AN ABSTRACT OF THE FINAL REPORT OF

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Title: Connections between Science and Business to Increase Environmentally-Friendly Food Production

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Abstract approved:

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This study represents an internship, as a requirement of the Professional Science Masters program at Oregon State University, performed with Western Ag Innovations Inc. The study consisted of two aspects -- one business and one science oriented. The two objectives of this internship were to: 1) qualitatively evaluate how two agrarian groups, Pesticide-Free Production Farmer's Cooperative and Shepherd's Grain, benefit from environmentally-friendly production and certification; and 2) quantitatively determine the belowground soil nutrient supply dynamics of intercropping pea with wheat using PRS^{TM}-probes in a dryland agricultural region of Northeastern Oregon.

The agrarian group Shepherd's Grain (SG) is located in the Pacific Northwest (PNW), USA, and the Pesticide-Free Production (PFP) Farmer's co-op was centered in the Western Canadian prairies. These food producers were changing from production-oriented models to consumer-driven systems by acquiring eco-friendly production certification in order to access niche markets. SG was successful while the PFP Farmer's co-op was unable to find value-added markets for their commodity products. A comparative case study was conducted to compare and contrast the two agrarian groups with regard to organizational structure and third-party certification. This study identified several factors contributing to the success or the failure of the agrarian groups. The major factors for success were establishing contracts with consumers and preserving the identity of food products. Effective direct marketing to consumers -- with a clear message backed by eco-friendly certification, to initiate market demand for branded products -- was critical. By comparing SG and the PFP Farmer's co-op, I found that market incentives can promote environmentally-friendly agricultural practices for sustainable crop production and increase farm profitability. This is consistent with present trends in agricultural production, which are driven by consumer demand for increased transparency and sustainable food production.

Plant Root Simulator^{TM} (PRS^{TM})-probes sold commercially by Western Ag Innovations in Saskatoon, Canada, were used to quantitatively determine nutrient supply rates in a dryland intercropping wheat-pea system. Intercropping is an agriculture system that is not practiced in the PNW of the USA. However, intercropping has the potential to serve as a tool for increasing environmentally-friendly agricultural practices. PRS^{TM}-probes are not used extensively in PNW dryland cropping systems either. The purpose of this research was to determine the potential benefits of intercropping by using the PRS^{TM}-probes as a diagnostic tool. PRS^{TM}-probes were used to measure nutrient supply rates within established agronomic trials at Pendleton, OR. PRS^{TM}-probes showed an increase in nitrogen (N) supply associated with the observed grain yield response to N fertilizer. Similarly, PRS^{TM}-probes did not show a difference in nutrient supply for

intercropping treatments when no grain yield response was observed. In general, intercropping did not benefit grain yield in this dryland agricultural system. PRS^{TM}-probe measurements of nutrient supply were related to plant response to N fertilizer and intercropping treatments in a 1-year field experiment.

by

Rebekka M. Rieder

Connections between Science and Business to Increase Environmentally-Friendly Food Production

by

Rebekka Martina Rieder

A FINAL REPORT

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

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Presented November 14, 2008

APPROVED:

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Major Professor, representing Crop and Soil Science

I understand that my final report will become part of the permanent collection of the Oregon State University Professional Science Master's Program. My signature below authorizes release of my final report to any reader upon request.

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Rebekka M. Rieder, Author

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The Professional Science Master's Program

In 2002, Oregon State University launched a new Professional Science Master's (PSM) program. The program offers a unique opportunity to fuse the fundamentals of business management, ethics, and communication with various scientific disciplines. A major component of PSM program is the internship experience requirement in lieu of conducting research and writing a thesis. This aspect of the program was very appealing to me both professionally and personally.

I entered the PSM program for its advantageous combination of communication and business courses with the inter-disciplinary curriculum of the Environmental Sciences Department. In the future, I intend to use my professional and educational experience as a means to serve as a liaison between science, business, and social issues on various projects within soil conservation and agricultural practices realm. Specifically, I would like to work for a non-profit or private consulting company as project manager or coordinator for environmentally-friendly agricultural practices and soil quality improvement projects by combining scientific and business aspects. My internship has given me valuable experience, professional contacts and the knowledge necessary to help me achieve these goals.

I chose this internship for several reasons. I wanted to work with Western Ag Innovations Inc. (Saskatoon, SK, Canada) because I see myself either working for or with a company that is applying research solutions to agriculture and the environment in order to sustain the earth and natural resources in my professional career. I gained insight as to how a small, successful business is structured and operated. I was also interested in working on a project that involved several different stakeholders and provided an opportunity to link soil science and agronomy with social and business aspects. The wheat-pea intercropping research experience combined with the analysis of two agrarian groups did all of those things. The essential objectives and goals of this project allowed me to be a part of the developing interface between science and business concerning agricultural practices. Finally, I wanted my internship to provide an opportunity to understand what is meant by "value-added" environmentally-friendly agricultural practices by combining science and business interests. I accomplished this goal by conducting a field experiment and examining the marketing of value-added crop production in which I gained basic working knowledge of ion-exchange membrane technology for measuring soil nutrient supply, soil fertility, and different agricultural practices.

CHAPTER 1

INTRODUCTION

The discussion of environmentally-friendly agriculture, as presented in this paper, will include agribusiness research promoting environmentally-friendly farming; through different market strategies, driven by consumer demands, for farm outputs. This is done because of the integral interdependence between the production sector and the supply and marketing sectors of modern agribusiness (Beus and Dunlap, 1990).

Agriculture is a business enterprise, incorporating science and technology in the interest of efficient food production. This production utilizes economies of scale to be globally competitive, and trends toward a product manufacturing-industrial model (Boehlje, 2006). At the same time, agriculture and other renewable natural resource-based industries serve as the major stewards of the nation's natural resources. These enterprises hold the vital responsibility for long-term productivity, while simultaneously providing food, fiber, and other biology-based products (Gliessman, 1998).

Agriculture businesses in the 21st Century stand ready for marketing sustainable practices. This is true because there is a trend towards more ecologically sustainable farming, which is driven by an increased awareness of informed and affluent consumers and producers concerned with their health and environmental issues related to foods and food production. Modern commercial agriculture and the food-processing industry are responding by increasingly transitioning from production-oriented models to consumer-driven systems. This provides new market opportunities with standardized products and specific attributes of raw materials for different market demands (Boehlje, 2006; Miller, 2008).

This trend is apparent because food producers are changing to a market-driven sustainability model by acquiring eco-friendly production certification in order to access niche markets. Two such agrarian group examples are Shepherd's Grain and the Pesticide-Free Production Farmer's co-op, which are discussed in detail in this report. In conjunction with increasing environmentally-friendly production, associated agribusinesses are needed to enhance profitability by providing support tools for environmentally-friendly farming. One example of such a tool is the Plant Root Simulator (PRS™)-probe (Western Ag Innovations Inc., Saskatoon, SK, Canada), which is used to provide an index of soil nutrient supply rates. The PRS™-probe is capable of measuring the bioavailability of soil nutrients in response to a cropping system. Soil testing has the potential to help producers minimize the risk of over-fertilization, which can degrade soil and water quality, earning them an eco-friendly certification through protection of natural resources.

The purpose of this PSM internship was to understand how the science and the business/social perspectives are combined to enhance environmental friendly farming practices of commodity products such as wheat and small grains in areas of the Pacific Northwest of the United States and Western Canada. The specific focus is how market incentives can help to promote the use of the best possible agricultural management practices for sustainable crop production and to obtain reasonable rates of return at the farm level. Additionally, an agriculture system -intercropping- was examined which has the potential to serve as a tool for further increasing environmentally-friendly agricultural practices. The two objectives of this internship project included: 1) qualitatively evaluate how two agrarian groups, the Pesticide-Free Production Farmer's co-op and Shepherd's Grain, benefit from environmentally-friendly production and certification; and 2) quantitatively determine the belowground dynamics of intercropping pea with wheat on soil nutrient supply rates, using PRS™-probes, under conventional and direct-seeding in an annual cropping system in the dryland agricultural region of Northeastern Oregon.

1.1 CONCEPT REVIEW

Connections between Science and Business to Increase Environmentally-Friendly Food Production

The concept review is a means to help the reader understand terms, ideas, and perspectives in this report. The concept review will serve to define the terms used throughout this report, which is necessary because concept perspectives, to a large extent, are influenced by the fundamental beliefs of a specific group or organization. This report compares different agricultural methods for cereal and row crops, which are grown in large areas in the Pacific Northwest of the United States and in Western Canada. Furthermore, the review provides information on market differentiation for value-added commodities and the value of environmentally-friendly third-party certification.

1.1.1 Business Perspectives: Increasing Importance of Environmental Sustainability and Efficiency in Agribusiness

The importance of connecting business and science principles is growing because of greater awareness of the need for environmental sustainability and efficiency. The Environmental Defense Fund (2008) looked at how businesses are incorporating environmental considerations, based on scientific verification, into basic business processes in order to create new markets, providing competitive advantages, and generate profits. They concluded that the following environmental benefits can be realized by a business:

- Greenhouse gas emissions reduced (e.g., carbon dioxide, methane, nitrous oxide)
- Energy use reduced or efficiency increased
- Hazardous pollutant releases to air, water or land reduced
- Solid waste reduced, materials use reduced or efficiency increased
- Supplier behavior influenced, resulting in environmental benefits
- Natural resources (land, water or wildlife) protected or restored
- Employee or consumer behavior influenced, resulting in environmental benefits

By considering these environmental considerations, businesses can gain benefits that include:

- Cost savings
- Increased revenues or earnings
- Reduced liability or risk
- Return on investment/payback period
- New market creation
- Investment attractiveness
- Employee retention or recruitment
- Benefits for customers
- Brand/reputation enhancement

An applicable example of linking scientific knowledge with a business application that incorporates environmental considerations and generates profits is the Plant Root Simulator (PRS)™ Nutrient Forecaster computer model. PRS™ Nutrient Forecaster is made commercially available through Western Ag Labs Ltd., a spin-off company from Western Ag Innovations Inc. in Saskatoon, SK, Canada.

This computer software application simulates soil and climate conditions that influence crop growth and yield, coupled with a crop nutrition application in order to maximize the growers' fertilizer investment (e.g., economic cost/benefit analysis). This type of software tool is one of many available tools to help farmers make profitable and sustainable farm-based decisions. The PRS™ Nutrient Forecaster uses the soil nutrient supply measures obtained through the PRS™-probe which is an ion exchange membrane. The PRS™-probe can estimate the bioavailability of soil nutrients by adsorbing positive and negative ions over time (WAII, 2002).

1.1.2 Sustainable (e.g., sustainability, sustain, sustainable, etc.)

The term sustainable encompasses many ideas and concepts. One of the broadest and most widely used concepts is sustainable development, defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" by the World Commission on Environment and Development (1987; as cited in Estes, 1993: pg. 1). The field of sustainable development can be conceptually broken into three parts: environmental, economic, and socio-political sustainability; where sustainability is a characteristic of the process or the state that can be maintained at a certain level indefinitely (Brown, 1991).

When substituting development with agriculture; then sustainable agriculture is meant to reduce environmental degradation, maintain agricultural productivity, promote economic viability over both short and long term, and maintain stable rural communities and quality of life (Brown, 1991). Sustainable agriculture is really a long-term process, not a specific set of farming practices. In practice, there is no single approach to sustainable agriculture, as the particular goals and methods must be adapted to each individual case, which will be influenced by environment, economics, and political settings (Lewis et al., 1997).

1.1.3 Environmentally-Friendly (e.g., environmental, ecological, eco- etc.)

Environmental and ecological sustainability are components of living in harmony with nature and with one another. Environmentally-friendly will be used as a synonym to refer to agricultural goods and services with minimal harm to the environment. Environmentally-friendly agricultural practices therefore imply the awareness of utilizing agricultural management methods that reduce the deteriorating impacts of agriculture on the environment and natural resources.

1.1.4 Agricultural Commodities: U.S. and Canada

Wheat is one of the major and important agricultural commodities grown in the Pacific Northwest (PNW) of the United States and the Prairie Provinces of Canada. Wheat is the third largest crop grown in the United States with an annual average harvest of approximately 2 billion bushels. This accounts for 13% of the world's wheat production and supplies about 25% of the world's wheat export market (EPA, 2008). About two-thirds of total U.S. wheat production is grown in the Great Plains, from Texas to Montana. However, winter wheat varieties are the major dryland crop grown in the PNW. The PNW wheat production area encompasses Oregon, Washington, and Idaho with a production of around 47, 129, and 84 thousand bushels respectively in 2007 (USDA, 2008a). The wheat is exported mainly to the Asian Pacific market.

Grains and oilseeds are the largest agricultural production sector in Canada accounting for 34% of production. The Prairie Provinces including Alberta, Saskatchewan, Manitoba, and the Peace River district of British Columbia are the largest grains and oilseed (wheat, durum, oats, barley, canola, rye, and flaxseed) producing region in Canada, accounting for 82% of total farm cash receipts in this agricultural sector in 1996. Globally, Canada produced 5% of the world's wheat, 17% of the world's rapeseed, 9.9% of the world's barley, 14% of the world's oats, and 1.4% of the world's corn in 1996. Approximately 50% of Canada's cereal production is exported (CFA, 2008).

1.1.5 Agricultural Region, Climate, and Management: US and Canada

The wheat production in the PNW, USA, includes the regions of eastern Washington, northern and southern Idaho, and north central Oregon (Figure 1.1). These dryland cropping regions experience a Mediterranean climate with cold and wet winters and warm to hot dry summers. Rainfall ranges from approximately 200 mm or less per year in the western regions of the area to more than 600 mm near the mountain range in Idaho (Schillinger et al., 2007).

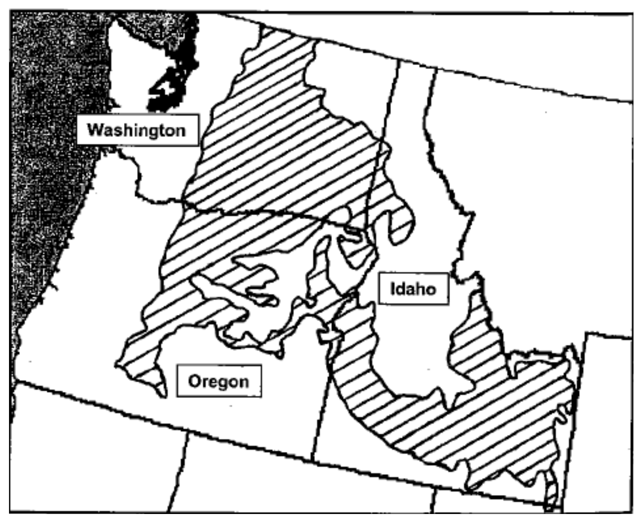

Figure 1.1 Wheat production region of the Pacific Northwest region (source: McCool et al., 1999)

The Canadian prairie encompasses an area of approximately 50 million ha, stretches from the border with the United States to the boreal forest in the north in the provinces of Alberta, Saskatchewan, and Manitoba (Figure 1.2) (Larney et al., 2004). The climate of the prairies is cold and semiarid to sub-humid. The sub-humid regions in the eastern prairies receive up to 500 mm of annual precipitation. Around

50% of the annual precipitation falls during the growing season from May through September, with 30% falling as snow in the winter months (Larney et al., 2004).

In the PNW, much of the cropland has been degraded by wind, water, and/or tillage erosion. The practice of growing one crop every two years in a tillage-intensive winter wheat-summer fallow cropping systems has degraded soils and contributed to environmental problems. Alternatively, to maintain and improve soil quality it is important to increase the cropping intensity (annual cropping), diversity (different types of rotational crops), and reduce or eliminate soil tillage (use conservation tillage) in this non-irrigated agriculture region (McCool et al., 1999; Schillinger et al., 2007).

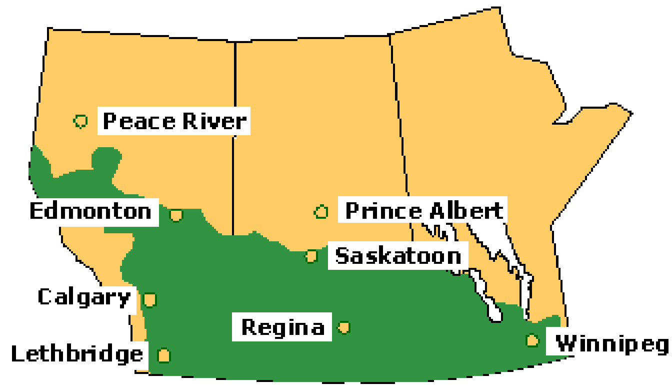

Figure 1.2 Major wheat production region on the Canadian Prairies indicated in green (source: Canadian Grain Commission, 2008)

Similar to the PNW, dryland agriculture on the Canadian prairies has faced severe challenges of soil degradation from drought and wind erosion. Therefore, conservation tillage practices have been widely adopted by farmers in the 1990s. Conservation tillage accounts for approximately 63% of the seeded area of the Canadian prairies. By adopting conservation tillage, the reliance on summer fallow has been reduced and soil quality has improved. As a result, agricultural practices of the widely adapted, traditional, small grain summer fallow systems have evolved into more diverse, annual rotations including oilseed and pulse crops (e.g. canola, mustard, flax, lentil, and field pea); (Zentner et al., 2002; Larney et al., 2004).

However, in the PNW, the traditional winter wheat-summer fallow system continues to dominate. By leaving a field fallow, sufficient soil water can be stored for the next year’s crop in these dryland cropping systems. This practice provides relatively stable grain yields and poses less economic risk compared to wheat or barley grown on an annual basis. As a contrast to Canadian agriculture management, Schillinger et al. (2007) reported that during an eight year field experiment in

Pullman, WA, annual crop rotation that included yellow mustard and safflower were always the poorest economic performers.

The dryland cropping area of Washington occupies nearly 1.8 million ha, of which 18% is under continuous cropping and 82% is under summer fallow. The region known as the Palouse encompasses about 0.8 million ha shared by Washington, Idaho, and Oregon. The continuous cropping area mainly concurs within this region. The Palouse is included in the higher rainfall region of the dryland area (yearly precipitation > 400 mm) and is therefore the most productive dryland area (Schillinger et al., 2007).

