Yield Management of Pulse Crops in Manitoba

by

Eric Edward Peters

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF SCIENCE

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Abstract

The production of pulse crops such as field peas, lentils and faba beans in Manitoba is considered to be riskier than production of the more traditional crops such as wheat, oats, barley, flax and canola. A lack of adequate information about pulse production is one reason why pulses are considered to have a high risk of production. The goal of this study is to enhance the level of knowledge about pulse crop management practices for the further development of a crop management strategy for Manitoba pulse producers.

A two stage process is used to achieve this goal. First, a production model for Manitoba field pea, lentil and faba bean producers is developed using available scientific and agronomic information. Second, the production model is subjected to Ordinary Least Squares regression analysis, using Manitoba Crop Insurance Corporation (MCIC) data and other information sources, to estimate the marginal physical product of certain factor inputs and determine which factor inputs have the greatest effect on yield. Parameters representing the duration of the vegetative growth phase and the duration of the reproductive growth phase are approximated and included in the production model.

The first main conclusion of this study is that the time of planting has a significant effect on the yield of field peas and lentils. In certain cases, a positive logarithmic relationship is observed between the duration of the growth phases and yield. Within the field pea and/or lentil producer's decision framework, the time of planting significantly influences the length of the growth phases which in turn effects yield.

The second conclusion of this study was that producers who applied high rates of nitrogen fertilizer to their field pea and lentil crops, as opposed to Rhizobium inoculation, appreciated a positive effect on yield.

A final conclusion of this study regards the quality of the MCIC data base as a general information source for production economics research. The experience of this study suggests that the MCIC data base has limited value for any comprehensive empirical research in the area of crop production economics.

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Chapter 1. Introduction

1.0 Introduction

In Manitoba, pulse crops such as field peas, lentils and faba beans are considered to have higher agronomic risks of production than more traditional crops such as wheat, oats, barley, flax and canola.

One of the reasons pulses are considered to have a high risk of production is the lack of adequate information about producing pulses. Pulse crops received little attention during the "Green Revolution" in the 1950s and 1960s. Consequently, a limited amount of research into the crop management practices of pulses was conducted at that time, relative to wheat and other cereals,.

Crop management involves the allocation of factors of production to satisfy the objectives of the producer. To achieve these objectives, the producer must be able to make informed decisions about alternative courses of action. These decisions are based on the producer's knowledge about the past and expectations of the future. As there is a lack of information about pulse crop management, many of these decisions are made with considerable uncertainty.

Pulse crops represent a major opportunity for crop diversification in Manitoba and the other prairie provinces. Lack of information about how states of nature (not under the producer's control) and specific management practices (under the producer's control) affect production, serves to impede the wider acceptance of pulses as viable crops for production in Manitoba. Some producers may be uncertain about how to include pulses in their cropping program or uncertain about particular production practices. In addition, in the past, there was a smaller potential growing area due to limited markets and more restrictive growing conditions.

Development of a crop management strategy requires, first, a thorough analysis of production practices with a subsequent identification of the factor inputs which make the greatest contribution to yield. By following these practices, the producer could maximize yield. Construction of a yield maximization model is not the ultimate objective however.

The net return to the producer is usually not maximized by maximizing yield. Production costs may increase at a faster rate than the growth in revenue. Net return could then decrease, which would obviously be to the detriment of the producer. First, the producer must therefore know, which factors of production have a significant impact on yield. Second, given that information, the producer should know the consequent economic effects when making decisions about employing those factors of production.

1.1 Goal

The goal of this study is to enhance the level of knowledge of pulse crop management practices in Manitoba, and thereby contribute information towards the further development of a crop management strategy for pulse producers.

To achieve this goal, two objectives are identified:

1. develop a production model for the production of field peas, lentils and faba beans in Manitoba: and,

2. estimate the marginal physical product of certain factor inputs employed in the production of field peas, lentils and faba beans in Manitoba and determine which factor inputs have the greatest effect on yield.

1.2 Outline of Thesis

Chapter 2 provides a description of the agronomic information on pulse cropping that will be incorporated into the empirical analysis. A description of the important biological factors of pulses that must be considered in formulating the production model is included.

Chapter 3 describes the theoretical basis and assumptions underlying the analysis of economic efficiency in this study. This chapter focuses on the input-output transformations defined by the production function. Definitions of the various economic terms and expressions used in the study are also provided.

Chapter 4 discusses the formulation of the theoretical production function based on the agronomic and scientific information detailed in the previous chapter. The empirical production model is developed and the data used for the empirical analysis are described.

The results from the empirical analysis are presented in Chapter 5. Three sections detail the results from regression analysis of the model for each of field peas, lentils and faba beans with an accompanying discussion and conclusions.

Chapter 6 provides a summary of the study as well as its conclusions. Suggestions for further research are also included in this chapter.

Chapter 2. Important Biological Factors of Pulses and Their Agronomic Production in Manitoba

2.0 Introduction

This chapter is divided into two main sections. Section 2.1 is a discussion of the biological characteristics of pulses that require consideration when establishing the theoretical production function. In section 2.2, a brief description of field pea, lentil and faba bean production in Manitoba is given, as well as a summary of the cropping recommendations issued by Manitoba Agriculture during the study period. A brief summary is provided at the end of this chapter.

