maximize labour use efficiency, lower fuel and input costs, and maximize sustainable yields. ➢ **Regional**: Livelihood, community, nutrition, food security benefits may be hard to quantify, yet significant. ➢ **Global**: Avoided costs of less soil, air and water degradation may be hard to estimate, but should be part of measuring R&D impacts.

Potential action	*Examples of sub-activities*	*Framework elements that apply*	*Scales to measure performance or impact*
Invest in planning and infrastructure and develop supportive policies	▪ Establish / modernize transport, storage, and processing facilities. ▪ Build land use monitoring systems and local and regional capacity for spatial planning and contribute data to global statistics. ▪ Revise agriculture, food, and climate change policies (e.g., MRLs, land tenure, cereal subsidies, purchasing programs) and facilitate financing to promote sustainable pulse production.	➢ **Environmental**: Multiple environmental benefits realized, such as decreased non-renewable fuel use and GHG emission minimization. Production increases are through yield improvements and increased crop rotations on a sustainable basis, not area expansion, and access to markets and information is facilitated. ➢ **Social**: Quality of food is enhanced through better post-harvest storage, improved access to markets. How to support domestic food security, while promoting export market access? Public-private partnerships to maximize public value and private sector investment? ➢ **Economic**: Production increases due to investments, so increased profits at all scales of supply chain? Post-harvest loss is minimized and quality of product brought to market is improved, exports are increased without risking domestic food security.	➢ **Production**: Farmers have better tools to adapt to climate/ market/economic circumstances through improved information and can more easily access markets. Access to fiscal incentives based on sustainable practices. ➢ **Regional**: Improved efficiency in markets, enabled by supportive policies, positively affects income levels. Food security and nutrition improvements at farm and regional/national scales should be enabled. Check for appropriately spreading value capture through supply chain, policies support gender equity. Appropriate water and soil management to support production increases. ➢ **Global**: Net GHG emission reduction, macro-scale diversification in plant-based proteins.

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