This trend can also be observed in Canadian prairies. The benefits of conservation tillage and annual cropping systems are greater in the more humid region because of a yield advantage and greater savings in land preparation costs. Zentner et al. (2002) states that crop rotations with oilseeds and pulses including conservation or no-till practices have higher and less risky returns than monoculture cereal rotations over a 12-yr period.

However, completely eliminating fallow from the rotation is not likely to occur in the near future in either country due to the economic conditions. In the dryer PNW regions, precipitation is not sufficient to support annual cropping and summer fallow is included in most rotations (McCool et al., 1999). The same can be said for more semiarid regions in Canada, where fallow remains important because historically it contributed to higher and more stable farm income and has lower direct costs for purchased inputs such as fertilizer (Zentner et al., 2002).

1.1.6 Market for Value-Added Commodities

The bulk commodity system of agricultural products is changing. The international market for value-added products is growing, which creates opportunities for profitable niche markets (Connor et al., 1997). The "produce-and-then-sell" mentality of the commodity business is being replaced by the strategy of first determining what attributes consumers want in their food products and then creating or manufacturing products with those characteristics (Boehlje, 2006).

Figure 1.3 shows bulk farm commodities flowing into the processing sector through the conventional commodity markets. In the traditional food marketing system, value-added activities occur in the final stages of the agricultural commodity-marketing channel. Conventional marketing for grain production consists of selling to grain elevators, terminal markets, feedlot operators, and other livestock producers**.** In contrast, Figure 1.4 portrays the new food marketing system that targets farm products at the production level in order to create more specific characteristics for different consumer demands. Therefore, farm outputs flow through narrower market channels to meet specific consumer needs (Barkema and Drabenstott, 1995).

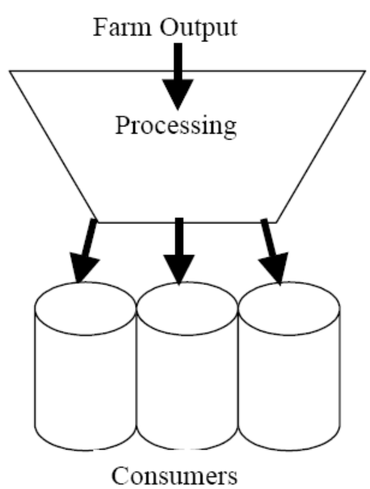

Figure 1.3 The traditional food marketing system.

Source: Barkema and Drabenstott, 1995

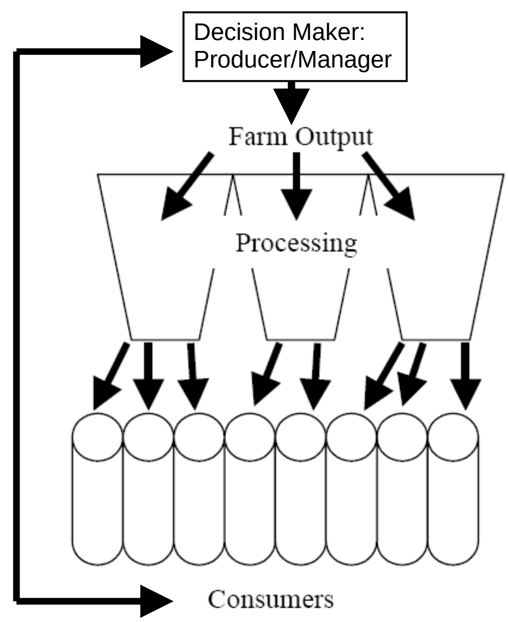

Figure 1.4 The new food marketing system.

The restructuring of the food distribution system to and from the producer can provide opportunities for adding value. Market forces an create greater opportunities for product differentiation and added value to commodity because of: 1) increased consumer demands regarding health, nutrition, and convenience; 2) efforts by food processors to improve productivity; and 3) technological advances that enable producers to produce what consumers and processors desire (Royer, 1995).

"Value-added" is a term describing the economic value of the future profitability of agricultural product or service. A broad definition of value-added is to economically add value to a product or service by changing its current place, time, and form characteristics to suit the demand of the marketplace (Boehlje, 2006). Commodities differ in the level of value-added processing. For example, grass seed crops directly from the field are almost ready for market distribution. On the other hand, raw milk requires preparation, processing, and packaging, especially when it is transformed into cheese products.

Adding value to products can be done through two main approaches: innovation and/or coordination (Kraybill and Johnson, 1989). Innovation focuses on improving existing processes, procedures, products, and services or creating new ones. Often, successful innovation focuses on narrow, highly technical, geographically large markets where competition is sparse. Innovative value-added activities, developed on farms or at agricultural experiment stations, change either in the kind of product or improve the technology of production (Kraybill and Johnson, 1989).

Coordination focuses on cooperation among producers and marketers of farm products. There are two common types of coordination: horizontal and vertical. Horizontal coordination combines of factors of production (land, labor, capital, and management-together with, research, education, and government) in order to produce a distinctive good or service. Vertical coordination pertains, on the other hand, to the system by which products move forward through the marketing sequence to final consumption (Lamont, 1993).

A horizontal market involves pooling or consolidation among individuals or companies at the same level of the food chain. An example would be wheat producers pooling their grain to send a truckload to market. A vertical market is a group of similar businesses and customers that engage in trade, based on specific and specialized needs. Often, participants in a vertical market are limited to a subset of a larger industry (a niche market). Vertical coordination includes contracting, strategic alliances, licensing agreements, and/or single ownership of multiple market stages in different levels of the food chain (Peterson et al., 2001). Horizontal market participants often attempt to meet enough of the different needs of vertical markets to gain a presence in the vertical market. The products tend to be less of a fit for specific consumer demands, but also less expensive and specialized than vertical marketing strategies (Lamont, 1993).

Vertical coordination is done either through ownership integration or contractual arrangements, and is necessary to link production processes and product characteristics to preferences of consumers and processors (Royer, 1995). Few individuals or organizations possess all the different skills necessary for processing, marketing, and business management, as well as staying efficient with their production enterprises. Therefore, a coordinated effort is needed, for example through a cooperative, to increase market efficiency, cost reduction, and/or differentiation (Sporleder, 1992).

Producers who invest in value-added projects past the farm gate (e.g., farmer's market) cause the market to become more vertically integrated. A totally integrated system can provide consistent quality from the field to the shelf, eliminating middlemen and even save money for consumers (O'Neill, 1997). Integration downstream towards consumers commonly involves an equity investment for processing; a popular way do to this is by means of forming a producer cooperative (O'Neill, 1997).

Producers involved with adding value to their products become more than commodity producers. They produce products for end users. They must know their consumers' desires (e.g., target markets), and minimize production cost (O'Neill, 1997).

1.1.7 Market Differentiation and Premium Pricing through Value-Addition

Market differentiation and premium pricing through value-addition can proceed in many different ways. One approach is through environmentally-friendly farming practices since there is a growing demand for food produced with environmentally-friendly techniques. The interest in environmentally-friendly farming can be linked to increased consumer awareness about human health and environmental issues, the deterioration of rural communities, and the concern for food safety. Many producers are looking for ways to be economically viable through voluntary, incentive-based solutions. This typically implies a product price that covers production costs and provides a reasonable return on investment. To achieve an economically viable product, the producer has to differentiate its product so that consumers view it as unique (Hayes et al., 2004).

Adding value to bulk raw commodities through environmentally-friendly differentiation claims is one way for producers to keep a larger share of the margins associated with further processing and/or market development. Progressive producers respond to market developments by adapting to changes that will drive the future of the industry. Growers who own their own brands and control production of branded quantities would not be inclined to minimize on quality or to allow other producers in the cooperative. Farmers can be rewarded for their innovation and coordination in both production and in marketing (Hayes et al., 2004).

This can be achieved through collective reputation by joining a cooperative or other brand recognition group, which sells specialty or regional products (Winfree and McCluskey, 2005). Collective reputation has two main characteristics. First, producers who share a collective reputation on aggregate quality are bound to each others' performance. That is, an entire group of wheat producers can lose consumer trust as a result of one grower's lack of diligence. Second, collective reputation induces price premiums on the market. Several empirical studies show that a positive collective reputation is a good tool to signal quality and is correlated with price premiums (Quagrainie et al., 2003). Price premiums work as incentives for food producers to seek a collective reputation by joining a cooperative or other brand recognition group.

An example of enhancing market differentiation and premium pricing is the legislation by the European Union (E.U.) (EC Regulations 2081/92 and 2082/92: as cited in Loureiro and McCluskey, 2000). This legislation to identify the designation of production systems provides protection of food names on a geographical or traditional basis. In three categories: 1) protected designation of origin (PDO), 2) protected geographical indications (PGI), and 3) certificate of specific character (CSC) (Loureiro and McCluskey, 2000; McCluskey and Loureiro, 2003).

Country-of-origin labeling, which is related to PDO and PGI labeling, is currently being considered in the United States. In the U.S., agencies promote state and locally-grown products such as Washington apples, Idaho potatoes, California peaches, Florida citrus, etc. (Loureiro and McCluskey, 2000; McCluskey and Loureiro, 2003).

The E.U. implemented the legislation for food product identification in an effort to transform a system based on government agriculture- price supports to a system based on income support. Income support is gained by the production of foods that command a premium in the market place by having a PDO, PGI, or CSC certified label (Loureiro and McCluskey, 2000). The E.U. regulations were directed at supporting the rural economy by encouraging diversification of agricultural production, thereby improving farmers' incomes, and retaining population in rural areas. The E.U. regulatory framework provides information and quality assurance to consumers willing to buy high-quality, guaranteed traditional products.

In conclusion, collective reputation can affect markets for quality-differentiated food products, such as environmentally-friendly foods. Examples of collective reputation groups are Shepherd's Grain, Pesticide-Free Production, organic foods, dolphin-safe tuna, free-range meat or eggs etc. As organic and other environmentally-friendly food products with unobservable quality attributes are increasingly marketed, labeling policies are often not sufficient. In these types of markets, which include many of the PGI, PDO, or CSC products, a third-party reputable certification agent can be required (McCluskey, 2000).

1.1.8 Certification

The most common type of certification in modern society is product certification. This refers to the various processes that are used to determine if a product meets minimum standards, similar to quality assurance. Product certification or product qualification is the process of verifying that a certain product has passed performance and/or quality assurance tests or qualification requirements specific to regulations or standards.

1.1.9 Value of Environmentally-Friendly Certification

A common and simplified value formula is: Value = Benefits - Costs[customer]. "Benefits" are features that are desirable to the customer for example, protecting soil resources and decreasing air, water, and soil pollution. "Costs[customer]" are the aggregate expenses sustained by the customer from buying and using the product.

Certification is one of the perceived values attached to a product, making customers believe that what the certified product brand or label is offering will help solve a problem (e.g., reduce environmental degradation) and make customers happy (e.g., can help prevent environmental degradation by purchasing the product). In this case, value can be split into instrumental (or extrinsic) value and intrinsic value.

An instrumental value is worth having as a means of achieving something else that is good. For example, purchasing certified products such as Shepherd's Grain flour with specific attributes, will allow buyers to know where the product is coming from and to support land stewardship. This is of instrumental value because consuming bread made with Shepherd's Grain flour is also directly supporting responsible land stewardship. Intrinsic value has traditionally been thought to lie at the heart of ethics. For example, organic food certification is valuable because it assures the consumer that ecosystem functions are being sustained for future generations.

Certain food quality attributes (value) having environmentally-friendly production and process claims are credence goods (e.g., Shepherd's Grain flour, Pesticide-Free Production) (McCluskey and Loureiro, 2003). Consumer verification for these values attributes can be accomplished through an independent third-party that monitors these claims. Caswell and Mojduszka (1996) argue that quality signaling through product labeling promotes market incentives with relatively limited government involvement. These monitoring and enforcement activities of independent third-parties are an attempt to ensure that the disclosures made are truthful and credible. Consumers also increasingly rely on brand or company reputations as quality guides (Connor et al., 1997). Two specific examples of this are products labeled as "Certified Angus Beef" and "USDA Organic foods", which allows producers to sell food products at a premium price.

1.1.10 National Standards of Certification

A classic example of a national standard certification is the United States Department of Agriculture organic sector. "The National Organic Program (NOP) develops, implements, and administers national production, handling, and labeling standards for organic agricultural products. The NOP also accredits the certifying agents (foreign and domestic) who inspect organic production and handling operations to certify that they meet USDA standards" (USDA, 2008b). Organic foods can be certified under state and private certification programs (e.g., Oregon Tilth) in addition to national USDA organic standards.

The 1990 Organic Food Production Act (OFPA) mandated that the United States Department of Agriculture (USDA) establish national standards for producing and marketing organic food products. According to the USDA (in 2002), organic food is produced without using most conventional pesticides, fertilizers made with synthetic ingredients or sewage sludge, bioengineering, or ionizing radiation. The system mandates certification and federal oversight to ensure truth in labeling of these organic production claims (McCluskey and Loureiro, 2003).

There are tradeoffs involved with setting national standards. Standardization of the term "organic" reduces the costs of monitoring and enforcement. It makes labels easier for consumers to understand. Consumers are benefiting from standardization and increased consumer confidence causing markets to expand and improve market efficiency, which results in lower prices. The main drawback of national standards is the loss of flexibility and incentives for innovation. The point is that government labeling standards do not or only slowly adjust to changes in consumer preferences or technology. Standards can also limit improvements. With a single standard, in general, there is no incentive for quality increases above the standard (Hatanaka et al., 2005).

1.1.11 Third-Party Certification

Third-party certification (TPC) is emerging as a prominent and influential regulatory mechanism in both the public and the private arenas of the current agricultural food system. Private or non-governmental organization (NGO) standards, labels, and certification systems are important mechanisms for providing information to consumers regarding products that are differentiated by a product's physical characteristics and furthermore by it's production practices. Such TPC allows stakeholders to differentiate agricultural food products by diverse attributes that concern them, such as food safety and quality, environmental sustainability, and worker and animal welfare (Hatanaka et al., 2005).

TPC is a scientific (and political) process responsible for assessing, evaluating, and certifying safety and quality claims based on a set of standards and compliance methods. Standards are measures by which products, processes, and producers are judged. Third-party certifiers also appeal to techno-scientific values such as independence, objectivity, and transparency in an attempt to increase trust and legitimacy among their customers, and to limit liability. The process of obtaining TPC typically includes four steps: first, a producer/supplier applies to a particular third-party certifier for certification; second, the third-party certifier conducts a pre-assessment and documentation review of a producer's/supplier's facilities and production operations; third, the third-party certifier conducts field audits; fourth, when compliance is verified, the third-party certifier issues a certification and allows the producer/supplier to label its products as certified. In general, producers are responsible for meeting the costs of the audit (Hatanaka et al., 2005).

TPC can reduce the time and expense needed for identifying, selecting and purchasing products claiming certain attributes. TPC can eliminate the need for governments to create bureaucratic laws and regulations that may restrict market access, safety, and delay the introduction of new technologies. Certifying organizations are concerned with maintaining their reputation and sustaining their integrity and can provide an excellent way to validate marketing claims while protecting consumers from myths, misconceptions, and misleading information. TPC is an important system that can improve social and environmental conditions throughout the food commodity chain (McCluskey, 2000; Hatanaka et al., 2005).

1.1.12 Third-Party Example: Food Alliance

Food Alliance - a third-party certification organization
"Good Food for a Healthy Future"
(www.foodalliance.org)

Food Alliance, a not-for-profit organization based in Portland, Oregon, describes their organization as a promoter of "sustainable agriculture by recognizing and rewarding farmers who produce food in environmentally-friendly and socially responsible ways, and educating consumers and others in the food system about the benefits of sustainable agriculture" (www.foodalliance.org).

Food Alliance started out as a project of Oregon State University, Washington State University, and Washington State Department of Agriculture in 1993. It began its certification program in 1998. Since then, the organization has certified 300 farms and ranches in 20 U.S states, Canada, and Mexico; and 17 food handlers (including 12 food processors and 5 distribution facilities) for sustainable agricultural and business practices.

There are three sustainability criteria a business and/or farm must provide for its product or service: traceability, transparency, and accountability. Food Alliance certification assures that these businesses make credible claims for social and environmental responsibility, to differentiate and add value to products, and to protect and support brand names. Therefore, consumers can be confident they are supporting farmers, ranchers, food processors and distributors with real commitment to environmental stewardship.

Farmers and ranchers must meet Food Alliance standards in order to become certified. These standards include some social and environmental considerations: provide safe and fair working conditions, reduce pesticide use and toxicity, conserve soil and water resources, protect wildlife habitat, ensure healthy and humane care for livestock, and no added-hormones or non-therapeutic antibiotics or genetically modified (GM) crops or livestock are allowed. The final requirement is to continuously improve these practices in order to achieve sustainable production at the farm level. Food Alliance has the only labeling program in the PNW that is defined by farm practices and requires third-party monitoring.

Food Alliance's environmentally-friendly certification standards can help growers develop market differentiation and access niche markets for their non-conventional products. The Food Alliance can "create market incentives" for adoption of sustainable agricultural practices by educating business owners and others involved in the food system (e.g., processors, handlers, consultants, and retailers) about sustainable agriculture and the people and practices that grow food. Food Alliance provides information of sustainable agriculture through news articles and word of mouth, and campaign in grocery stores and annual food events. Food Alliance does not market for growers, instead they work with growers who have marketing and development practices in place. Food Alliance facilitates relationship between grower and retailer and ultimately, consumers. The growers benefit by increased access to markets and product differentiation by branding of environmental sound message, which can gain some price premium. The cost of Food Alliance certification is $400 at the time of application for farmers and it lasts for three years. The grower pays an annual fee to the organization based on the gross of the products sold with Food Alliance certification.

1.2 LITERATURE REVIEW: Science Perspective

The literature review is intended to provide information for the scientific aspect of this report. The literature review introduces intercropping management with a focus on cereal-legume based cropping systems. Furthermore, the review presents intercropping systems as alternative agricultural practices with the potential to increase environmentally-friendly agricultural management. Lastly, the literature review discusses ion-exchange membrane (IEM) technology as a mean to measure soil nutrient availability. The review focuses on a patented form of IEM called a Plant Root Simulator (PRS^{TM})-probe.