2.1 Important Biological Factors

Pulses have three characteristics that distinguish them from wheat and other cereals. First, like canola, certain varieties of pulses may display indeterminate growth. Second, pulses can form a nitrogen-fixing symbioses with Rhizobium bacteria. Third, pulses like flax and canola, are broadleaf plants. Each of these characteristics must be considered when formulating the theoretical production function.

The way pulses grow and develop, in particular the potential for certain varieties to display indeterminate growth, can determine how yields are affected by weather. The capacity of pulses to fix nitrogen through the symbioses with Rhizobium bacteria means that fertilizer requirements will be different than those for cereals and most oilseeds. As broadleaf plants, pulses are susceptible to certain plant diseases that also affect flax and canola, but do not affect cereals. The broadleaf nature of pulses also has implications for the types of pesticides that can be used. Susceptibilty to diseases and pest control are major considerations in how pulses can be included in crop rotations.

2.1.1 Growth and Development of Pulses

Pulse plants have two growth phases, the vegetative phase and the reproductive phase. The vegetative growth phase begins with germination and continues with the production of leaves, stems, tendrils and stipules until flowering. The reproductive growth phase begins with flowering and continues with the production of pods and seeds.

A number of varieties of field peas, lentils and faba beans have an indeterminate growth characteristic. This means that the vegetative components of the plant, i.e., leaves, stems, tendrils and stipules continue to grow after flowering. Therefore unlike wheat and other cereals, flowering does not mark the complete cessation of vegetative growth. Vegetative growth and reproductive development may continue simultaneously after flowering. This means that there are effectively two competitive developing sinks, each drawing on the plant's overall supply of nutrients, metabolites and water. Reproductive growth has a stronger sink activity and consequently after flowering the pods and seeds will grow rapidly relative to the vegetative parts of the plant, i.e., stems and leaves (Hardwick and Kelly, 1986). However, certain environmental conditions after flowering may be more conducive to vegetative growth than reproductive growth.

If flowering occurs late in the growing season because of conditions favouring vegetative growth, yields will be lower due to decreased reproductive growth, i.e., development of pods and seeds. Flowering early in the growing season may also result in decreased yields. As reproductive growth is a stronger development sink, vegetative growth may be impaired or may cease completely. Reproductive development is dependent upon the vegetative components of the plant for sustenance; photosynthesis occurs in the leaves. Without adequate vegetative structures, reproductive growth can not be sustained. The yield potential will therefore be diminished (Headley and Ambrose, 1985).

2.1.1.1 Factors Effecting Time of Flowering

Flowering, effectively the switching from the vegetative phase to the reproductive phase, is subject to the effects of photoperiod, mean daily temperature and heat or drought stress. The time of flowering and subsequently the number of seed pods formed will determine whether or not the plant will make optimal use of the growing season (Hadley, Summmerfield and Roberts, 1983).

Most pulses can be categorized into two groups with respect to their response to photoperiod: those in which flowering is induced by a photoperiod that is longer than some critical duration (long day) and those which flower sooner in response to a photoperiod that is shorter than some critical duration (short day).

The present day cultivars of field peas, lentils and faba beans have their ancestral origins in temperate climates. In temperate climates the plants would be exposed to lengthening days during the vegetative growth period. Consequently the time taken to flower decreases with an increased daylength in field peas, lentils and faba beans (Hadley, Summerfield and Roberts, 1983). Certain cultivars of these species may be neutral with respect to photoperiod. The majority will however have some response.

Time taken to full flower can be effected by the prevailing temperature during vegetative growth. Generally, the time taken to flower decreases with an increasing mean daily temperature. This phenomenon will persist up to an optimum temperature at which flowering is most rapid. At higher than optimal temperatures flowering will be delayed (Summerfield and Roberts, 1983). Under a continuous temperature greater than $23^{0}C$ an inhibition in flowering of faba beans with consequent lower reproductive growth and yields have been observed (Saxena, Saxena and Mohamed, 1986).

Drought or heat stress may induce flowering in some pulses. Field peas and lentils in particular are sensitive to these forms of stress. Temperatures over 30 degrees celsius persisting for two or three days may switch the plants from the early reproductive phase to the late reproductive phase (Slinkard, 1988).

2.1.1.2 Environmental Conditions and Development

An Australian study showed that the duration of the vegetative growth phase was positively and highly correlated with both the durations of time between planting and flowering, and planting and seed maturation (Aitken, 1978). In separate regressions of the days to flowering and days to seed maturation on the duration of the vegetative growth phase, highly significant linear relationships were observed.

Field experiments in western Canada showed that planting date was of greater importance than seeding rate on faba bean yields in western Canada (McVetty, Evans and Nugent-Rigby, 1986). Decreased yields of 28 percent and 36 percent were reported in experiments on delayed planting in 1983 and 1984 respectively. Seeding rates over the range of 75-125 percent of the normal recommended rate had minimal effects on yield or seed quality. Overall faba bean quality and protein content were unaffected by planting date. Yield losses due to delayed planting could be partially offset by increasing the seeding rate. Although a two week delay in planting consistently resulted in lower yields; even when the seeding rate was 125 percent above normal.

