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).

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 CO₂eq 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
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 CO₂eq, 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.

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).