1.2.1 Intercropping Systems

Intercropping is one of many crop production methods that embraces ecologically based management and environmentally-friendly faming practices. Intercropping is the agricultural practice of cultivating two or more crops simultaneously on the same field during the same crop year. Intercropping is a form of polyculture, using companion planting principles by making use of resources that would otherwise not be utilized by a single crop, a practice often associated with sustainable agriculture (Sullivan, 2003). Numerous types of intercropping systems exist and they can vary to some degree in the spatial and the temporal overlap in the two or more crops. In intercropping, each of the crops can be harvested for economical return; but there is often one main or cash crop and one or more added crops, where the cash crop is of most importance due to higher economic return (Sullivan, 2003).

Intercropping has been an important production system in tropical regions for many hundreds of years (Sullivan, 2003). Research has focused primarily on the potential of cereal/legume intercrops and has demonstrated a yield benefit over that of sole cropping for species such as maize and bean, maize and soybean, and sorghum and pigeon pea (Haymes and Lee, 1999). The “Three Sisters” is a traditional example of intercropping, in which maize, beans, and squash are grown together; this system was extensively used by indigenous people in North and South

America (Matson et al., 1997). Maize provides support for beans to grow upright, while the beans provide the “nourishment” (nitrogen and phosphorus) for maize and squash. Squash covers the ground with its vigorous foliage protecting the soil and decreasing weed growth.

Intercropping was once common in temperate regions; its use has declined over the past 150 years with the development of monocultures (Francis, 1986). The transfer to monocultures allowed the global cereal production to double over the past 40 years. This was achieved by new technology developments after the 1940s and breeding novel crop cultivars, which are globally utilized. The “Green Revolution” in agriculture after the 1940’s was able to sustain the world population by increasing food production and lowering food prices (Sullivan, 2003). These developments of new technology were adapted for high intensive agricultural management through high rates of synthetic fertilizer applications, irrigation, and chemicals (Tilman et al., 2002).

The “Green Revolution” in agriculture depends on highly non-renewable external inputs and as a result does not support agricultural sustainability (Van Kessle and Hartley, 2000; Robertson and Swinton, 2005; Fox et al., 2007). Furthermore, during the 1990’s to present time, yield increases for major crops have become more difficult and expensive to achieve (Ruttan, 1999; Tilman et al., 2002). This is due to many factors such as increased prices for fossil fuels, physical limits to breeding plants for higher yields, limited fresh water supplies, deteriorating soil quality, and limited arable (Miller, 2008; Stringer, 2008).

The implementation of intercrop systems with cereal and legume crops can decrease fertilizer requirements, and reduce weed and disease pressures. This can result in yield advantages and enhance yield stability and simultaneously improve the use of environmental resources such as light, nutrients, and water (Sullivan, 2003). The renewed interest in intercropping is an indication of interest in sustainable agricultural systems (Tilman et al., 2002; Crews and Peoples, 2005).

In low soil nitrogen (N) conditions, the relative contribution of peas to intercrop productivity is greater than under high soil N conditions (Hauggaard-Nielsen and Jensen, 2001; Anderson et al., 2004). Li et al. (2007) found intercropping increased grain yields of maize and faba beans by 43% and 26% respectively, compared to sole maize and faba beans in a 4-yr study. The attribute of increased yield was due to the inter-specific belowground interactions between maize and faba bean (Li et al., 2007). Faba beans acidified the rhizosphere by excreting organic acids which enhanced P solubility, on a P-deficient soil.

Integrated weed management is an important component of increasing crop density in intercropping systems as a means to reduce weed pressure and herbicide use (Karpenstein-Machan and Stuelpnagel, 2000; Hauggaard-Nielsen et al., 2006). Szumigalski and Van Acker (2005) showed that intercropping can enhance both weed suppression and crop production. They found that a canola-pea intercropping tended to be the most consistent treatment in terms of increased land use efficiency as measured by the frequency of increased yield (mean LER = 1.22) when in-crop herbicides where used. When no in-crop herbicides were used, wheat-canola and wheat-canola-pea intercropping suppressed weeds better compared to the sole crops in some years.

Crop diversification provides an ecological approach to disease control (Zhu et al., 2000). The genetic heterogeneity of intercropping system can provide greater disease suppression by creating barriers in space over large areas (Piper et al., 1996). Cowger (2007) investigated blended wheat varieties (two or three varieties) that show either beneficial or neutral interactions with respect to diseases when grown in the field together. This resulted in an average increased yield of 2.3 bushels per aces (3.2% yield advantage) by the blended wheat cultivars compared to the pure varieties.

Additionally, the belowground mechanisms of inter-specific N transfer in cereal-legume mixtures can occur by several means. The long-term N transfer (year by year) of decomposing plant debris (roots, nodules, and/or leaves) or sloughing off the cortex cells is subsequently mineralized and can be reabsorbed by the plant or taken up by a plant growing in the mixture (Marschner, 1995; Johansen and Jensen, 1996; Paynel et al., 2001). The interplant short-term N transfer can involve N exudation into the rhizoshpere by legume and re-absorbed by non-legume plants. When plants were grown in non-sterile controlled environment conditions, Paynel et al. (2001) demonstrated that as much as 15% of total plant N in ryegrass can originate from N exuded from companion white clover. This interplant short-term N transfer involved exudation of N compounds into the rhizosphere by relatively young clover plants and re-absorption of these compounds by the ryegrass. Ammonium and amino acids were the major N compounds released by both white clover and ryegrass in this study. Another mechanism of short-term nutrient transfer can occur directly through arbuscular-mycorrhizal (AM) fungi via extraradical hyphae interconnecting the root systems of the two plant species (Johansen and Jensen 1996). Johansen and Jensen (1996) found that pea and barley plants colonized with AM fungi can transfer small amounts of N and P between plants. Their results indicated that the flow of N and P between two plants interconnected by AM hyphea is enhanced when the root system of one of the plants is decomposing.

Studies show that intercropping systems can be more efficient. For example, N losses through leaching can be reduced in mixed cropping stands with oat and pea in comparison to sole cropped pea (Neumann et al., 2007; Hauggaard-Nielsen et al., 2003). Caviglia et al. (2004) compared sequential and relay wheat–soybean double-crop systems with single crops to test which system is more efficient in the ability to capture and use resources. Their results showed that double crops increased capture efficiency in regards to water productivity on an annual basis compared to sole crops.

The intercrop literature shows mixed results regarding yield. Intercrops can decrease yields by competition or increase yield up to 89% by reducing limitation of crop growth by nitrogen (Stern, 1993; Kundsen et al., 2004). Ultimately, breeders and growers would need to accept reductions in sole crop yield to maximize yield in double- or multi- crop systems (Sullivan, 2003). The concept of Land Equivalent Ratio (LER) is a useful measure of yield improvement per unit area by growing two or more crops together, which is defined as the relative land area under sole cropping that is required to produce the yields achieved in intercropping (Hauggaard-Nielsen and Jensen, 2001). The LER is generally used to quantify the advantages of intercropping, which increases the productivity per unit of land when LER's exceeds 1.0 (Sullivan, 2003).

Intercropping can offer higher productivity and resource utilization that exhibits greater yield stability compared to single cropping (Karpenstein-Machan and Stuelpnagel, 2000; Tsubo et al., 2005; Zhang et al., 2007). The LER of pea–barley intercrop showed that plant growth resources were used from 17 to 31% more efficiently than by the single crops (Hauggaard-Nielsen et al., 2003). Intercropping cereal with pea can increase forage and N yields (Carr et al., 2004). Chen et al. (2004) demonstrated that intercropping barley and peas in mixed arrangements produced a greater total biomass (LER= 1.24) and N yields (1.29 protein) compared to separated row arrangements of barley and peas (LER= 1.05) (1.05 protein). Dhima et al. (2007) showed that yields in intercropping systems of common vetch with wheat and oat at two different seeding ratios was generally less than it was in monocropping. Nevertheless, the assessment indicated the vetch–wheat mixture (LER = 1.05) at 55:45 seeding ratio and the vetch–oat mixture (LER = 1.09) at 65:35 seeding ratio mixtures had a significant advantage from intercropping which was attributed to better economics and land-use efficiency.

The competition for environmental resources is an inherent risk when a producer decides to grow one or more crops on the same field. Therefore, component crops should be chosen that complement each other. Through the utilization of different resources at different times (e.g., different maturity dates), in different parts of the soil profile (e.g., different root depth) or aerial canopy, or in different forms (e.g., mineralized nitrogen vs. N_2 fixation). A more complementary and efficient use of resources can be accomplished as compared to monoculture (Sullivan, 2003).

Therefore, early competition in the growth cycle for soil N plays a key role in the outcome of competition between legume–non-legume intercrops (Andersen et al., 2005; Corre-Hellou et al., 2006; Corre-Hellou et al., 2007). The dominance of cereal and legume intercrop is often attributed to the fact that crop growth of cereal takes place earlier and possesses a faster growing root system and so is capable of accessing a larger volume of soil for nutrients compared to legume crops

(Hauggaard-Nielsen et al., 2001; Andersen et al., 2005). Understanding plant competition for resources agriculture managements can consider appropriate cultivars with highest complementary effects, seeding density, and fertilizer requirements in order to limit competition.

1.2.2 Intercropping Winter Wheat and Pea

The scientific aspect of the PSM internship project was to evaluate the belowground dynamics of intercropping pea with winter wheat including soil nutrient supply rate, using PRS^{TM}-probes, and soil microbial biomass under conventional and direct-seeding in an annual cropping system in the dryland agricultural region of Northeastern Oregon. Understanding the belowground dynamics of growing wheat and pea in mixture can help growers to improve soil fertility management in an intercropped system.

Growing wheat and pea crops concurrently in the same field is a cropping system that can increase the efficiency of resources utilization and can reduce fertilizer N requirements (Francis, 1986). Peas may provide benefits to cereal-based cropping systems in the dryland agricultural region of the PNW. Legume crops can biologically fix atmospheric N_2 through symbiosis with Rhizobium bacteria, making N available to both the legume crop and subsequent non-legume crops. This practice can reduce the need for inorganic N fertilizer inputs (Badaruddin and Meyer, 1994; Beckie and Brandt, 1997; Beckie et al., 1997; Walley et al., 2007). In addition, legume species tend to acidify the rhizosphere more by excreting organic acids into the soil and enhance P solubility, especially in P-deficient soils. The mobilized P not only enhances the legume productivity but that of other species (Li et al., 2007).

An intercrop yield benefit over that of sole cropping was observed when wheat and beans were grown together (LER = 1.40). The researchers concluded that winter intercropped wheat-bean can perform well if both wheat and bean plants are of similar heights and soil nutrients are not limiting (Haymes and Lee, 1999). In Europe, many studies were done with intercropping spring barley-pea and showed that yield and protein content of barley in intercropped systems were relatively higher then compared to separate barley and pea crops (Hauggaard-Nielsen et al., 2003). Corre-Hellou et al. (2006) demonstrated that intercrop advantages were mainly based on 1) better light use, and 2) a deeper root growth of cereal vs. pea; leading to a more important soil N acquisition and water utilization compared to single crop (Hauggard-Nielsen and Jensen, 2001).

In order to take advantage of intercropping currently practiced in Saskatchewan, Canada and to facilitate adoption of intercropping in the PNW, it is necessary to understand soil nutrient fluxes of intercrop systems. For this project, a form of ion exchange membrane, called Plant Root Simulator (PRS™)-probes, which provide a functional measure of nutrient supply rates, was used to understand the supply rate of nutrients in an intercropping system.

The soil nutrient supply rate of the intercrop system of wheat and pea was compared to monocultures of wheat in the dryland cropping system of the Columbia Basin near Pendleton, OR, USA. Intercropping cereal and legume crops may fit into the agricultural practices in the PNW in order to increase environmentally-friendly farming practices. This can be accomplished because such a cropping system can require less chemical inputs and increase biodiversity by exploiting biological processes (e.g., N_2 fixation) and growth resources more efficiently.

1.2.3 Ion Exchange Membrane for Soil Nutrient Supply Testing

The ion exchange resin membrane technology is capable of simultaneous adsorption and extraction of both cations and anions from soil solution. This brings a desirable means of assessing nutrient availability because ion exchange membranes (IEM) simulate a plant roots by the ability of acting as a sink for nutrients uptake over time. A requirement for addressing the nutrient demands of any crop is to be able to predict the nutrient-supply power of the soil in which the crop is grown. The IEM, which is sensitive to environmental factors affecting nutrient flux *in-situ*, seems to be a suitable research tool for measuring and comparing the nutrient supply over a growing season. This review focuses on a patented form of IEM called a Plant Root Simulator (PRS^{TM})-probe.

Ion exchange technology is commonly known and widely used for the treatment of groundwater, surface water, and leachate. This technology has over 50 years of history in research application measuring soil nutrient availability. Since the 1980's, ion exchange technology has been used in soil testing for fertilizer recommendations in Canada (Qian and Schoenau, 2002). Ion exchange resins have been used to determine plant available nutrients since approximately 1951 (Pratt, 1951). An ion exchange resin beads device called UNIBEST resin capsules provided by Unibest, Inc., Bozeman, MT, USA is commercially avaiable. The ion exchange membranes have been used since around 1964 (Saunders, 1964) and made commercially available since 1998 through Western Ag Innovations Inc., Saskatoon, SK, Canada, called Plant Root Simulator (PRS^{TM})-probes for measuring soil nutrient availably (Qian and Schoenau, 2002)

The resin membranes can be made from natural or synthetic organic, inorganic, or polymeric materials that contain functional, labile ionic groups that are capable of exchanging with other ions in the surrounding media (Dorfner, 1991). IEM is found to be chemically stable in many various solvents (Qian and Schoenau, 1997). This ensures that the resin will not be chemically altered by ionic interactions that occur at the surface of the functional groups. Usually counter-ions with the lowest affinity to the resin are used for the exchange of other soil nutrients (Tran et al., 1992).

This exchange of counter-ions for nutrients is similar to plant roots. Nutrient uptake by roots occurs primarily through the transport across plant cell membranes. In order for ions and other solutes to accumulate against a concentration gradient, expenditure of energy is required, either directly or indirectly. Energy-dependent uptake may be cation movement along an electrochemical gradient maintained by electrogenic proton (H^+) pumps. The proton pump moves H^+ into the outside soil solution in relation to the movement of cations into the cytoplasm so that the negative electrical potential is maintained. Since the interior of the cell is negative, respiration energy is necessary to move negative anions against the electrochemical gradient. In this process the root releases biocarbonate (HCO_3^-) and hydroxide (OH^-) into the exterior soil solution (Barber, 1995; Marschner, 1995).

Factors affecting nutrient supply in plants and IEM involve physical, chemical, and biological reactions. Similar to plant roots, IEMs are a sink for nutrients that become available by mineralization over time (Qian and Schoenau, 2002). For example, nutrients such as nitrogen or sulfur may be present in large amounts in organic matter, which can mineralize and release organically combined ions to inorganic forms and subsequently diffuse to roots (Barber, 1995). Additionally, IEMs measure the available nutrient supply rate on the basis of an adsorbing area, which is similar to nutrient uptake at a root surface (Greer et al., 1997).

The nutrients absorbed by roots depend on the affinity of a root for a certain nutrient and the concentration of the nutrient at the root surface (Barber, 1995). Plants take up nutrients in their available form. Bioavailable nutrients are present in a pool of ions in the soil and can move to the plant root during plant growth if the root is close enough. The movement of available nutrient ions to roots is governed by three major forces: 1) mass flow is the movement of ions to the root in the convective flow of water, caused by plant water absorption; 2) diffusion is the movement of ions by random kinetic motion of molecules from high concentration to low concentration; and 3) root interception with soil particles, soil nutrients at the root interface are available for absorption (this force is of minor important for nutrient uptake). For example, roots absorb nutrients across a concentration gradient existing from locations of 'high' concentration of the bulk soil to locations of 'low' concentration at the root surface (Barber, 1995).

Soil temperature and soil moisture influence the ion influx to plant roots. As soil temperature increases, ions have a greater kinetic energy. As a result, rates of water influx and root respiration generally parallel the increases in ion influx with increased temperature. Therefore, soil temperature is directly related to the diffusion of an ion in water. The diffusion of an ion in water and the soil moisture affect the effective diffusion of an ion through the soil. In dry soil, the pathway of diffusion it tortuous; therefore, it takes more time for a nutrient to move through the soil. These soil properties have direct control of nutrient availability to the plant roots, as well as the direct control of the amount of nutrients that can be adsorbed by the IEM over time (Yang et al., 1991a; Yang et al., 1991b; Yang and Skogley, 1992). Because the

IEM are exposed to the same factors as plant roots in soil, IEM should be capable of quantitatively simulating soil nutrient availability to plants (WAII, 2002).

The diffusion of an ion in water and the soil moisture affect the effective diffusion of an ion though the soil. The effective diffusion of an ion through the soil is expressed by the following equation:

$$D_e = D_l \theta f_l dC_l / dC_s$$

In this equation, D_e is the effective diffusion coefficient in the soil, D_l is the diffusion of ion in water, θ is the volumetric water content, f_l is the tortuosity factor, and dC_l / dC_s is the reciprocal of the soil buffering capacity (Barber, 1995).

Nutrient availability measurements with IEM have been shown to be sensitive to soil water content and temperature and competition for nutrients from microorganisms and plant roots (Schaff and Skogley, 1982; Binkley, 1984; Huang and Schoenau, 1997; Hangs et al., 2004). Schoenau et al. (2001) measured relatively large decreases in the amount of N, P, K^+, and S adsorbed by IEM below 70% of field capacity. Qian and Shoenau (1997) showed that temperature effect on adsorption of N, P, K^+, and S by buried IEMs was significantly decreased between 4 and 10ºC. The affect was more apparent for N and S than for the other nutrients. However, at temperatures between 10 and 20ºC, and 20 and 30ºC, nutrient flux to IEM did not differ.