A study by Van Dobben (1962) investigated the influence of temperature and photoperiod on dry matter distribution, development rate and yield in field peas. Both the rate of the growth and the length of the growth period were found to be determinants of yield. The effect of temperature on the duration between emergence and flowering was independent of the effect of temperature on the rate of growth. A positive relationship was identified between temperature and the rate of growth. Conversely, there was a negative relationship between temperature and the number of days from emergence to flowering.

The Van Dobben study showed that the development rate, measured as the inverse of the number of days to reach a certain stage of development, increased with higher temperatures, but there was not a concomitant increase in growth. Although both the growth rate, measured as the time required for a tenfold increase in dry weight, and the development rate increased at high mean temperatures; the field pea plants had a lower dry weight at flowering. Conversely, dry weight of the field pea plants at flowering and maturity was greater when grown at a lower temperature.

The effect of temperature on the rate of development in pulses was also examined in controlled experiments by Hadley, Summerfield and Roberts (1983). The relationship between the time required to reach a particular stage of development (D) and temperature was shown to be linear.

$$\frac{1}{D} = a + bt_k \; ,$$

where: D = *number of days*,
a = *cultivar specific constant*,
$-(\frac{a}{b})$ = *base temperature*.
b = *inverse of the number of thermal units above the base temperature*,
t_k = *mean daily temperature*.

2.1.2 Nitrogen Fixation

Field peas, lentils and faba beans are legumes and therefore have a symbiotic relationship with nitrogen-fixing Rhizobium bacteria. The particular species with which they form a symbiosis is *Rhizobium leguminosarum*.

The Rhizobium can exist in the soil or the seed itself can be inoculated with the bacterium. The bacterium infects the root-hairs of the developing seedling causing a nodule to form. A nodule is a specialized organ formed from the root cortical tissue of the plant and contains clusters of bacteria in the central infected zone. The bacterium has a nitrogenase enzyme which converts atmospheric nitrogen (N_2), into ammonia (NH_3).

Ammonia produced from the nitrogen-fixing reaction can then be incorporated into amino acid synthesis by either the plant or the bacteria. In turn, the amino acids may be further incorporated into proteins (Lehninger, 1982).

In the symbiosis the plant benefits by having a source of nitrogen in a form which it can metabolize. The bacterium benefits in that the host plant provides: a source of energy, and a microaerophilic environment inside the nodule which allows it to fix nitrogen for its own metabolic requirements.

2.1.2.1 Inoculation

Inoculation with Rhizobium bacteria is generally recommended for pulse crop production in Western Canada. Although under certain circumstances, where a high-yielding and well nodulated field pea or lentil crop has been grown in a field, the soil-borne Rhizobium may remain viable in that field for a number of years and the need for seed inoculation may be precluded (Slinkard, Drew and Holm, 1988).

An inoculant is a mixture of a strain or strains of Rhizobium bacteria and a carrier material (Saskatchewan Agriculture, 1987). The carrier material functions to sustain and protect the live bacteria. Powdered inoculant, the most common form, uses finely ground peat or clay as a carrier. Powdered inoculant must be applied to the seed, prior to planting, with a sugar or powdered milk based solution to ensure that the inoculant adheres to the seed. The second type of inoculant has a granular form and may be applied with the seed during planting. The granular inoculum is more convenient to use but is more expensive on a per acre basis than powdered inoculum.

The concentration of the Rhizobium inoculum used is of extreme importance. In faba beans, reduced yields can occur when one half of the normal seed inoculation rate is used (University of Manitoba, 1976).

2.1.2.2 Factors Effecting Biological Nitrogen Fixation

The conversion of atmospheric nitrogen into ammonia is an exothermic reaction, meaning that energy is released in the reaction. Energy is required however, to activate it. In the Haber-Bosch process, the procedure used to manufacture nitrogen fertilizer, hydrocarbons are consumed to produce the high temperatures and pressures required for the reaction to proceed non-enzymatically. In biological nitrogen-fixation the source of the energy for the reaction comes from carbohydrate metabolism. Carbohydrates are formed by photosynthesis (carbon-fixation). The rates of photosynthesis and carbohydrate formation in the plant may therefore be limiting factors in nitrogen-fixation (Elkan, 1984).

Other factors which can have an on effect nitrogen-fixation are the crop variety, soil structure and mineral content, water availability, planting date and the particular strain of Rhizobium present (Askin, White and Rhodes, 1985). Reduced nodule growth, hence decreased nitrogen-fixing capacity, has been observed where there is a water deficit. High soil salinity may also impair nodule formation and growth (Sprent, Stephens and Rupela, 1986).

Low concentrations of mineral nitrogen in the soil may stimulate nodule formation, leading to subsequent nitrogen-fixation. The presence of mineral nitrogen also functions to give the plant an overall better start in the early stages of growth. However, in subsequent periods there is an inverse relationship between mineral nitrogen concentrations and the amount of nitrogen fixed symbiotically (Jardim Freire, 1984).