Low soil moisture and soil temperature also limits diffusion by influencing the activity of soil microorganism essential to nutrient cycling and supply. Under dry and/or cool soil conditions plant growth and nutrient assimilation are slow; the nutrient uptake by IEM might not be as relevant under such conditions (Schoenau et al., 2001).

Correlations between IEM measurements of soil nutrient availability and plant nutrient uptake have produced mixed results, with some studies showing good correlations (e.g., Skogley et al., 1990; Qian and Schoenau, 1995, Qian and Schoenau, 2005; Li et al., 2001) and some showing little or no correlation (e.g., Walley et al., 2002; Johnson et al. 2005). In a plot experiment, Li et al. (2001)

measured soil-available S extracted by the IEM at two burial times, 24-hour and 2-weeks; both time intervals significantly correlated with total S uptake by corn and rice. The researchers also showed that S extracted by IEM significantly correlated with S extracted by four chemical methods: 0.01M $CaCl_2$, 0.01M Ca $(H_2PO_4)_2$, 0.016M KH_2PO_4, and 0.5M $NaHCO_3$. IEMs have shown strong correlation with K uptake in spring wheat. Spring wheat grown in greenhouse showed responses to K fertilization that was closely related to the amount of supply rate of available K in the soil (Qian et al., 1998). In the research studies of Walley et al. (2002) and Johnson et al. (2005), IEM did not correlate well to N mineralization or the pattern of extractable mineral N over time nor with crop N accumulation.

Qian et al. (1992) extracted four plant-available nutrients, N, P, S, and K, using anion and cation exchange membranes (ACEM). They compared the amount of nutrients extracted by ACEM with conventional chemical-based extraction of P and K (0.05 $NAHCO_3$) and N and S (0.001M $CaCl_2$) for 135 soil samples including different soil types from Western Canada. Canola plants uptake of N, P, S, and K were more closely correlated with ACEM extractions compared to the conventional methods in this experiment. The ACEM were used as a soil test for a structure-less soil sample in the lab at room temperature and adequate soil moisture. As a result, diffusion pathways were not an important factor affecting nutrient supply rates.

IEM also offers an effective technique that provides a good index for the differences in soil N supply capacity as affected by long-term management, such as crop rotation and fertilization history. Qian and Schoenau (1995) found in laboratory incubation, a higher N mineralization potential in soil that was continuously cropped with alfalfa compared with soil cropped with canola, lentil, and barley. These results are consistent with expected N mineralization potentials for a soil cropped with a legume. In addition, grain yield of wheat grown on pea stubble was significantly higher then grain yield on lentil stubble. This was associated with significantly higher IEM nutrient supply rates of N and P measured over the season in the pea stubble plots than in the lentil stubble plots. This implies that increased nutrient availability contributed to the yield benefit in plots previously cropped with pea (Adderley et al., 2006). The close correlation of the

IEM burial method with plant uptake of available nutrients and IEM's ability to reflect the effect of different managements such as rotation with different crops, on mineralization suggests its potential use to further refine fertilizer recommendations. This technology can help to achieve economical fertilization and reduce environmental concerns (Greer et al., 2003).

The anion and cation Plant Root Simulator (PRS^{TM})-probe contain bicarbonate (HCO_3^-) and sodium ions (Na^+) as negatively or positively charged surface functional groups (i.e., counter-ion) respectively. Bicarbonate is exchangeable with other anions due to its low affinity to the resin membrane. Anion exchange membranes adsorb quantities of NO_3^-, HPO_4^{2-} or $H_2PO_4^-$, SO_4^{2-}, BO_3^-, and Cl^- in the soil. The cation PRS^{TM}-probe adsorbs quantities of NH_4^+, K^+, Ca^{2+}, and Mg^{2+} in soil solution. The sodium ion (Na^+) is a good counter-ion for the cation resin membrane because it has a low affinity for the resin. In addition, Na^+ is desirable because the ion will not interact with calcium carbonate ($CaCO_3$) affecting the adsorption of NH_4^+ and K^+. Although, H^+ has the lowest affinity for the resin, it is not routinely used as a saturating ion because it increases Ca^{2+} adsorbed by cation exchange membranes. This may interfere with the adsorption of NH_4^+ and K^+ to the membrane buried in soil over a longer period of time. The HCO_3^- is desirable for saturating the anion resin because this ion displaced into the soil somewhat simulates the HCO_3^- produced in the rhizosphere from the respiration of microorganisms and plant roots (Qian and Schoenau, 1997; Qian and Schoenau, 2002).

Common chemicals and standard soil test lab procedures and equipment are used to analyze IEM samples. Each PRS^{TM}-probe pair is prepared for analysis by eluating with 17.5 mL of 0.5M HCl. The analysis for levels of nitrate (NO_3^-) and ammonium (NH_4^+) can be analyzed by using an automated colorimetry, while most other nutrients can be analyzed by inductively coupled plasma (ICP) spectrophotometer. PRS^{TM}-probes are regenerated in 0.5N $NaHCO_3$ (pH 8.5) to coat the membrane of the anion -probes with HCO_3^- and cation -probes with Na^+ ions (WAII, 2002).

Cation exchange resins are able to extract micronutrient metal ions from soil solution. However, metal ions are present in very low concentrations in solution in uncontaminated soils because they can precipitate with compounds and/or form complexes with organic compounds and other ligands that make then unavailable to plants (Qian and Schoenau, 2002). Therefore, a chelating pre-treatment of the anion exchange membrane (AEM) with EDTA (disodium salt dehydrate) is employed when measuring supply rates of the micronutrient polyvalent cations such as Mn^{2+}, Fe^{2+}, Cu^{2+}, Zn^{2+}, Al^{3+}, and Pd^{2+}. The AEM is placed in a dilute solution of chelating agent (0.01M EDTA); the chelating agent binds to the anion exchange membrane producing a membrane with the ability of adsorbing anions and cations. The EDTA attached to the membrane forms complexes with metals, in competition with the adsorption sites on soil particles (Liang and Schoenau, 1995). The IEM can be regenerated by re-saturating in the chelating agent solution after analysis.

Tejowulan et al. (1994) compared extraction of bioavailable micronutrients, Cu, Zn, Mn, and Fe, using anion exchange membrane chelated either with EDTA or DTPA (Diethylene triamine pentaacetic acid and elongated version of EDTA) with conventional soil tests DTPA-TEA or EDTA-$(NH_4)_2CO_3$. The amounts of Cu, Zn, Mn, and Fe measured by the supply rates of anion exchange membrane were significantly correlated with the micronutrients removed by the conventional soil tests. In addition, canola plant tissue concentration of Cu, Zn, Mn, and Fe related well to the anion exchange membrane chelated either with EDTA or DTPA micronutrient uptake. Liang and Schoenau (1995) removed Cd, Cr, Pb and Ni from soils that had been spiked with those metals and found that the supply rates of metals to the membrane were closely correlated with different plant (oats, radish, and lettuce) metal uptake and toxicity. Liang and Schoenau (1996) showed that anion and cation exchange resin membranes were able to define the lability, potential bioavailability, and leachability of different metals (Cd, Cr, Pb, and Ni) within different pH ranges. They found that sandy-texture soils that are subject to acidification (low pH) have higher supply rates of these metals. The researchers concluded that IEMs are useful because they can predict the availability and mobility of metals in different pH environments.

Ion adsorption by the resin membrane is affected by competition, both biologically and chemically when the resin is placed in soil, since plant roots and microorganisms are essentially a more competitive sink for nutrients (immobilization) than IEMs. Competition from nutrient conversion by plant roots will affect supply available to the resin membrane for adsorption (Giblin et al., 1994; Subler et al., 1995).

When IEMs are buried near plant roots, over days or weeks, the IEM will measure the difference between total soil nutrient supply and plant uptake, meaning that IEMs adsorb the nutrients that are in surplus rather than net mineralization. If a researcher wishes to overcome this situation, plant roots can be excluded from the IEM experimental area by inserting a "root exclusion cylinder", constructed of polyvinyl chloride (PVC) pipe, approximately ~ 10 cm diameter × 16 cm long, which can be placed into the soil at the sampling point. By removing plants, IEM are placed into soil in the center of the enclosed area. With this approach burying IEM both inside and outside of the cylinders - a more complete picture of the soil nutrient supply dynamics can be obtained. The difference between ion fluxes inside and outside of the root exclusion cylinders can be used as an index of plant nutrient uptake (Huang and Schoenau, 1997). These researchers also determined that the PVC pipe had negligible effects on soil moisture and temperature within the immediate vicinity of the PRS^{TM}-probes.

The use of a "root exclusion cylinder" is appropriate when interested in net mineralization, for example in crop rotations with grains and legume crops. Adderley et al. (2006) showed that the residual supply of available N and P to spring wheat was greater after previously cropped with pea compared with lentils. The higher N and P supply rate under the pea stubble correlated with significantly higher grain yields compared to the grain yields on lentil stubble. IEMs, in conjunction with root exclusion cylinder, are a useful tool in assessing the residual nutrient supply rates achieved with different crop rotations.

A large number of extraction methods are used in routine soil testing for nutrients. Soil testing methods determine the fraction of available nutrients, which is the quantity component/capacity of nutrients in the soil (Figure 1.5), in order to forecast fertilizer requirements. Fertilizer prediction can be improved by considering other soil properties such as soil pH, redox potential, clay, and organic matter content (Figure 1.5). Traditional soil test measurements are snapshots at discrete intervals for homogenized soil samples. The relative importance of mass flow and diffusion for the supply of soil nutrient ions to plant roots is not considered by traditional soil tests (Marschner, 1995).

The use of IEM has attracted new interest as a possible means for characterizing the buffer power of soils for specific nutrient ions or simultaneously for various cations and anions (Marschner, 1995). IEM takes into account mass flow and diffusion for the supply rates of soil nutrient ions, which is important for both ion concentrations and the rates of replenishment of these ions in the soil solution (Figure 1.5) (Marschner, 1995; Qian and Schoenau, 2002). In addition, direct burial of IEM in the soil under field conditions takes into account factors which affect nutrient ion flux to roots, including soil texture and structure, soil moisture and temperature, and nutrient mineralization and immobilization (Qian and Schoenau, 2002).

Furthermore, this method does not require soil collection, making the technique suited to multiple measurements of soil nutrient supply, causing minimal disturbance, and allowing re-measurement of specific points in the soil over time (Huang and Schoenau 1996a). This is important because nutrient uptake by plants over time is not linear since nutrient fluxes depend on environmental conditions (WAII, 2002). Therefore, IEM represents a more integrated and cumulative measure of soil nutrient availability over time. The possibility of obtaining cumulative supply rates can be correlated with plant uptake of nutrients over a growing season.

Comparisons between field measurements of IEMs and traditional soil measurements are difficult. Since values from IEM exposure cannot be related to specific amounts of soil. The values for IEM measurements tend to be expressed as weights or moles of nutrient per unit weight or surface area of resin per time (i.e., mg/area/time) rather than in weights or moles of nutrient per unit weight of soil (i.e., mg/kg soil). Another consideration is that with *in-situ* field use of IEM, there is an inherently larger coefficient of variation (CV). When diffusion-sensitive systems

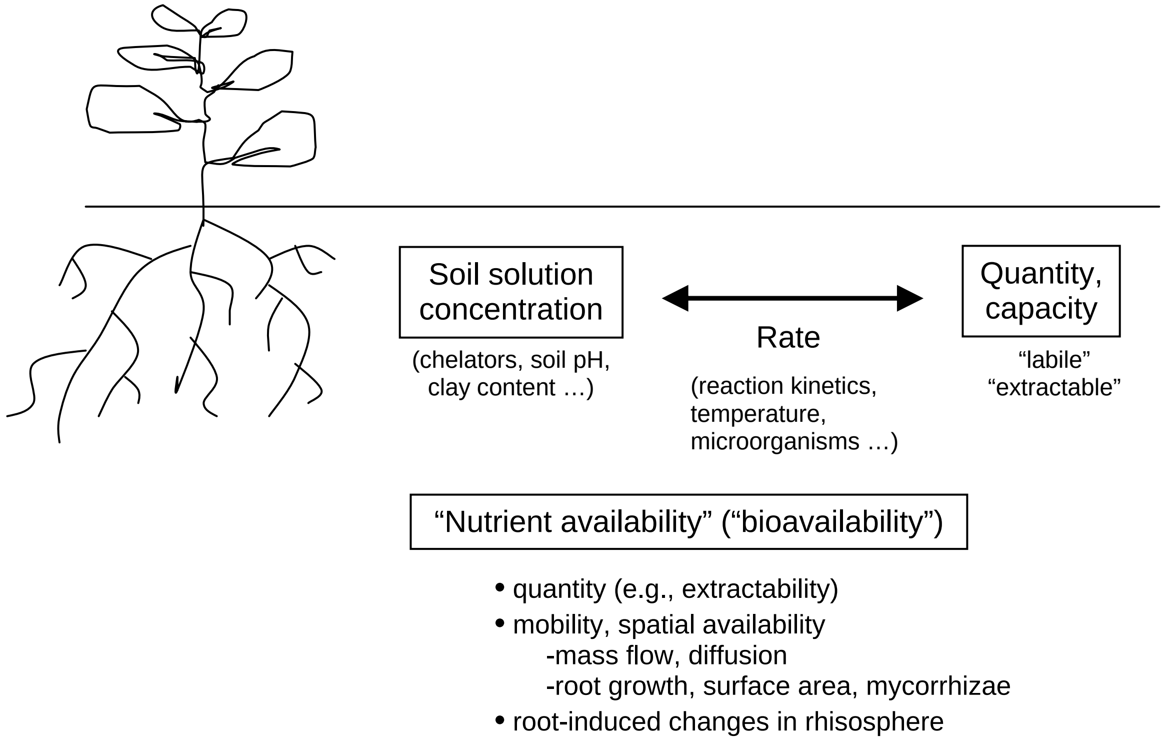

Figure 1.5 Factors determining the bioavailability of mineral nutrients.
(source: Marschner, 1995)

are used directly in unprocessed soils, a larger CV can be expected as soil is not homogenous. Microscale variations in environmental conditions such as moisture, texture, biological conditions (e.g., competing plant roots and microorganisms), and physical-chemical conditions such as residual fertilizer from banding all create larger variability in *in-situ* measurements in the field. In traditional soil testing, soil samples are taken to the lab and homogenized prior to analysis so that the CV among sub-samples from the same prepared soil sample is small. Therefore, proper sampling design is essential when using IEM (Qian and Schoenau, 2002).

Low soil moisture content is a limitation of IEM because nutrient ions cannot be replenished by mass flow or diffusion to IEM in the field. It has been shown in laboratory settings that nutrient adsorption significantly decreased with decreasing moisture content in the soil (Qian and Schoenau, 1997; Schaff and

Skogley, 1982). In dryland agriculture, such as in North Central (NC) Oregon, IEM may not be ideal for *in-situ* application because of the low surface soil water content and cool soil temperatures that are common in NC Oregon. This reduces sensitivity of ion-exchange membranes to accurately measure plant-available nutrients (Redman, 2002). Redman (2002) illustrated that low soil water content and cool soil temperature cause poor correlation between the soil supply rate and wheat uptake of P and S in NC Oregon.

The susceptibility of IEM to plant root and microbial competition for nutrient ions cannot be entirely prevented. Variable quantities of roots growing right next to or into the "root exclusion cylinders" can make interpretation of nutrient supply rate data complicated. In addition, comparison between nutrient measurements obtained by IEM and conventional soil tests cannot be compared because the mode of quantifying nutrients is vastly different. Nonetheless, IEMs are an alternative research tool in quantitatively determining nutrient supply rates as compare to traditional soil tests.

In conclusion, soil biology, chemistry, and physical properties are altered in an intercropping system, and the IEM seems to be a suitable tool for measuring various nutrient fluxes *in-situ* over a growing season. This would add to the body of knowledge regarding the belowground nutrient dynamics in a dryland cereal-legume based intercrop systems.

1.3 SUMMARY

Food producers are changing to a market-driven sustainability model by acquiring eco-friendly production certification in order to access niche markets. The study focused on how market incentives can help to promote the use of the best possible agricultural management practices for sustainable crop production in order to find value-added markets. Additionally, an agriculture system was examined called intercropping, a type of polyculture, which has the potential to serve as a practice for increasing environmentally-friendly agricultural managements. The two objectives of this internship are: 1) evaluate how two agrarian groups, the Pesticide-

Free Production Farmer's co-op and Shepherd's Grain, benefit from environmentally-friendly production and certification; and 2) determine the belowground dynamics of intercropping pea with wheat on soil nutrient supply rate, using PRS^{TM}-probes in an annual cropping systems in the dryland agricultural region of Northeastern Oregon.

In Chapter 2, the two agrarian groups' Shepherd's Grain and the Pesticide-Free Production Farmer's co-op, are discussed in a comparative case study. This was done in order to compare and contrast the two agrarian groups on the basis of organizational structure and third-party certification to evaluate how the agrarian groups benefit from environmentally-friendly production and certification. In Chapter 3, Plant Root Simulator (PRS^{TM})-probes are used to quantitatively determine multiple nutrient supply rates in a dryland intercropping wheat-pea system. The purpose is to determine the potential of intercropping and the use of PRS^{TM}-probes as a diagnostic tool within established agronomic trails at Pendleton, OR.

CHAPTER 2

Comparing and Contrasting Shepherd's Grain and Pesticide-Free Production Farmer's Cooperative

2.1 ABSTRACT

Market incentives can help to promote the use of the best possible agricultural management practices for sustainable crop production to increase farm profitability. A comparative case study was conducted in order to compare and contrast two agrarian groups on the basis of organizational structure and third-party certification. The study objective was to explore the question: Why was Shepherd's Grain successful and Pesticide-Free Production Farmer's Cooperative not successful in finding markets for their environmentally-friendly produced products? The data collection was done through semi-structured interviews, published documents, archival records, peer-reviewed literature, and internet. A SWOT analysis was applied as a strategy to understand the development of value-addition, brand recognition, and premium pricing when considering marketing commodity food products. Shepherd's Grain (SG) was successful because they maintained contracts ensuring identity preservation of their products and fair return on investments to their members, while the Pesticide-Free Production (PFP) Farmer's co-op was unable to do so. SG effectively employed direct marketing to consumers with a clear message backed by the Food Alliance certification. The PFP Farmer's co-op was not successful in direct marketing to consumers due to a lack of investment and failed to communicate the value of their PFP certification. Therefore, no demand was established in the marketplace for PFP certified products. This study showed that market incentives can promote environmentally-friendly agricultural management and secure a reasonable rate on investment, but are not sufficient in and of themselves. Progressive producers have to respond to market developments and educate their consumers about the benefits of eco-friendly farming. This is important because the present trends in agricultural production are driven by consumer demand for increased transparency and sustainable food products.