High concentrations of mineral nitrogen may inhibit nodule formation. The plant would then be primarily reliant on mineral nitrogen rather than symbiotic nitrogen-fixation for its nitrogen requirements.

Availability of phosphorous in the soil may also affect nitrogen fixation. Low soil phosphorous concentrations can adversely affect nitrogen-fixation. Plants which are solely dependent on symbiotic nitrogen-fixation require more phosphorous than those reliant on mineral nitrogen (Jardim Freire, 1984).

2.1.2.3 Nitrogen-Fixation and Fertilizer Application

Application of too much nitrogen fertilizer, may lead to reduced nodule formation and decreased fixation of atmospheric nitrogen. The form of nitrogenous compound applied as fertilizer can also affect the degree to which nodulation is impaired. Ammonia is the least detrimental, followed by urea, then nitrate which has the most detrimental affect (Jardim Freire, 1984).

A study conducted in India showed a significant yield response in field peas to nitrogen application in the absence of the legume-Rhizobium symbiosis (Mahler, Saxena and Aeschlimann, 1986). Although observed yields increased by 43 percent with inoculation alone, the study showed that both inoculation and nitrogen application together improved yields. Maximum yields were observed with inoculation and the application of nitrogen fertilizer at a rate of 17.9 pounds per acre. The same study suggested that nitrogen application was necessary when nodule formation was poor or failed.

In field experiments conducted on two sites in Manitoba, Dean and Clark (1980) examined the effects of a low concentration of nitrogen fertilizer on nodulation and dry weight of faba beans and field peas. Application of 17.8 pounds per acre of nitrogen fertilizer was shown to cause an inhibition of symbiotic nitrogen-fixation in both field peas and faba beans. Significant increases in the dry weight of faba beans were not observed. In certain cases, the dry weight of field peas showed a positive response to the low level application of nitrogen fertilizer.

In growth chamber experiments, Richards and Soper (1979) investigated the effects nitrogen fertilizer application on yield, protein content and nitrogen-fixation in faba beans. Application of nitrogen fertilizer was found to have no effect on the yield or protein content of the faba beans. In the absence of applied nitrogen, faba bean plants were able to obtain their nitrogen requirements from nitrogen-fixation. Very low concentrations of nitrogen applied at seeding failed to produce a starter effect in the plants during early growth. This suggested that the combination of nitrogen available in the seed, soil and through nitrogen-fixation was adequate during early plant development. The authors suggested that increasing levels of applied nitrogen fertilizer would cause reduced nitrogen-fixation without increasing yield or the total uptake of nitrogen by the faba bean plants.

A more recent study conducted in Manitoba, showed that the Century and Express varieties of field pea grown in a controlled environment were capable of meeting all nitrogen requirements through nitrogen-fixation (Vessey, 1991). However the same study found that under field conditions, nitrogen-fixation declined after flowering in the

Century variety. This phenomenon was attributed to environmental stresses occurring during the field trials.

Ukrainetz, Soper and Nyborg (1975) observed positive yield responses in faba beans to supplemental nitrogen application when the legume-Rhizobium nitrogen-fixing symbioses was under environmental stress.

Application of phosphorous in phosphorous deficient conditions, where field peas were reliant solely on symbiotic nitrogen-fixation, increased nitrogen concentrations in shoots and also increased dry weight (Robson, 1986). In field peas positive yield responses in field peas to sulphur have also been documented (Mahler, Saxena and Aeschlimann, 1986). Sulphur deficiencies may also have an adverse effect on the legume-Rhizobium symbiosis, thereby limiting nitrogen-fixing capacity.

2.1.3 Broadleaf Nature

The broadleaf nature of pulses is a major determinant of what management practices can be used to control diseases and pests in the crop. Management options available to the producer for the control of diseases and pests are discussed in the following three sub-sections.

2.1.3.1 Disease

Ascochyta blight is an important fungal disease of field peas. Although the Century variety of field pea is resistant to certain strains of this disease, it does not have resistance to the strain of Ascochyta most common in Manitoba. The disease may originate from infected seed, wind blown spores, over-wintered straw and stubble or may be soil borne. Suggested control measures against this disease are: planting of pedigreed seed, tillage after harvest, treating seed with a fungicide, and only including peas in the crop rotation once every five years (Ali-Khan and Zimmer, 1980).

Other fungal diseases of field peas are root rots and seedling blights. These include Fusarium root rot, Rhizoctonia and Sclerotinia. Crop rotation is the recommended method of cultural control for these diseases. By rotating crops the buildup of patheogenic organisms in the soil can be prevented. Chemical control involving the use of fungicides such as Captan or Thiram has also been proven effective. The fungicide, Vitavax, may be used to control to reduce seedling blight in peas caused by soil-borne Rhizoctonia. It is imperative that the fungicide used is not toxic to the nitrogen-fixing Rhizobium bacteria (Bernier, 1975).

Fusarium wilt is a soil-borne disease which can not be controlled by crop rotation. The field pea varieties Alaska and Arthur have a strong resistance to this disease. Although observed in eastern Canada, this disease has had a low occurrence in western Canada (Ali-Khan and Zimmer, 1980).