2.2 INTRODUCTION

The purpose of this project was to understand how agrarian groups benefit from environmentally-friendly production and certification which differentiates them from conventional agricultural management. It is believed that environmentally-friendly third-party certification can indirectly help growers to develop market differentiation and access niche markets for their products (Hatanaka et al., 2005). Two agrarian groups, Pesticide-Free Production Farmers' Cooperative (PFP Farmer's co-op) and Shepherd's Grain (SG), were compared and contrasted on the basis of organizational structure and third-party certification. This is a critical issue if we hope to use market incentives to help promote the use of the best possible agricultural management practices for sustainable crop production while obtaining reasonable rates of return.

The PFP Farmer's co-op, centered in the Western Canadian prairies, and SG, located in the dryland agricultural region of the Pacific Northwest (PNW), have given a priority to environmentally beneficial growing practices. The practices include conservation tillage, crop rotation, and minimal or eliminated chemical use during crop growth. Despite the groups' shared goals, SG successfully found markets for their environmentally-friendly products while the PFP Farmer's co-op did not. SG farms were Food Alliance certified, a third-party certification, which helped SG to differentiate and sell their products. The Food Alliance seal is recognized as one of the United States' leading third-party certification organizations for environmentally and socially responsible agricultural practices. The PFP Farmer's co-op secured certification through PFP Canada, a Canadian organization ensuring pesticide-free production. However, the PFP Farmer's co-op, despite a Canadian third-party certification ensuring pesticide-free production practices, did not find a market for their products.

The major question this report explores is: Why was SG successful and the PFP Farmer's co-op not successful in finding markets for their products? In order to address this question, the two agrarian groups were compared through a comparative case study approach. The study looked at different factors involved in value-addition, brand recognition and premium pricing. These factors can contribute to the agrarian group's success and effectiveness in the market place. The comparative element of the case study with two examples has therefore been developed along the following lines: 1) common study objectives and themes were used across the two examples; 2) comparisons across examples were facilitated by using the same theoretical base; and 3) the collected data enabled comparisons to be made on three levels: value-addition, brand recognition and premium pricing, and combinations of these (Halinena and Törnroos, 2005).

2.3 PROCEDURES AND METHODS

A comparative case study method was used as the primary research methodology in order to compare and contrast two agrarian groups, SG and the PFP Farmer's co-op. Each example is constructed to provide detailed information on the group's organizational structure and third-party certification. The content investigation of the case uses a general SWOT analysis (strengths, weaknesses, opportunities, and threats). The SWOT analysis is an appropriate strategy to understand the development of value-addition, brand recognition and premium pricing when considering marketing commodity food products.

This research did not seek to objectively determine causal explanations, but rather to identify important phenomena and influences surrounding landowners' participation in environmentally-friendly food production. A multi-methods approach was required to understand how a particular phenomenon (e.g., increase of customers' awareness on agricultural practices) are evolving and shaping the modern agriculture systems in North America.

2.3.1 Study Design

A comparative case study was applied to two agrarian groups, SG and the PFP Farmer's co-op. The data collection was done through a multi-methods approach including semi-structured interviews, participant observation, and review of websites and archived materials. The multi-method data collection focused on the role of certification and brand recognition to enhance the growers' success in marketing their products. A SWOT analysis was applied for the data analysis, comparing the two agrarian groups on the bases of value-addition, brand recognition and premium pricing.

2.3.2 Semi-Structured Interviews

Semi-structured interviews were employed to generate a range of perspectives on the value of environmentally-friendly certification and brand establishments. As recommended in qualitative case study research, sampling was done purposefully and directed by ongoing data analysis proceeding until the point of redundancy (Robson, 2002). A total of seven participants voluntarily participated in the study. They were SG growers certified by Food Alliance, researchers concerned about sustainable agricultural management practices, and growers involved in the PFP. For the PFP Farmer's co-op group, subject identification was done through Western Ag Innovations Inc. and for the SG group subjects were identified via the SG website.

With prior consent, interviews were transcribed and written notes were taken during the interviews of participant responses. A field log was kept recording interview reflections on the researcher's thoughts, feelings, and intuitions about the interaction and the perceived authenticity of participant responses.

Interviews were conducted using mostly open-ended questions as a general guideline (see Appendix A for questionnaire). The interviews took place at farms or in public places. Questions asked varied somewhat over time, as interviews ranged in length from 45 minutes to three hours. As a result all questions were not necessarily asked of all people and questions were not asked in the same order. The open-ended approach was intended to encourage interviewees to lead the conversation into topics they considered most significant to environmentally-friendly production implementation.

2.3.3 Participant Observations

Observing subjects participating in activities helped triangulate information gathered from interviews and minimize any response or deference effects stemming from the interviewee/interviewer biases. Examples of activities during the three months of participant observation included: riding along on the combine; having lunch or meeting with informants at conferences (Plant Canada –Growing for the Future; Farm 2 Fork Hospitality Party-Farmer's Market of Sustainable Solutions; Small Farms and Farm Direct Marketing); and attending various community events including university extension field days (Pullman, WA; Pendleton and Moro, OR) and Western Canada Farm Progress Show.

2.3.4 Review of Websites and Archived Materials

Additional data were gathered from published documents of SG and Food Alliance, archival records of PFP and the PFP Farmer's co-op, peer-reviewed literature, and the internet. Specifically, I obtained information from SG and Food Alliance through their websites and took notes on their published newsletter from January 2007 through July 2008. The review of information from SG and Food Alliance focused on direct marketing, value-addition, brand recognition, premium pricing, sustainable agriculture, and eco-friendly third-party certification.

A census strategy was applied to investigate all the information available about the PFP system and the PFP Farmer's co-op, with a focus on the same factors as in the review of SG and Food Alliance. Information on the pesticide-free production systems was obtained through peer-reviewed literature and websites of sustainable agriculture of the University of Manitoba, Canada. Archival records of PFP and the PFP Farmer's co-op was available through Western Ag Innovations Inc. The collection, reviewing, and note taking of information was done from May 2007 trough January 2008.

2.3.5 Data Analysis

The collected data were used to characterize the strengths, weaknesses, opportunities, and threats on the three components of value-addition, brand recognition, and premium pricing for each agrarian group. The incorporation of the SWOT analysis allowed comparisons to be made on these three critical components with a focus on key marketing issues such as product, price, promotion, people, place, process, and physical evidence. SWOT analysis is a tool for auditing an organization and its environment (SWOT Analysis by RapidBI, 2008). It involves specifying the objectives of an organization and identifying the internal and external factors that are favorable and unfavorable to achieving those objectives. The primary objective in both agrarian groups was to establish market incentives to obtain reasonable rates of return on investment by using environmentally beneficial agricultural practices for sustainable crop production.

2.3.6 Definitions

The following six definitions are used throughout the description and discussion of the two agrarian groups, SG and the PFP Farmer's co-op. The definitions help to differentiate between people involved in the agricultural production and the food consumption industries.

- **Farmers/growers/producers:** SG or PFP Farmer's co-op (agrarian groups) members/growers
- **Distributors:** Provide SG and PFP Farmer's co-op bulk flour (or other commodities of PFP Farmer's co-op) to customers (i.e., bakeries, restaurants, universities, etc.)
- **Consumers:** Wholesale customers, flour customers, and retail consumers
- **Wholesale customers:** Buy wheat (or other commodities of PFP Farmer's co-op) from SG or PFP Farmer's co-op for wholesale distribution
- **Flour customers:** Buy bulk flour (or other commodities of PFP Farmer's co-op) and process into end products
- **Retail consumers**: Buy products (i.e., end products) made with SG or PFP Farmer's co-op grain, including labeled products (SG flour), in stores or restaurants

2.4 SHEPHERD'S GRAIN

Columbia Plateau Producers, founded in 2002, is a stand-alone private LLC company belonging to two owners, Karl Kupers and Fred Fleming (owning more than 50% of company). The company is more commonly known as Shepherd's Grain (SG), which is the trademark and brand name on their products. SG consists of a progressive group of 30-plus family farms in Eastern Washington, Oregon and Idaho who are dedicated to practicing sustainable agriculture. The primary mission of SG is to get the marketplace to reward local, no-till farmers.

In the last seven years, the group has been successful in growing high quality, highly differentiated branded wheat that is processed into flours with a credible sustainability story. Their products are high and low gluten, and whole wheat flour. They grow their wheat with other crops (garbanzos, lentils, red beans, and sunflowers) in rotation and practice direct-seeding (no-till) with minimal use of pesticides.

Farmers can participate as a member by contributing grains to SG or they can become co-owners of SG at a cost of approximately $4000. Individual farms joining the company have to go through a one-year probation period monitored by SG. All farms have to commit to the direct-seeding practices and become Food Alliance certified in order to have the right to use the SG label.

Food Alliance, an independent not-for-profit third-party certification organization, is a promoter of "sustainable agriculture by recognizing and rewarding farmers who produce food in environmentally-friendly and socially responsible ways, and educating consumers and others in the food system about the benefits of sustainable agriculture" (www.foodalliance.org). Food Alliance certification assures that farms make credible claims for social and environmental stewardships. Farmers and ranchers must meet the Food Alliance standards as presented in Table 2.1 in order to become certified.

Each producer has to take responsibility to evaluate and certify his or her farm by Food Alliance. This requires self-evaluation, application, inspection by Food Alliance, and continuing compliance with the third-party standards. At the time of application, the grower pays Food Alliance $400. Once certified, the grower can use the Food Alliance seal to market and label products. The grower pays an annual fee to the organization based on the gross of the products sold with Food Alliance certification seal. The certification lasts for three years; after the third year individual growers can re-certify the farm by documenting, in an annual report, the progress in attaining sustainability goals he or she has set.

SG economically adds value to wheat products by having established contracts with distributors, wholesale and flour customers, and providing traceability and transparency of their products and price. SG products are processed and handled separately from other commodity products. This enables traceability or identity preservation (IP) of the products, meaning that their wheat and flour are not mixed with lower quality or non-identified commodity products. The introduction of IP grains and processing wheat into flour provides both value-adding opportunities and quality assurance to SG consumers. The identity preservation of SG products allows retail consumers to see the SG label in the store or restaurant.

Table 2.1 Food Alliance criteria:
(source: www.foodalliance.org)

- Provide safe and fair working conditions (employment manual)
- Ensure the health and humane treatment of animals
- No genetically modified crops or livestock
- No use of hormones or non-therapeutic antibiotics
- Reduce pesticide use and toxicity through integrated pest management
- Protect soil and water quality
- Protect and enhance wildlife habitat
- Continuously improve management practices

SG is marketing directly to wholesale and flour customers including bakeries, restaurants (e.g., pizza parlors), and food service companies (e.g., colleges and universities) primarily through word of mouth. Farmers, wholesale and flour customers also receive regular newsletter about the SG production process.

SG works closely with its distributors, wholesale and flour customers to ensure a transparent pricing strategy that, while flexible, helps ensure some stability in a fluctuating market. The SG pricing structure is transparent so that distributors, wholesale and flour customers can see the costs that are associated with the production of the SG products. SG established a commitment to provide fair returns to its members. Therefore, an effective two-way communication with SG distributors, wholesale and flour customers is necessary. The yearly renegotiations of contracts with distributors, wholesale and flour customers accommodate price fluctuations. This allows SG to gain an added baseline premium of approximately 50 cents per pound, which covers the cost of production plus a reasonable rate of return back to the farm (15 to 20% return to management and capital).

SG initially processed about 2,000 bushels of SG wheat in 2002 and is currently producing 500,000 to 600,000 bushels a year to meet growing demand. In 2008, SG expanded into the retail market with the “Stone-Buhr” line of flour being sold in 200 northwest grocery stores.

2.5 PESTICIDE-FREE PRODUCTION FARMER’S COOPERATIVE

The concept of Pesticide-Free Production (PFP) originated at the University of Manitoba and AgriFood Canada in 1999. Together they formed PFP Canada at the University of Manitoba’s Faculty of Agriculture. In 2000, the University received grants from the Manitoba Rural Adaptation Council, which was funded through the federal government’s Canadian Agricultural Rural Development program, to implement and test the PFP system on Manitoba grain farms. Additionally, the University of Manitoba went through the legal process to trademark the term “Pesticide-Free Production” and the acronym “PFP” with the intention that the PFP approach would be adopted by many farmers. PFP was based on the concept that benefits need to be focused on consumers, farmers and the environment. PFP Canada defined Pesticide-Free Production as: “Crops bred using conventional techniques, that have been not been treated with pesticides and have not been genetically modified, from the time of crop emergence until the time of marketing. In addition, such crops cannot be grown where residual pesticides are considered to be commercially active" (University of Manitoba website: www.umanitoba.ca/outreach/naturalagriculture/articles/whatispfp.html).

As scientists and farmers have established that crops can be grown with fewer pesticides, PFP products could capture premium prices since consumers are increasingly looking to purchase foods with fewer pesticides. The Pesticide-Free Production Farmer's Cooperative Ltd. was formed in 2001 to help its members to capture some of the emerging sustainable food production markets. The PFP Farmer's co-op was granted exclusive rights to the PFP trademarks by the University of Manitoba for two years.

The Farmer's co-op was a farmer-owned and managed agricultural marketing cooperative - government and industry funded, non-profit corporation. The Farmer's co-op established a five member Board of Directors with an official office located in Boissevain at the Manitoba Agriculture, Food and Rural Initiatives Center. Any producers from the Canadian prairies were able to join the Farmer's co-op. The membership fee was a minimum of $100 - 100 shares at $1 per share.

Individual farmers joining the co-op could choose to meet PFP criteria by fallowing the specific guidelines and standards defined by PFP Canada in order to be certified through the co-op (Table 2.2). Individual producers had to apply for certification every year before harvest. After crop harvest PFP certification was not possible.

Table 2.2 Pesticide-Free Production criteria:
(source:www.umanitoba.ca/outreach/naturalagriculture/articles/whatispfp.html)

- No pesticide used during production and storage
- No GE seeds
- Non residual pesticides allowed during non PFP crop rotations
- Pre-seeding weed control with a non-residual herbicide (glyphosate) allowed
- Buffer zone (1 meter) from non PFP fields
- PFP crops must be harvested and stored separately from conventionally produced crops if marketed separately

PFP Canada developed protocols and coordinated the field inspection requirements for the PFP certification process. Independent field inspectors were trained by the University of Manitoba. The inspection report, which documented the field history of the past three seasons, was left with the grower. The date, crop, variety, field size, location and grower contact information portions of the certification were then completed by the inspector. PFP Canada agreed to do field inspections for no charge in Manitoba. In Saskatchewan and Alberta third-party inspectors certified PFP fields at a cost of around CD $250, while the Farmer's co-op covered the cost of members' inspections through government grants.

If a certain field passed PFP inspection the farmer applied to the Farmer's co-op for the full certification for that specific product. The farmer then signed and dated that the information was correct. If the specific market requested, there was space for a commissioner of oaths to sign beside the farmer's signature. Once the crop was PFP certified, it could be marketed with the PFP trademarks and disclaimer: "Pesticide-Free Production certifies that the farmer did not apply pesticides to the growing crop. However, this does not guarantee the crop to be entirely free of pest control products."

Each member of the Farmer's co-op could decide each year how many fields to certify as PFP. The PFP system could be desirable to farmers because they could incorporate non-pesticide control methods in certain years on certain fields, while allowing conventional control methods on the remainder of the farm. Furthermore, if a PFP certified field became infested with a pest, the grower could spray pesticides in order to prevent economic loss, although that product would no longer be certified as PFP.

The PFP Farmer's co-op plan was to take on the responsibilities of liability, logistics, marketing, and consumer relations on behalf of its members. The Farmer's co-op carried the potential to deliver not only substantial premiums, but also sizable dividends and overall improvement of farm profitability. The main method for capturing premiums for its members' products was through overseeing the certification process of PFP production and labeling.

In addition, the co-op provided services and was promoted heavily in the farm communities in Western Canada. Services included PFP Canada Farming with Fewer Chemicals Field Day, annual marketing seminars, advisory services, inspection/certification of land information, and newsletters for producers.

Promotional events included approximately 30 news stories, interviews, two field workshops, a PFP-specific tour, and Farmer's co-op booths and presentations at three major conferences.

2.6 SWOT ANALYSIS

Each agrarian group, SG and the PFP Farmer's co-op, has been described to provide information on the organizational structure, certification, and services the groups provided for their members. The SWOT analysis can now be applied to both agrarian groups with a focus on three factors: brand recognition, value-addition, and premium pricing. The comparison approach was done by incorporating key marketing issues such as product, price, promotion, people, place, process, and physical evidence. This allowed identifying problems, limitations and success in regards to value-addition, brand recognition, and premium pricing, and combinations of these for the two agrarian groups.

2.6.1 Brand Recognition

Brand recognition is the extent to which a brand is recognized within a product class for certain attributes. Table 2.3 summarizes the SWOT analysis including the internal strengths and weaknesses and external opportunities and threats for each agrarian group regarding their brand recognition.

SG promotion strategy was based on personal selling, direct marketing, and public relations. They made extensive use of information technology, improving wholesale and flour customer services by discovering their preferences and adapting product attributes in response to demand. This reflects the focus on quality products associated with the SG brand.

Food Alliance helped in promoting the SG brand by advertising SG on their website and frequently used SG as an example of direct marketing. Also SG was represented at Food Alliance annual events, which helped the group increase public relations and foster potential marketing contracts. This was important because it

Table 2.3 SWOT analyses focused on SG and the PFP Farmer's co-op brand recognition.