Bacterial blight has had a low incidence in western Canada in the past. Control of bacterial blight involves crop sanitation measures. The Victoria pea variety has some resistance to bacterial blight (Langilee, MacLeod, Bubar and Jones, 1986).

Diseases affecting lentils in Manitoba are Anthracnose, Ascochyta blight, Fusarium root rot, Rhizoctinia root rot, and Sclerotinia wilt. Crop rotation, the use of fungicides and disease free seed are recommended control measures.

Fungal diseases infecting faba beans in Manitoba are; rust, Ascochyta blight, Fusarium root rot, Sclerotinia root rot and powdery mildew. Control measures for these diseases include crop rotation, planting disease free seed and the use of fungicidal seed treatments. In the past a recommended fungicidal seed treatment was benomyl combined with Captan or Thiram (Bernier, 1975). More recent research showed Captan to be harmful to seed applied Rhizobium bacteria (Rennie, 1986).

2.1.3.2 Pests and Their Control

The most common insect pests of pulses are aphids. Aphids can propagate rapidly in hot dry weather and are capable of causing serious damage. In addition, aphids can spread fungal diseases. Recommended insecticides for the control of aphids are dimethoate and malathion (Manitoba Agriculture, 1988).

Pulses compete poorly with weeds. Weeds that begin growth concurrent with or shortly after germination of the crop will have the most detrimental effect on yield (Hunter, Sexsmith, Keys and Chubb, 1975). Weed control may be achieved by cultural practices or with herbicides.

Cultural methods of weed control include the use of clean seed and seeding into relatively weed free fields. Tillage prior to planting is suggested as an effective means of weed control.

Preplant incorporated herbicides recommended for field pea cropping during the period of this study included: trifluralin (Treflan, Rival, Triflurex), triallate (Avadex BW). Postemergent treatments recommended included: barban (Carbyne), diclofop methyl (Hoe Grass 284), dalapon (Basafapon, Dalapon, Dowpon), sodium trichloroacetic acid (TCA), metribuzin (Lexone, Sencor), methyl chlorophenoxy acetic acid (MCPA sodium salt), sethoxydim (Poast), a mixture of methyl chlorophenoxy butyrate and methyl chlorophenoxy acetic acid (MCPB and MCPA mixed - Tropotox), and bentazon (Basagran) (Manitoba Agriculture, 1987).

Since 1988, barban and dalapon were both withdrawn from Manitoba Agriculture's list of herbicides recommended for field pea production. Herbicides that were added to the list are ethalfluralin (Edge), mixed Sencor and Edge, mixed Sencor and triflualin, and Excel (Manitoba Agriculture 1993).

Lentils compete poorly with both grassy and broadleaf weeds. Intensive weed control must be practised as yields may be decreased by up to 75 percent due to competition with weeds. Chemical methods of weed control in lentils include both preplant incorporated and postemergent herbicides. Trifluralin was the only preplant incorporated herbicide recommended for lentil production in Manitoba during the period of this study. Recommended postemergent herbicides included diclofop methyl and metribuzin. It should be noted that metribuzin under the trade name Sencor was the only form of metribuzin recommended for use in lentils in Manitoba (Manitoba Agriculture, 1987). Herbicides added to the crop production recommendations for lentils since the period covered by this study are: BioMal, Excel and Poast (Manitoba Agriculture, 1993).

In faba beans, consistent weed control has been attained by fall applications of tank mixes of trifluralin and metribuzin. Other recommended herbicides include diclofop methyl, and bentazon (Manitoba Agriculture, 1987). Since the period covered by this study, Edge, Poast, mixes of Sencor and Edge, and mixes of Sencor and trifluralin were added to the crop production recommendations for faba beans (Manitoba Agriculture, 1993).

Canada thistle is a major weed problem in pulse cropping. Only one herbicide, bentazon, is recognized as a chemical control measure of Canada thistle in pulses. The effectiveness of bentazon to control Canada thistle is limited, as the herbicide only kills topgrowth in the weed.

2.1.3.3 Crop Rotations

Due to the susceptibility of pulses to certain plant diseases; pulses should be included in a crop rotation only once every three to five years. Pulses should not precede or follow sunflowers, canola, flax or another pulse in the rotation.

The lack of chemical controls for specific weed problems in pulses must also be considered in the design of the crop rotation. If there are no herbicides available that can safely control a particular weed in the pulse crop, attempts should be made to control that weed, by cultural or chemical measures, prior to planting the pulse. Canada thistle is an example of a weed against which there is no safe and effective chemical control in pulses. Therefore an infestation of Canada thistle in a field should be remedied by chemical application in the year preceding the pulse in the crop rotation or by tillage prior to planting the pulse.

Including pulses in the crop rotation with the subsequent incorporation of plant residue into the soil can reduce the level of nitrogen fertilizer required in successive crops. Peas grown before wheat and canola in a crop rotation has been shown to facilitate a reduction in nitrogen fertilizer requirements (Planquaert and Desbureaux, 1985).