	Shepherd's Grain LLC	Pesticide-Free Production Farmer's Co-op Ltd.	
S	Direct marketing; branding; Food Alliance certification	Promotion of PFP to producers; info/training for PFP	Internal
W	Only domestic market?-Limiting markets; perceived complexity of Food Alliance certification	No marketing to consumers – no clear message	
O	Extend SG brand to other crops	Promote to consumers; different name or certification	External
T	Organic brands	Liability restriction in Canada; Organic brands	

permits communication to distributors, wholesale and flour customers, which in tern helped SG brand to receive recognition.

A potential weakness be that SG could experience limited markets because they are focusing on local, domestic markets for their wheat products. The complexity of the Food Alliance certification could prove a weakness as this certification is not yet well recognized compared to organic certification. Established organic brands of commodity products may be threats to SG branded products. At the same time opportunities exist in the domestic market by expanding the SG brand to other crops (e.g., garbanzos, lentils, red beans, sunflowers, etc.) they produce.

The PFP Farmer's co-op mainly marketed towards and provided marketing and educational services to the farming community and to its members. However, they did not market to distributors and wholesale, flour, and retail consumers to initiate demand and communicate the value of PFP certified brand products. Since there were no marketing efforts by the PFP label in conveying a value in Pesticide-Free Production there was no demand for the brand.

Therefore, an opportunity would be to increase the promotion to consumers by embracing information technology. Information technology allows effective communication between growers and consumers in order to provide quality and environmental considerations consumers' desire, thereby increasing PFP brand recognition.

Additionally, a different certification could be obtained providing more flexibility. The PFP certification was based on the requirement that a crop has to be inspected and certified as pesticide-free before harvest on a year by year basis. This system of certification can be more expensive because annual inspections can add considerable cost and administrative burden. Furthermore, this certification added to the uncertainty in production. PFP producers cannot be certain until later in a given crop year whether the crop passes certification. This can limit or delay the establishment of production contracts with consumers.

The PFP brand recognition could not be established in the marketplace because of liability issues in Canada. The Canadian government indicated that PFP was not truly a "Pesticide-Free" production system and so labeling food as such would be misleading. The main concern was that the PFP system allows a non-residual pre-emergence herbicide application, and so the production system was, in fact, not pesticide-free. Therefore, the government did not allow Farmer's co-op to use the term "Pesticide-Free Production" or "PFP" in any marketing or promotional activities for food products directed to Canadian consumers. The liability issues restricted the Farmer's co-op marketing their products at the retail level (i.e., retail consumers).

2.6.2 Value-Addition

Value-addition to products can be done in a variety of ways. Value-addition, in this case by an agrarian business, can be done by promoting and marketing their brand products on behalf of its members. The establishment of contracts within the supply chain can assure identity preservation/protection (IP) and a reasonable price in return for their products. In addition, obtaining independent third-party certification, in this case at the farm and/or production level, was an attempt to ensure that the disclosures made by the agrarian members were truthful and credible. Table 2.4 summarizes the SWOT analysis for each of the agrarian groups regarding their value-addition through the organization and third-party certification.

Table 2.4 SWOT analyses focused on SG and the PFP Farmer's co-op value-addition.

	Shepherd's Grain LLC	**Pesticide-Free Production Farmer's Co-op Ltd.**	
S	Food Alliance; IP flour; direct marketing	PFP certification	Internal
W	Only for wheat	Certification not communicated to consumers; quantity and quality variability	
O	Expanding and improving to other crops; retail brands	Integrating in processing and distribution (contracts) - IP	External
T	Losing contracts; cost of commodity; certification complexity	Cost of certification; credibility of certification	

The value of Food Alliance certification and the SG brand name was considerably high because SG growers economically benefit. Their brand name had a verifiable reputation, communicating the holistic embrace of the whole farm and production system. Food Alliance certification assisted SG flour in entering niche markets with their non-conventional products, serving in two ways: 1) as a tool to create alternative production and consumption systems; and 2) as a way to incorporate ethical practices into existing production systems.

SG brand guarantees IP of 99% pure SG flour. IP adds value to the wheat because the consumers were willing to pay a higher price for SG wheat. An internal weakness was that SG can only add perceived value to their wheat, which was processed into flour, but not for the other crops they grow. However, this can also bring opportunities by expanding their value-addition and establishing retail brands for their other crops. External threats facing SG can be the potential loss of wholesale and flour customer contracts as well as the fluctuation of commodity prices and production costs.

The strength of the PFP Farmer's co-op was their PFP certifications assuring that their products were in fact pesticide free. However, the Farmer's co-op did not promote and communicate the value of their certification to consumers. In addition, the quantity and quality of its members' products were inconsistent.

Opportunities exists for the Farmer's co-op to acquire facilities to further process their diverse products into a more valuable state by moving up the supply chain. Also, building contacts throughout the distribution system and using production and/or marketing contracts to establish IP can further increase the perceived value of PFP brand and products. Another opportunity would be to acquire a different certification process.

Since, a possible external threat to the Farmer's co-op is the credibility of their certification. PFP Canada, which took the responsibility to train PFP inspectors and was founded through government grants, does no longer exist. Plus, the cost associated with their PFP certification was considerably high, since yearly certification was required.

2.6.3 Premium Pricing

Premium pricing is gained through organizational attributes that add value to their products. When the organization and its products are perceived by consumers to have a higher value compared to other brand products with similar attributes, then the organization can ask for a premium price. Table 2.5 illustrates the SWOT analysis done on premium pricing for both agrarian groups.

Table 2.5 SWOT analyses focused on SG and the PFP Farmer's co-op premium pricing.

	Shepherd's Grain LLC	**Pesticide-Free Production Farmer's Co-op Ltd.**	
S	Transparent, stable price structure; IP; retail brands; specialty promotional products	Producers willing to adopt certification; consumers willing to pay more	Internal
W	Contracts locks in low prices; limited markets - promotion costs	No revenues collected; price never determined due to variability in quality and quantity	
O	Increase customer's loyalty and market shares; increase price	Increase demand internationally; specialized markets	External
T	Staying competitive	Over supply – price decreases; competitors	

SG's transparent and stable pricing structure benefited its producers because the prices for their products were not depended on the open market price for commodities. The transparency and IP makes it possible for wholesale and flour customers to see a wide range of product attributes, justifying the higher price for SG products. SG flour is now available in retail stores under the "Stone-Buhr" line of flour. In addition, SG provides flour for The Davenport Hotel (Spokane, WA) Homemade Bread Kit available to retail consumers to make their own bread at home.

Even though SG price structure allowed a reasonable rate of return, in some years the commodity prices may actually be higher then SG wheat. This was due to the fact that SG prices were locked into contracts. While the pricing structure can be a weakness, however, the stable price can also provide opportunities by increasing wholesale and flour customers' loyalty and market shares because these customers can rely on the SG price. The SG pricing model and production have to be reevaluated each year in order to stay competitive and realistic in the market place, ensuring their products were not too expensive but high enough to obtain a reasonable rate of return.

The strength of the PFP Farmer's co-op was their promotion to the farming community to adapt the PFP system. The Farmer's co-op could demonstrate that the PFP concept was manageable at the farm level and so producers were willing to adopt PFP criteria and certification. In addition, consumer research conducted at the University of Manitoba, Department of Agribusiness, found that retail consumers in Canada were willing to pay a 5-10% premium for Pesticide-Free Production – hypothetically, because PFP products were never available in the retail stores – over conventionally produced food products (Cranfield and Magnusson, 2003).

The Farmer's co-op was never able to collect revenues from trademark royalties. This was expected to be their main income source. One of the reasons was that Farmer's co-op lost control over their grains and brand once sold because no market contracts were established. No market contracts for PFP products also meant that a premium price could not be estimated with any precision. The uncertainty in total production volume of each crop and crop quality variability were also issues in establishing set premium prices as well as negotiating contracts.

A potential opportunity for the Farmer's co-op was to extend PFP promotion to the international markets and/or focus on specialized marketing. The large production capacity of its members gave them the ability to sell products in large quantities (i.e., tons). Therefore, the international market looked promising for high volume production. However, the possibility of over supply could decrease the price of their products international or domestically.

2.7 DISCUSSION

The SWOT analysis identified the major factors contributing to SG's success and the PFP Farmer's co-op's failure in finding markets for their products. These major findings are presented in Table 2.6.

The privately owned SG was successful in finding value-added markets for their participants' products. SG market development and promotions were done through direct and collective marketing with a focus on local markets in the PNW, including retail brand recognition. SG negotiated contracts which included a transparent price stability mechanism allowing SG growers to cover the cost of production with a reasonable rate of return back to family farms.

Additionally, SG added economic value to their wheat products by processing them into IP flour. This preserved attributes such as quality and associated image of sustainability that their consumers desire. SG brand communicated sustainable, local, safe, and IP food products. This accountability of their products and story was verified by the independent third-party Food Alliance certification. The certification was a tool for brand differentiation for SG products.

The PFP system had many interested farmers in the concept due to heavy marketing among farming communities in Western Canada. However, the lack of investment resulted in no establishment of contracts with wholesale and flour customers or distributors to exploit IP and/or premium pricing of PFP products. No contracts also meant that the Farmer's co-op was never able to economically benefit

Table 2.6 Major finding from the SWOT analysis by identifying the value-addition by both agrarian groups and their certification for marketing their products.

Added Value by:		**Shepherd's Grain LLC**	**Pesticide-Free Production Farmer's Co-op Ltd.**
Agrarian Group	- Organization	Collective marketing; Effective communication between involved parties	Information, training, marketing services, and newsletter for producers
	- Market promotion	Clear message with direct marketing	No clear message to consumers – no marketing
	- Price transparency	Yes - through contracts	No
	- Distribution	Vertical supply chain with contracts -IP	No contracts – no IP
	- Consumers	Newsletter to consumers	None
Certification	- Process	Independent - self certification of each growers farm	Governmental funded - academic certification for PFP production systems
	- Significance	Food Alliance valuable because independent organization	No value because not communicated to consumers; Governmental funded
	- Complexity	Every 3 year renewed – done by individual farms	Yearly certified, paid by government grant
	- Message	Clear – Food Alliance criteria	Not clear – not really "pesticide-free"

from the PFP brand because the co-op had no control over the products once sold.

The PFP brand and its certification were not successfully communicated to the consumers because there was no clear message. Therefore, no demand was established by the Farmer's co-op for the PFP label. There were no marketing efforts by the PFP label conveying a value in 'Pesticide-Free Production' and PFP certification. The limited direct marketing of the PFP product and certification was due to liability restriction in Canada not permitting food products to carry the PFP label. Also, the wide-spread and geographically isolated regions of potential distributors, consumers, and PFP growers across Canada limited effective communication between the Farmer's co-op, producers, and consumers.

2.8 CONCLUSION

This study identified many factors contributing to SG success and the PFP Farmer's co-op failure in the marketplace. The main factors were that SG can maintain contracts ensuring IP products and fair return on investments to their members, while the PFP Farmer's co-op was unable to do so. SG was effectively employing direct marketing to consumers, while their message was clear and ensured by Food Alliance certification. The PFP Farmer's co-op was not successful in direct marketing because the co-op failed to communicate the value of their PFP certification to consumers. Therefore, no demand was established for PFP certified products in the market place. Further, this study concludes that an effective environmentally-friendly third-party certification can indirectly help growers to develop market differentiation and access niche markets for their products; but only when the value of certification is communicated and with the presence of a marketing program.

The present trends in agricultural production are driven by consumer demand for increased transparency and sustainable food production (Conner et al., 1997). Therefore, market incentives can promote environmentally-friendly agricultural managements. Agrarian groups such as SG and the PFP Farmer's co-op wanted to differentiate their production practices from conventional agriculture for multiple reasons. As a response, certification of eco-friendly agriculture was acquired. Certification added value to agrarian groups' brand products due to legitimate assurance to consumers. Agrarian groups can further increase their product value by direct marketing and contract establishments; thereby ensure IP and quality of their products. As a result, the organizations can ask for premium price in the marketplace. Progressive producers have to respond to market developments and educate their consumers about the benefits of environmentally-friendly farming. If, progressive producers want to promote the use of the best possible agricultural management practices for sustainable crop production in order to increase farm profitability.

CHAPTER 3.

Belowground Dynamics of Intercropping Wheat and Pea in a Dryland Cropping System

3.1 ABSTRACT

The Plant Root Simulator (PRS^{TM})-probes (Western Ag Innovations Inc., Saskatoon, SK, Canada) are an emerging tool for the study of *in-situ* nutrient supply rates. PRS^{TM}-probes have not been used extensively in Pacific Northwest dryland cropping systems. The objectives of this study were to 1) evaluate soil nutrient supply rates for intercropping treatments and addition of N fertilizer in relation to agronomic performance; 2) determine optimum sampling times for observing differences in nutrient supply rates; and 3) compare nutrient supply rates in root exclusion cylinders to supply rates adjacent to plant rows. PRS^{TM}-probes were used within established agronomic trials at Pendleton, OR, where N fertilizer and pea inter-seeding with wheat were the treatments. Differences in nutrient supply rates were observed in connection with N fertilizer application. Few or no differences were observed for intercropping treatments. PRS^{TM}-probes identified an increase in N supply associated with the observed grain yield response to N fertilizer. Also, PRS^{TM}-probes did not detect a difference in N supply for intercropping where no grain yield response was observed. For most nutrients, the supply rates were greater earlier in the measurement period (April), associated with higher soil moisture. Most nutrient supply rates were not affected by the PRS^{TM}-probe placements (in-row or within root exclusion cylinders) during this period. PRS^{TM} nutrient supply measurements were related to plant response to N fertilizer and intercropping treatments in a one-year field experiment. Most relevant nutrient data were obtained during April. PRS^{TM}-probe placements inside a root exclusion cylinder did not appear to be essential for nutrient measurements in this dryland cropping system.

3.2 INTRODUCTION

Cereal-legume intercropping systems can increase the efficiency of resource utilization and can reduce nitrogen fertilizer requirements (Sullivan, 2003; Tilman et al., 2002; Crews and Peoples, 2005). In a dryland agricultural system, interspecies competition for water is a major concern and can result in the suppression of growth and yield responses by less competitive species (Szumigalski and Van Acker, 2005). Therefore, growing winter pea (*Pisum sativum*) with winter wheat (*Triticum aestivum*) simultaneously in the same rows can negatively affect wheat yield by scavenging water prior to wheat grain development.

Preliminary research showed that intercropping wheat with pea in North Central Oregon (Pendleton and Moro, 2004-05, OR) resulted in a grain yield increase (Machado and Tuck, 2005, unpublished data). In that preliminary study, grain yield increased 470 kg/ha in Pendleton and 1278 kg/ha in Moro when wheat was intercropped with peas.

Rotations or intercropping with legumes bring a natural source of N into agricultural soils. By determining the optimal wheat-pea ratio and synthetic N rate for wheat-pea mixtures, this knowledge can be used to develop a wheat-pea cropping system that relies less on artificial N and more on natural fixed N (Machado and Tuck, 2005 unpublished data). Additionally, legume crops acidify their rhizosphere by producing and excreting more organic acids as compared to cereals. This acidification of the rhizosphere can enhance P solubility (Li et al., 2007) and other nutrients that become more bioavailable with changing soil pH.

An additional factor to take into account is soil tillage and crop residue, which influence soil nutrient availability. Previous studies have confirmed that direct-seed (DS) management increases soil microbial biomass in agricultural soils as compared to conventional tillage (CT) (Doran, 1987; Granatstein et al., 1987; Carter, 1991). The large amount of soil disturbance of CT accelerates carbon loss and promotes nitrogen mineralization (Stewart and Bettany, 1982). Therefore it is important to understand how soil nutrients are affected by intercropping wheat with pea crops under both conventional and direct-seed management conditions.

Presently there is an interest in the dryland Pacific Northwest wheat production to adopt direct-seeding practices**.**

The focus of this one-year research study was the belowground nutrient supply dynamic of wheat-pea mixtures. The objectives of this study were to 1) evaluate soil nutrient supply rates for intercropping treatments and N fertilizer addition in relation to agronomic performance (grain yield); 2) determine optimum sampling times for observing differences in nutrient supply rates; and 3) compare nutrient supply rates in root exclusion cylinders to supply rates adjacent to the plant rows.

3.3 METHODS AND MATERIALS

3.3.1 Site Location and Soil

This field experiment was conducted at the Columbia Basin Agricultural Research Center (CBARC), Pendleton, Oregon (Umatilla County) (45.7ºN, 118.6ºW; elevation 438 m) in 2006-2007. The field site was conventionally tilled until the initiation of the experiment in the fall of 2005.

The soil type is a Walla Walla silt loam, classified as coarse-silty, mixed, super-active, mesic Typic Haploxeroll. The Walla Walla series consists of deep and very deep, well-drained soils formed in loess on hills (slopes are 0 - 20%) at elevations of 400 to 500 meters. The soil at CBARC receives 70% of its precipitation during the winter months from September to February. Wheat is seeded in the fall (September/October) and harvested in the following July/August. The mean annual precipitation is approximately 406 mm (12 to 15 inches).

3.3.2 Experimental Design and Treatments

Experimental design was a randomized complete block design with two, non-replicated systems: direct-seeding (DS) and conventional tillage (CT). The size of each system was 55 by 43 m. Each system had 6 different treatments plots, including a control, replicated 3 times (Table 3.1).

‘Stephens’ soft white winter wheat (*Triticum aestivum*) and ‘Spector’ winter pea (*Pisum sativum*) were seeded together on October 25, 2006 with a Fabro drill. Seeding depth for both crops was approximately 2.5 cm with a band of fertilizer (urea: 46-0-0) placed 7 cm deep and 2.5 cm to the side of the seed. Rhizobium-inoculated pea seeds were used. Seeding rate for winter wheat was 270 seeds/m^2 for all treatments, whereas pea seeding rates were: zero for 0% pea, 37.5 seeds/m^2 for 50% pea, and 75 seeds/m^2 for 100% pea.

Table 3.1. Treatments for direct-seed (DS) and conventional tillage (CT) systems. The 6 treatment plots consist of 3 different pea seeding rates (0, 50, and 100%) and 2 different rates of synthetic N application (0 and 45 kg ha^{-1}).