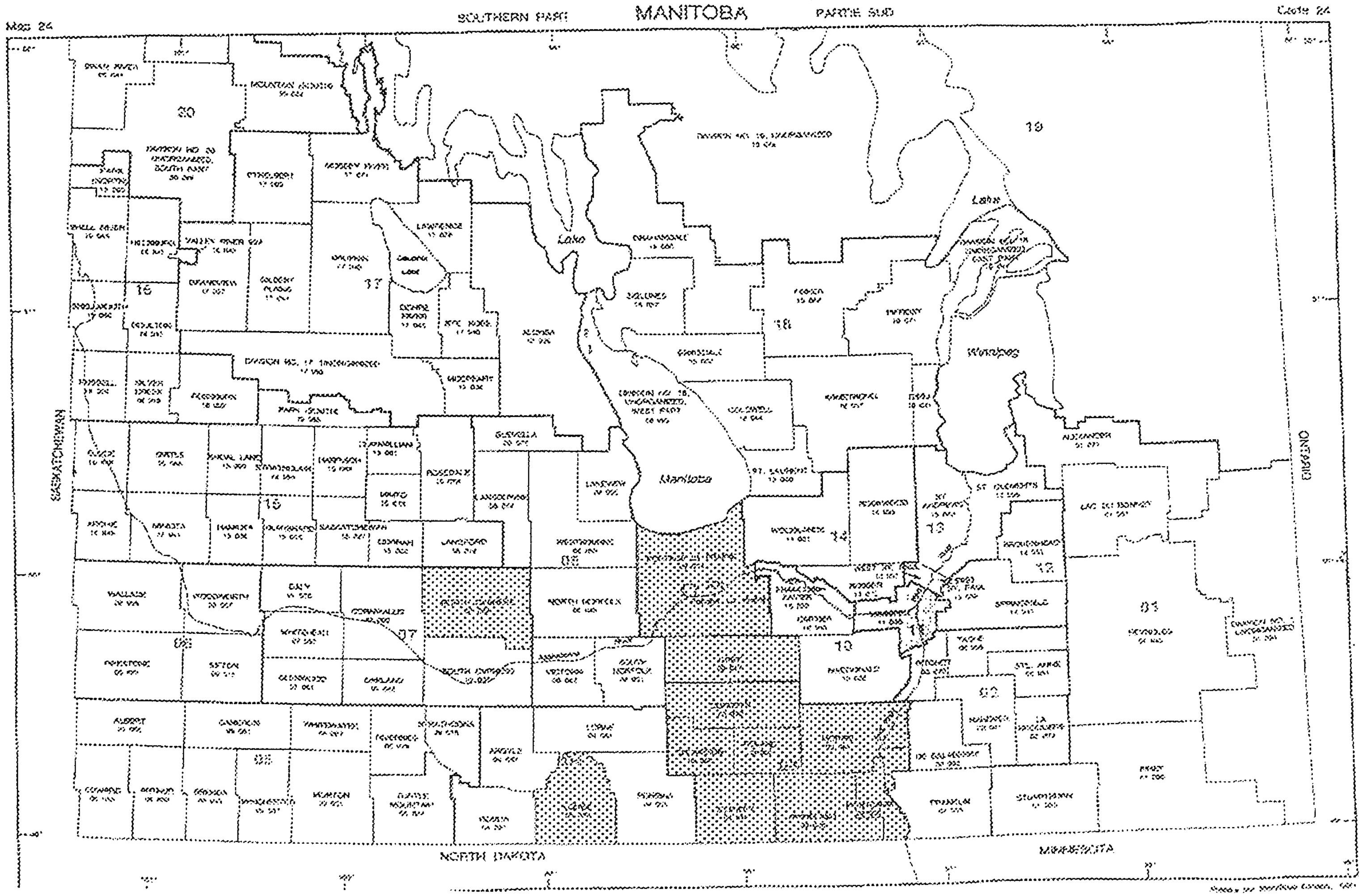
2.2 Production of Pulses in Manitoba

Although field peas, lentils and faba beans have many agronomic requirements in common, their response to climate and soil types may differ. As most of these crops were grown under producer-buyer contracts, a producer's proximity to a buyer may also have been a factor in where cropping was located. For these reasons, production of one or more of these pulses tended to be concentrated in certain regions of Manitoba.