Treatments	% Wheat	% Pea	kg ha^{-1} N
1	100	0	0
2	100	0	45
3	100	50	0
4	100	50	45
5	100	100	0
6	100	100	45

3.3.3 Soil Measurements

Soil temperature was measured *in-situ* from March 28 to June 20 at a depth of 10 to 15 cm, using a Dallas semiconductor DS 1920 temperature iButtonÂ® (computer chip enclosed in a 16 mm thick stainless steel can). One 15-cm deep soil core from each treatment plot was taken every two weeks at the time of PRS™-probes exchange to determine gravimetric water content and baseline soil properties for each treatment combination. Every four weeks during the field experiment, three separate sub-samples from the main soil sample were used for soil microbial biomass carbon (MBC) determination by the $CHCl_3$ (chloroform)-fumigation extraction method (Horwath and Paul, 1994). Another three separate sub-samples were extracted with 100 mL of 0.5M K_2SO_4, shaken for 30 min on a rotary shaker at 350 rpm and filtered through a Whatman no. 1 filter. The filtrate was analyzed for soil NO_3^-–N and NH_4^+–N using a Lachat Quick Chem 4200 analyzer (Milwaukee, WI). All soil analyses were done at the USDA-ARS National Forage, Seed, Cereal Research Unit, Corvallis, OR.

3.3.4 Plant Biomass and Wheat Yield

A one-meter length of row was sampled for wheat biomass at the physiological maturity of wheat, one week before harvest in July, 2007 from each plot across both systems (DS and CT). The wheat was harvested during the second week of July with a plot-sized combine to determine wheat yield. Peas where not harvested in this experiment.

3.3.5 Ion-Exchange Membrane

Plant Root Simulator (PRS^{TM})-probes (Western Ag Innovations Inc., Saskatoon, Saskatchewan, Canada) (Figure 3.1) treated with $NaHCO_3$ were used to measure soil nutrient flux in the field. A PRS^{TM}-probe is designed as either cation or anion- exchange resin membrane enclosed in a plastic holding device, creating a probe (Figure 3.1). Nutrient supply rates were expressed as µg of nutrient adsorbed per 10 cm^2 of ion-exchange surface area over 2-weeks (i.e., µg/10cm^2/2wks). Nutrient accumulation on the ion-exchange membrane during the burial period can be considered as an estimate of the potential nutrient supply rate to an absorbing surface such as a plant root (Gibson et al., 1985; Casals et al., 1995; Huang and Schoenau, 1996b). Anion exchange membranes were used to obtain quantities of NO_3^-, HPO_4^{2-} or $H_2PO_4^-$, SO_4^{2-}, and BO_3^-. The cation exchange resin adsorbed NH_4^+, K^+, Ca^{2+}, and Mg^{2+} from soil solution. Supply rates of micronutrients, Mn^{2+}, Fe^{2+}, Cu^{2+}, and Zn^{2+}, were also measured. Therefore, a chelating pre-treatment with EDTA of the anion exchange membrane was employed,

Figure 3.1 A PRS^{TM}-probe pair consists of one cation (orange) and one anion (purple) PRS^{TM} -probe.

in addition to $NaHCO_3$. The chelating agent adsorbed to the anion exchange membrane forms complexes with these metal ions.

The PRS^{TM}-probe sampling events started on March 28, 2007, which included six, 2-week sampling periods. The sampling period began at the jointing/tillering stage and continued to the fully matured wheat growth stage. PRS^{TM}-probes were vertically inserted into the soil to a depth of 15 cm to measure nutrient flux *in-situ* with minimal disturbance. In each treatment plot, 2 PRS^{TM}-probe pairs were installed. Each PRS^{TM}-probe pair was buried in the field next to the seeding row, approximately 10 cm apart from each other (Figure 3.2).

Root competition is a potential problem, since roots can be stronger sink for nutrients than the PRS^{TM}-probes (WAII, 2006). Therefore, another 2 PRS^{TM}-probe pairs were buried (~ 4 cm apart) in the center of two separate root exclusion cylinders (REC) that were installed in the mid row of each treatment plot (Figure 3.2). By using the REC, competition for nutrients by plant roots is prevented and the net nutrient supply rate (total nutrient supply from soil) can be measured rather than the surplus of nutrient supply rate. The RECs were made from 10 cm diameter PVC-pipes cut to a length of 15 cm (WAII, 2006).

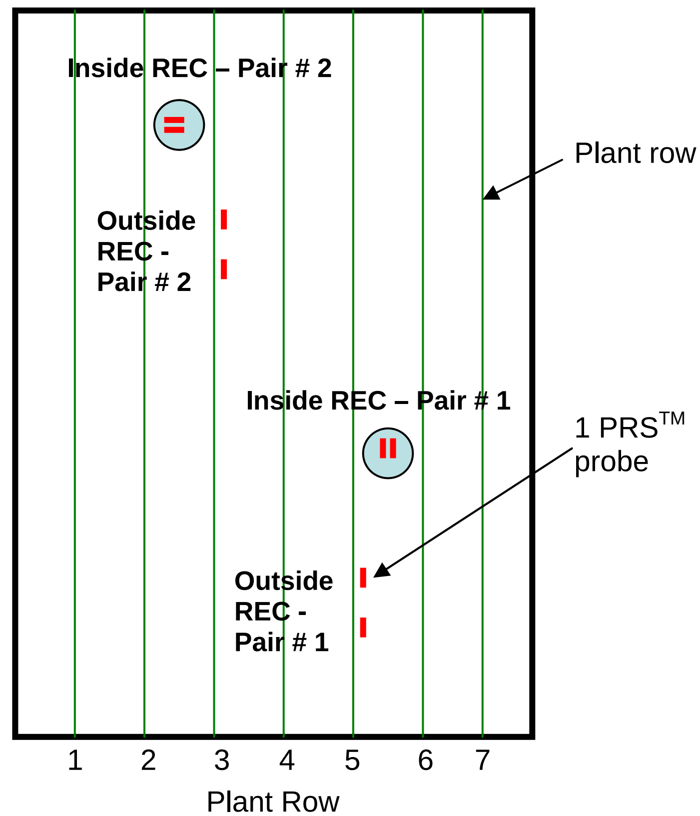

Figure 3.2 Diagram of treatment plot showing PRS^{TM}-probe placements. Outside the root exclusion cylinders (REC) PRS^{TM}-probes were inserted into the soil next to the plant rows; PRS^{TM}-probes inside the REC were placed in the mid-row between plant rows.

All buried PRS^{TM}-probes were exchanged biweekly with 'fresh' PRS^{TM}-probes into the same soil slots (sampling occurred at the same soil slots). The buried

PRS^{TM}-probes were removed and placed in polyethylene bags, transported on ice to the lab and stored in a refrigerator until cleaning. The PRS ^{M}-probes were rinsed with deionized water and scrubbed clean under running water to remove adhering soil. After cleaning, the PRS^{TM}-probes were stored in clean polyethylene bags in the refrigerator until shipment to Western Ag Innovations for analysis.

Twelve nutrient ions were measured with the PRS^{TM}-probes and extracted with 0.5N HCl simultaneously with one 1-hr extraction. The two PRS^{TM}-probe pairs (per plot) inside the REC were eluted together and the same was done for the two PRS^{TM}-probe pairs (per plot) outside the REC. The analysis for levels of nitrate (NO_3^--N) and ammonium (NH_4^+-N) was done via automated colorimetry (FIA Lab 2600). Other nutrients (PO_4^{2-}, SO_4^{2-}-S, BO_3^--B, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+}) in the eluate were measured by an inductively coupled plasma spectrophotometer (IRIS Intrepid II XSO, Thermo Scientific) (WAII, 2006).

3.3.6 Statistical Analyses

Statistical analyses were done using analysis of variance (ANOVA) with random component - Date; to test for statistically significant differences (p-value $\leq$ 0.05) among treatments within each system (DS and CT) for each nutrient supply rate over time. Statistical analyses for the nutrient supply rates were done using SAS System version 7. Four different ANOVAS with random component: Date, were done as follows:

1. DS experiment including root exclusion cylinders (REC) nutrient supply rate
2. DS experiment including outside REC nutrient supply rate
3. CT experiment including root exclusion cylinders (REC) nutrient supply rate
4. CT experiment including outside REC nutrient supply rate

Four separate ANOVAs were employed because nutrient supply rates measured outside the REC and inside REC are two different measurements of nutrient availability and have to by analyzed individually. For each of the ANOVAs, the independent variables were: pea rates (0, 50, 100) and N-fertilizer (0, 45 N- kg ha^{-1}). Soil nutrients were the dependent variables. The data: Inorganic N (NO_3^-–N and NH_4^+–N), PO_4^{2-}, SO_4^{2-}, Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+} was log transformed to improve random distribution in order to satisfy ANOVA assumptions. Results are presented using untransformed data.

Statistical analyses for soil nitrate-N, microbial biomass carbon, plant biomass, and wheat yield were obtained using ANOVA in JMP 4 (SAS Institute, Inc. version 4.0.4) to test for significant differences (p-value ≤ 0.05) among treatments within each cropping system, direct-seed (DS) or conventional till (CT).

3.4 RESULTS AND DISCUSSION

Data collection was done during one season. The data are presented in different ways to address the study objectives. First, soil measurement responses to treatments are discussed in relation to grain yield. Second, temporal aspects of 11 nutrient supply rates are presented to determine optimum sampling times for observing differences in nutrient supply rates among treatments. Lastly, nutrient supply rate measurements are compared to PRS^{TM}-probes placements inside vs. outside the root exclusion cylinders.

3.4.1 Soil Measurement Response to N fertilizer and Intercropping Treatments in Relation to Agronomic Performance

In the CT system, the N fertilized treatments significantly increased grain yields (p-value 0.0001), by around 300 to 600 kg ha^{-1}, compared to the non-fertilized treatments (Table 3.2). In the DS system, N fertilized treatments did not significantly affect grain yields (p-value 0.059) compared to the other treatments. Wheat yield was not significantly (p-value > 0.05) affected by the different pea seeding rates in either cropping system.

Mean wheat biomass and MBC were not affected (p-value > 0.05) by N fertilization or intercropping treatments in both CT and DS systems (Table 3.2). Significant effects were measured for soil nitrate (mg NO_3-N/kg soil) in fertilized treatments. DS (p-value 0.024) and CT (p-value 0.044) systems had twice as much soil nitrate concentration in fertilized treatments compared to non-fertilized treatments (Table 3.2). There were no statistical differences were observed

Table 3.2 Effect of N fertilizers and pea intercrop treatments on mean grain yield, wheat biomass, microbial biomass C (MBC), and soil nitrate-N. All treatments were seeded at same rate for wheat.

Seeding Rate % Pea	**Urea - N kg ha^{-1}**	**DS**	**CT**
		Grain yield, kg ha^{-1}	
0	0	1553	1677
0	45	2458	2107
50	0	1517	1464
50	45	2198	2128
100	0	1789	1768
100	45	1904	2060
Significance (ANOVA) (n=3)			
N fertilizer		NS	**
Pea rate		NS	NS
		Wheat biomass, g m^{-1}	
0	0	553	560
0	45	710	577
50	0	427	447
50	45	623	510
100	0	560	430
100	45	650	517
Significance (ANOVA) (n=3)			
N fertilizer		NS	NS
Pea rate		NS	NS
		Microbial biomass C, µg g^{-1}	
0	0	138	117
0	45	166	140
50	0	185	164
50	45	131	147
100	0	145	152
100	45	205	194
Significance (ANOVA) (n=15)			
N fertilizer		NS	NS
Pea rate		NS	NS
		Soil nitrate-N, mg kg^{-1}	
0	0	2	2.7
0	45	4.6	5.4
50	0	1.6	1
50	45	3.9	4.9
100	0	1.8	1.4
100	45	4	3.1
Significance (ANOVA) (n=15)			
N fertilizer		*	*
Pea rate		NS	NS

Significance level: 0.01, 0.05, NS = **, *, or NS in N fertilized treatments for soil ammonium-N (mg NH_4-N/kg soil) (data not shown). Soil NO_3-N and NH_4-N concentrations were not affected by pea seeding rates in either cropping system.

Similar to the standard soil test for soil nitrate-N, PRS™-probes measured a significant N fertilizer effect on inorganic N supply availability during the experiment (Table 3.3). The two soil tests identified an increase in N supply associated with the observed grain yield responses to N fertilization. Generally, PRS™-probes detected more significant differences in nutrient supply rates with N fertilization addition for the main macro nutrients N, P, and K compared to the pea intercropping treatments. PRS™-probes detected fewer significant effects with no consistent trends in the intercrop wheat-pea treatments (Table 3.3).

Table 3.3 Effect of N fertilizers and pea intercrop treatments on mean PRS™-probe nutrient supply rates inside and outside the root exclusion cylinders. All treatments were seeded at same rate for wheat.

PRS™--probes placement	**Seeding Rate % Pea**	**Urea - N kg ha^{-1}**	**DS**	**CT**
			NH_4^+ -N + NO_3^--N, µg/10cm^2/12wks	
In - REC	0	0	114	88
	0	45	100	85
	50	0	93	37
	50	45	111	91
	100	0	86	52
	100	45	157	93
	Significance (ANOVA) (n=18)			
	N fertilizer		*	NS
	Pea rate		NS	NS
Outside - REC	0	0	47	23
	0	45	82	69
	50	0	54	13
	50	45	84	48
	100	0	22	14
	100	45	87	42
	Significance (ANOVA) (n=18)			
	N fertilizer		*	**
	Pea rate		*	NS
			P, µg/10cm^2/12wks	
In - REC	0	0	2.7	2.1
	0	45	2.2	1.7
	50	0	2.8	2.5
	50	45	2.5	1.8
	100	0	2.3	2
	100	45	2.3	1.9
	Significance (ANOVA) (n=18)			

	N fertilizer		NS	*
	Pea rate		NS	NS
Outside - REC	0	0	3.1	3.2
	0	45	2.6	1.9
	50	0	3.4	2.5
	50	45	2.4	2
	100	0	3.3	2.4
	100	45	3.3	1.9
	Significance (ANOVA) (n=18)			
	N fertilizer		NS	**
	Pea rate		NS	NS
			K, μg/10cm^2/12wks	
In - REC	0	0	275	220
	0	45	220	208
	50	0	262	210
	50	45	251	202
	100	0	307	243
	100	45	279	195
	Significance (ANOVA) (n=18)			
	N fertilizer		*	**
	Pea rate		*	NS
Outside - REC	0	0	308	228
	0	45	229	166
	50	0	299	191
	50	45	226	137
	100	0	302	211
	100	45	270	157
	Significance (ANOVA) (n=18)			
	Fert N rate		**	**
	Pea rate		NS	*

Significance level: 0.01, 0.05, NS = **, *, or NS

3.4.2 Optimum Sampling Time for Observing Differences in Nutrient Supply Rates

The temporal aspects of 11 nutrient supply rates are discussed for observing differences among treatments. This section focuses on nutrient supply rates outside the root exclusion cylinder (REC) for reasons that are addressed in the next section. For nutrients supply fluxes of total inorganic N, P, S, Mn, Fe, Zn, and Cu the supply rates were generally greater during the first four weeks (April) compared to the later sampling dates (Table 3.4). This was associated with higher soil moisture and biological activity (i.e., MBC) early in the growing season (Table 3.5). Whereas the nutrient supply rates of K, Mg, Ca, and B stayed relatively constant during the experiment (Table 3.4), and were less affected by soil moisture and biological factors (Table 3.5). Drohan et al. (2005) found similar results for relative constant supply rates for basic cations at low soil moisture in the Mojave Desert, USA. Despite of low soil moisture (2.2 - 4.8%) to a depth of 25 cm PRS^{TM}-probes were able to continuously adsorb Ca and Mg over three months (Drohan et al., 2005).

Table 3.4 Mean nutrient supply rates from PRS^{TM}-probes at each 2-week exchange.

Exchange Date	**Inorganic N**	**P**	**K**	**S**	**Mg**	**Mn**	**Ca**	**Fe**	**Zn**	**Cu**	**B**
	-------------------------------------µg/10cm^2/2wks-------------------------------------										
14-Apr	236	5	240	9	289	16	1066	15	0.4	0.5	0.8
28-Apr	69	2	198	5	176	4	557	7	0.6	0.2	0.8
12-May	60	3	276	3	261	3	865	7	0.3	0.1	1.4
26-May	15	1	202	1	183	1	567	3	0.4	0.0	1.8
9-Jun	17	2	235	3	198	3	642	3	0.2	0.1	1.0
23-Jun	22	2	252	1	212	2	706	3	0.4	0.1	0.8

Table 3.5 Mean gravimetric soil water content and soil microbial biomass carbon (MBC).

Sample Date	Soil Water %	MBC µg C/g soil
28-Mar	25	234
14-Apr	20	156
12-May	12	187
9-Jun	7	107
23-Jun	6	100

Soil temperature remained below 20˚C until mid-May and did not rise above 30˚C during the time of the experiment was employed (Figure 3.3). The mean monthly soil temperatures were approximately 11, 17, and 21˚C in April, May, and June respectively. It appears that soil temperature was not as an important factor influencing ion diffusion and microbial activity (i.e., MBC) as soil moisture content. Soil temperature affects diffusion of nutrients in the soil, but does so indirectly (Barber, 1995; Yang et al., 1991a). Cool soil temperature generally decreases the diffusion of nutrients by slowing the activity of soil microorganisms crucial to nutrient cycling. Soil microorganisms are active throughout a large range of soil temperature, however, in temperate regions, the microorganisms with a prominent role in nutrient cycling are mesophilic (Sylvia et al., 2005). The temperature range of maximum mesophilic activity and therefore optimum nutrient cycling in soils of temperate regions ranges between 15 and 35˚C. Soil temperature in this study did not rise to 15˚C until the end of April beginning of May (Figure 3.3). For that reason, soil temperature influenced ion diffusion rates and biological activity less compared to soil water content. Nutrient supply fluxes and MBC correlated with soil moisture (Tables 3.4 and 3.5).