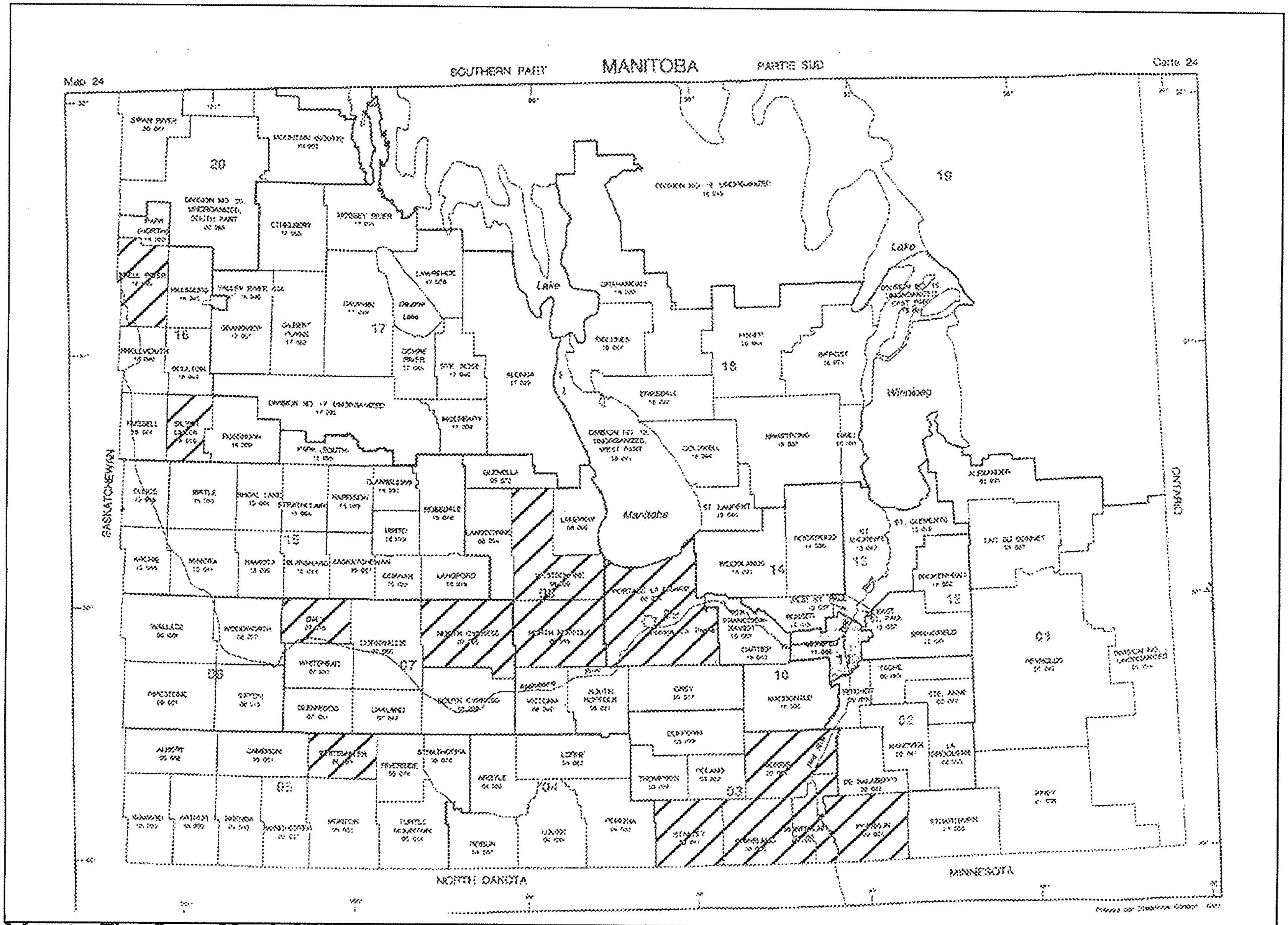
Map 1 shows the geographic areas of Manitoba where field pea production was concentrated in the 1981 to 1987 period. Although field peas were grown in many regions of Manitoba, production was concentrated in the southern Red River Valley, the Portage La Prairie area and the Pembina Valley. Over seventy-seven percent of field pea producers were located in municipalities shown by the shaded area on Map 1.

The shaded portions on Map 2 show the areas where lentil production was concentrated. Most lentil growers were located in the southern Red River Valley, southern Pembina Valley and the south central region of the province including the Portage La Prairie area. Approximately sixty-eight percent of lentil growers were located in municipalities represented by the shaded areas on Map 2.