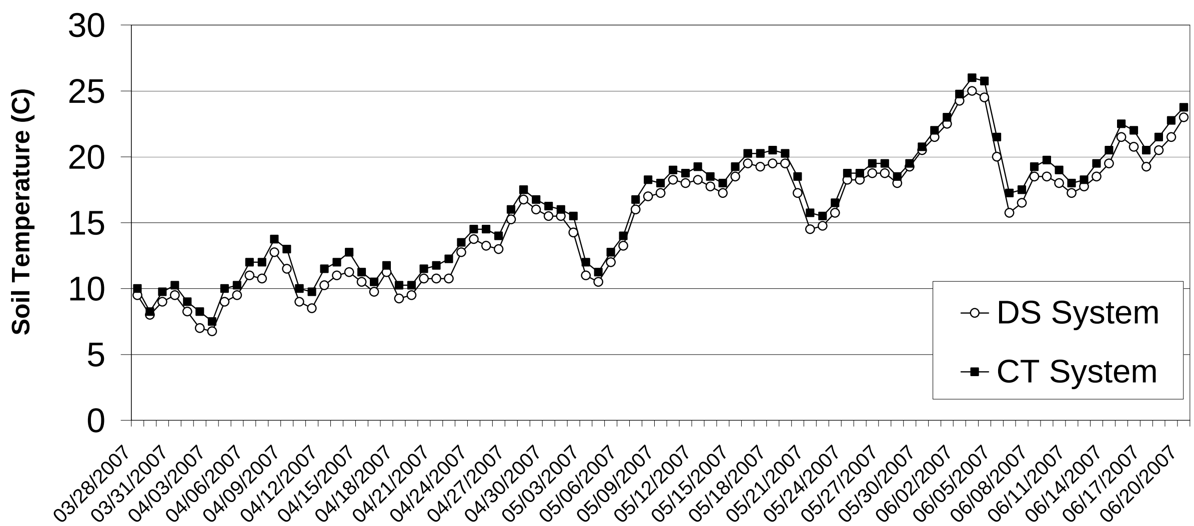

Figure 3.3 Soil temperatures for direct-seed (DS) and conventional till (CT) systems.

PRS™-probes were most sensitive in detecting N fertilizer treatment differences during the early period (April). The mean inorganic N (NH_4^+-N + NO_3^--N) in both DS and CT systems was significantly higher (p-value 0.028 and 0.001, respectively), by about 50 times, in the N fertilized treatments compared to non-fertilized treatments (Figure 3.4). Treatment differences for inorganic N supply rates were observed in April but not later in the growing season.

In the CT system, P supply rates were significantly lower (p-value <0.05), by about one fold, in N fertilized treatments compared to non-fertilized treatments (Figure 3.5). No significant N fertilizer effect on P supply rate was observed in the DS system (data not shown). The supply rate of P was not affected by the different

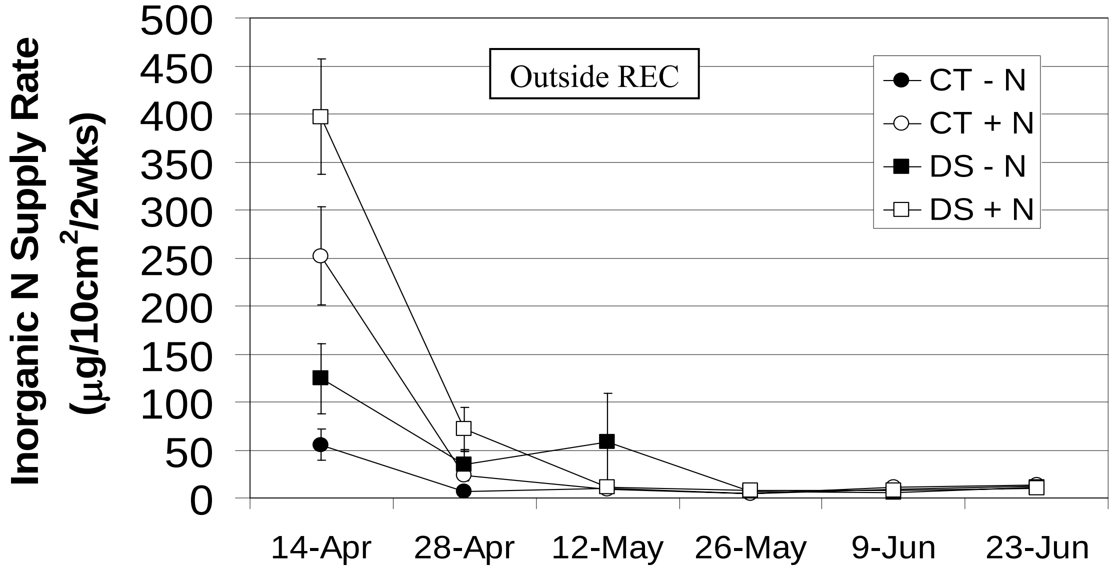

Figure 3.4 Supply rate of inorganic nitrogen from PRS™-probes at each 2-week exchange, measured in N fertilized (+ N) and unfertilized (- N) treatments for both direct-seed (DS) and conventional tillage (CT) systems. N fertilized treatments were greater (p-value < 0.05; n=9) than non-fertilized treatments.

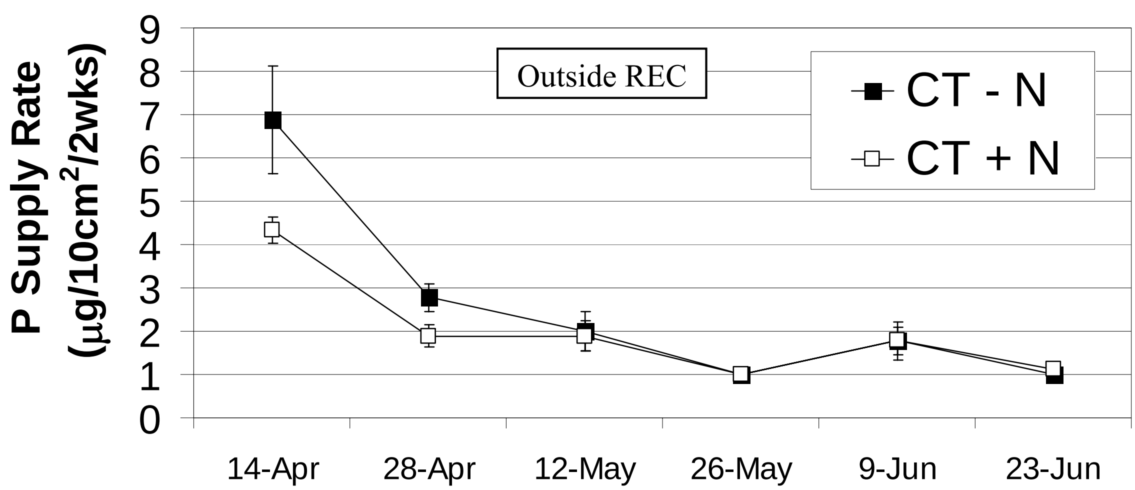

Figure 3.5 Supply rate of P from PRS™-probes at each 2-week exchange, in the conventional till (CT) system in N fertilized (+ N) and unfertilized (- N) treatments. The supply rate of P was less (p-value < 0.05; n=9) in N fertilized compared to unfertilized treatments.

pea seeding rates in either tillage system. Treatment differences for P supply rates were observed in April but not later in the growing season.

The mean K supply rate in the DS and the CT system, was significantly lower, 60 and 40% respectively, in the N fertilizer treatments compared to non-fertilized treatments (p-value 0.001 for both systems) (Figure 3.6). The timing for measuring treatment differences in K supply rate was not as important as compared to inorganic N and P supply rates. Early measurements for inorganic N and P were important to observe treatments differences but not for K supply rates (Figures 3.4, 3.5 and 3.6).

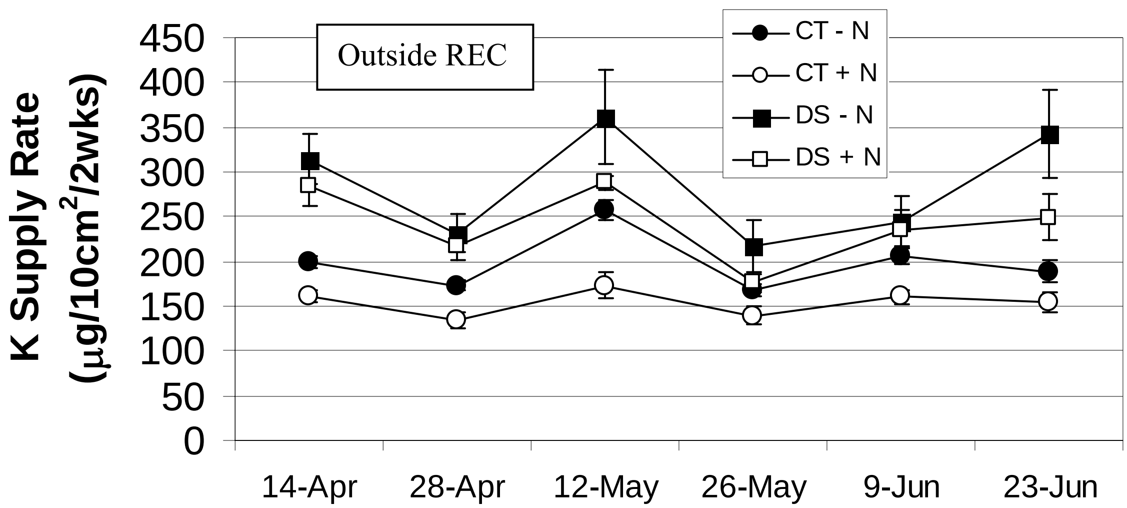

Figure 3.6 Supply rate of potassium from PRS™-probes at each 2-week exchange, measured in N fertilized (+ N) and unfertilized (- N) treatments for both direct-seed (DS) and conventional tillage (CT) systems. The supply rate of K over time was lower (p-value 0.05; n=9) in N fertilized compared to unfertilized treatments.

3.4.3 Nutrient Supply Comparisons of Root Exclusion Cylinder to Supply Rates Next to Plant Row

Most nutrient supply rates were not affected by the PRS™-probe placements, in row (next to plant rows) or in root exclusion cylinders (REC), during the early measurement periods (Table 3.6). When nutrient fluxes were greatest and were associated with higher soil moisture and MBC early in the growing season

(April) (Table 3.4 and 3.5). Table 3.6 shows the overall mean nutrient supply rates for the first two 2-week exchange periods inside versus outside the REC. Table 3.6 indicated that the dominant nitrogen species was nitrate-N and was the largest fraction of the inorganic N (NO_3^--N + NH_4^+-N) supply rate in both DS and CT systems.

Table 3.6 Mean PRS^{TM}-probe nutrient supply rates, for the first two 2-week exchange periods, differences observed for inside vs. outside the root exclusion cylinders (REC) in DS and CT systems.

DS System				
	Inside REC		**Outside REC**	
Nutrient ion	Mean supply rate µg/10cm^2/4wks	SE	Mean supply rate µg/10cm^2/4wks	SE
Inorganic N	216	23	157	30
NO_3^--N	207	23	148	30
NH_4^+-N	9	1	9	1
PO_4^{2-}	3	0	5 **	0
K^+	235	12	274 *	16
SO_4^{2-}-S	9 *	2	5	0
Ca^{2+}	815 **	54	613	43
Mg^{2+}	234 *	13	193	11
Mn^{2+}	12	2	12	2
Fe^{2+}	14 **	1	10	1
Cu^{2+}	0.4	0.1	0.3	0.1
Zn^{2+}	0.4	0.1	0.4	0.1
BO_3^-	0.6	0.1	0.6	0.1
CT System				
	Inside REC		**Outside REC**	
Nutrient ion	Mean supply rate µg/10cm^2/4wks	SE	Mean supply rate µg/10cm^2/4wks	SE
Inorganic N	152	28	85	21
NO_3^--N	146	28	77	21
NH_4^+-N	6	1	7	1
PO_4^{2-}	3	0	4 *	0
K^+	186	5	181	16
SO_4^{2-}-S	9 **	2	4	1
Ca^{2+}	934	50	884	90
Mg^{2+}	250	9	253	23
Mn^{2+}	9	2	8	2
Fe^{2+}	12	2	8	1
Cu^{2+}	0.4	0.1	0.3	0.0
Zn^{2+}	0.6	0.1	0.5	0.1
BO_3^--B	1.1	0.1	0.9	0.1

Significance level (ANOVA): 0.01, 0.05 = **, * (n=36)

In both DS and CT systems, P supply rate was significantly higher (p-value < 0.05) outside the REC compared to inside the REC (Table 3.6). The wide range of inorganic and organic acids produced by microorganisms and plants can act as chelating agents resulting in the release of orthophosphate into the soil solution (Li et al., 2007, Sylvia et al., 2005; Brady and Weil, 2002; Barber, 1995; Marschner, 1997). This acidification effect of the rhizosphere could explain the higher P supply rate to the PRS^{TM}-probes, which are buried next to the plants roots outside the REC.

Regardless of the PRS^{TM}-probe placements inside or outside the REC, the PRS^{TM}-probes measured nutrient supply rate differences in N fertilizer treatments. These trends are shown in Table 3.3; the different PRS^{TM}-probe placements did not alter the direction of N fertilizer effect on N, P, and K fluxes. That is, in N fertilized treatments, inorganic N supply rates were higher compared to zero N fertilizer. For P and K supply rates in N fertilized treatments were generally lower compared to zero N fertilizer. These trends appear regardless whether measurements were taken in or outside the REC (Table 3.3).

The approach of burying PRS^{TM}-probes *in-situ* both inside and outside of the REC can provide a more complete picture of the soil nutrient supply dynamics. The difference between ion fluxes inside and outside of REC can be used as an index of plant nutrient uptake (Huang and Schoenau, 1997). In this study, if this approach of estimating the index of plant nutrient uptake would have been taken, it could not be applied to P and K supply rates in the DS system and to P supply rate in the CT system. Because these ion fluxes were greater outside compared to inside the REC (Table 3.6). Therefore, a negative value would be obtained as an index of plant nutrient uptake.

3.5 CONCLUSION

The anticipated result of this field study was to gain a better understanding of a wide variety of soil macro-and micronutrient supply rates and their responses to intercropping treatments, application of N fertilizer, and grain yield in a dryland agricultural system. PRS^{TM}-probe measurements of nutrient supply rates were related to agronomic performance (grain yield) affected by N fertilizer and intercropping treatments in this one-year field experiment. Furthermore, the study provides insight on the optimum sampling times for observing treatment differences in nutrient supply rates and whether PRS^{TM}-probe placements (in row or in root exclusion cylinders) affected nutrient supply dynamics.

Wheat yield, in the CT system, was significantly higher in N fertilized (p-value < 0.05) compared to non-fertilized treatments where urea fertilizer was applied. There were no significant differences in wheat yield among the intercropping treatments in either the DS or the CT systems. In treatments that received N fertilizers, in both DS and CT systems, the PRS^{TM}-probes identified an increase in N supply associated with observed grain yield response to added fertilizer N. The PRS^{TM}-probe measurements provided similar results as the traditional soil test for inorganic N with added N fertilizer. Few or no differences were observed for intercropping treatments. Therefore, PRS^{TM}-probes did not detect a difference in nutrient supply for intercropping treatments where no grain yield response was recorded.

In this study, PRS^{TM}-probes were most successful in measuring greater nutrient supply rates earlier in the observation period (April), at a time that was associated with higher soil moisture. Differences between N fertilizer treatments were found early in the observation period and suggest that early measurements were more useful in relation to estimating wheat yield response. Lastly, PRS^{TM}-probe placements (in row or in root exclusion cylinders) did not affect the supply rates of most nutrients during the early sampling (April) when nutrient fluxes were greatest and measured values were related to grain yield. This indicates that different PRS^{TM}-probe placements may not be essential for nutrient measurements in this dryland cropping system.

This study shows that the fluxes of soil nutrient ions depend on soil moisture and biological factors. Since soil moisture and MBC decreased over the growing season, so did nutrient supply rates. Low soil moisture may have impaired the rate of decomposition, microbial growth, and diffusion of ions. Therefore, future PRS^{TM}-probe samplings should be conducted earlier in the growing season (e.g., in

February or beginning of March) or based on gravimetric water content more than 15% to get greatest sensitivity in detecting treatment differences in this dryland agriculture system. Measurements could be omitted after the middle of May when gravimetric water content is less than 15- 10%. In addition, PRS^{TM}-probe monitoring may not be ideally suited for identifying pea-wheat nutrient interactions in this dryland cropping system because peas do not produce much biomass (i.e., root growth) until later in the season (May) after most of the topsoil has dried out.

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Appendix A: Questionnaire

- How big is your farm?
- What do you grow? Do you grow anything else?
- How much of that is dedicated to Shepherd's Grain? Please explain.
- How long have you been farming? Please explain.
- Why did you become a member of Shepherd's Grain?
- How long have you been a member?
- What motivated you to become a member?
- Did you had to make changes on your farm and farming practices in order to become a member? Please explain. What kind of changes?
- What do you see as the benefits/drawbacks of Shepherd's Grain?
- What value do you see in environmentally friendly agricultural practices (conservation practices)? Why/why not? Please explain.
- What do you see as the benefits/drawbacks of environmentally friendly agricultural practices? Have you experienced any improvements as a result of the change?
- What value do you see in Shepherd's Grain brand? Please explain.
- Do you think there is a need for Shepherd's Gain in this region? Please explain. Why/why not?
- Has being a member of Shepherd's Grain group increased your return on investments? Why/why not? How did it increase your return on investments? And at what percent has it increases (or decreased)?
- What are your thoughts about Shepherd's Grain? And how it relates to you?
- Do you think Shepherd's Grain is a good idea in general?
- What would make Shepherd's Grain (more) successful, in your opinion?
- What are your thoughts about value-added products? How can they benefit you?
- Is Food Alliance certification essential to Shepherd's Grain? Why/why not? Please explain.
- Should Food Alliance certification be required for Shepherd's Grain? Why or why not? Please explain.
- Is there anything else you think I should know about Shepherd's Grain and Food Alliance at this point that would give me a better insight into how it's working or not working for people?