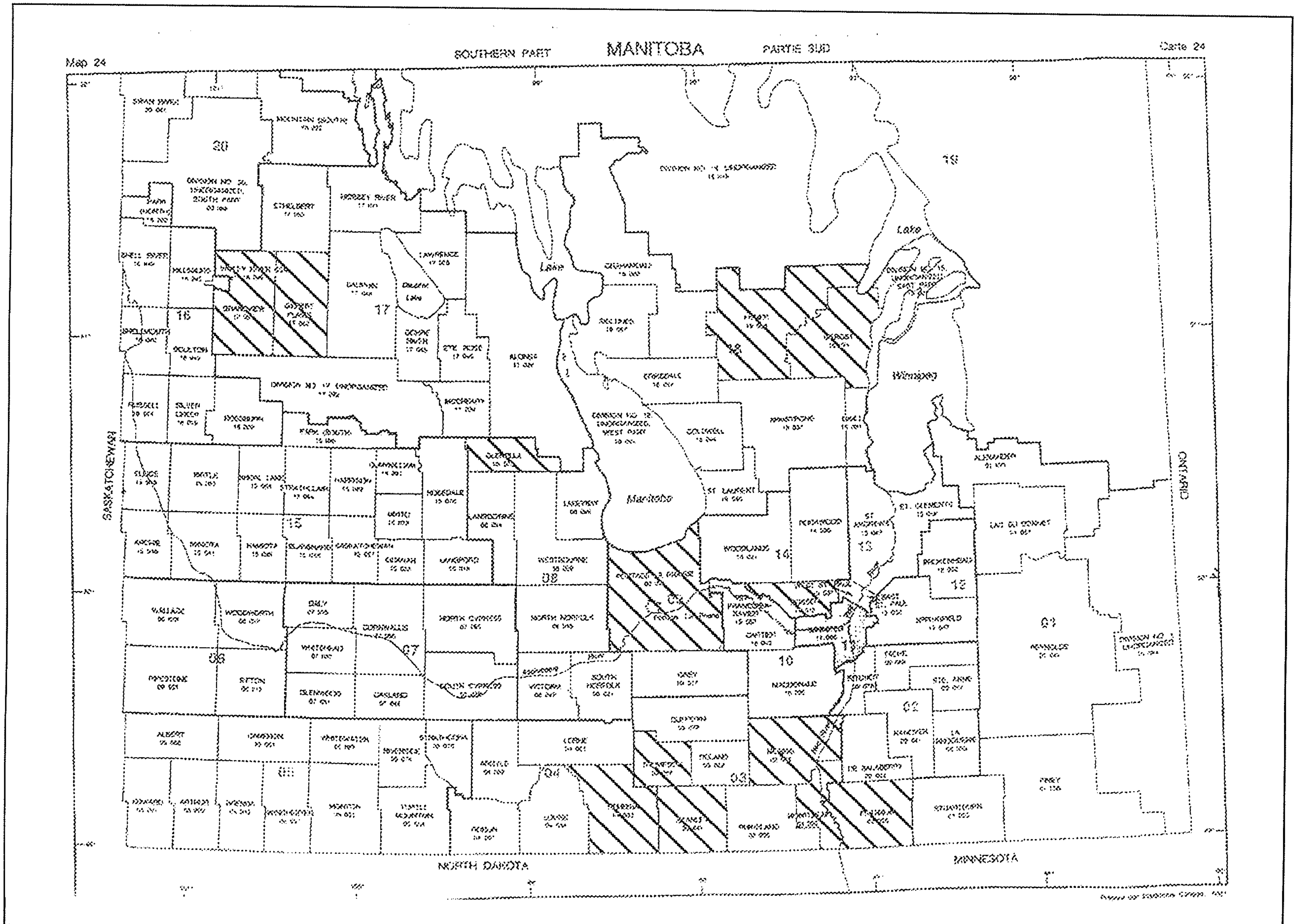
Almost seventy percent of faba bean growers were located in municipalities represented by the shaded areas on Map 3. Faba bean production was concentrated in the northern Interlake, southern Red River Valley, southern Pembina Valley, the Portage La Prairie region and the Grandview-Gilbert Plains area.



Map 1. The Shaded Area Indicates the Location of Field Pea Production



Map 2. The Cross Hatch Indicates the Location of Lental Production in Manitoba.



Map 3. The Cross Hatch Indicates the Location of Faba Bean Production in Manitoba

2.2.1 *Weather*

The climate in many agricultural areas of Manitoba is well suited to the production of field peas, lentils and faba beans. Field peas are a cool season crop with mean maximum temperatures of 20°C to 21°C being optimum for yields. High temperatures occurring after flowering may negatively effect yields. In field peas the period in which the plant is the most sensitive to damage from high temperature, ranges fromfive to ten days after full flower (Saxena, Saxena and Mohamed, 1986).

Lentils can tolerate higher temperatures than either field peas or faba beans. In some cases, heat or drought stress may be required to induce flowering in lentils (Slinkard, 1975).

In warm conditions, high temperatures can adversely affect vegetative growth in faba beans. Periods of hot and dry weather can also result in wilting.

Field peas have a low tolerance to drought stress during and immediately after flowering. Alternatively in lentils, high moisture conditions can promote vegetative growth by causing a delay in flowering and thereby delay crop maturity. In Manitoba, high lentil yields have been observed where the seasonal rainfall was in the 25 to 28 centimeter reange (Manitoba Agriculture, 1986). Faba beans require higher levels of moisture than either field peas or lentils.

Environmental stresses such as heat or drought stress generally affect populations of Rhizobium bacteria less severely than the host pulse plant. However a water deficit may inhibit nodule growth on the roots of the plant and thereby decrease nitrogen-fixing capacity (Sprent, Stephens and Rupela, 1986).

In addition to the considerations noted above, temperature and moisture will also effect the rates of growth and development of the pulse crop during the growing season. Given a particular planting date, both the time of flowering and the time the crop matures will be largely determined by weather conditions.

2.2.2 *Soils*

In Manitoba, well drained clay loam soils are reported to be the best for field pea production. Lower moisture holding capacities of light sandy soil produces lower yields. However with adequate rainfall, higher yields have also been observed on the light sandy soils. Heavy clay soils with adequate surface drainage have also produced high yields (Manitoba Agriculture, 1986).

Lentils are fairly well adapted to conditions in the Black soil zone of Manitoba. The most suitable Black soil type is deep sandy-loam soil that is well drained (Manitoba Agriculture, 1986).

Calcium and magnesium soil deficiencies for pulse cropping have been rarely reported world-wide. In cases where calcium deficiencies were reported, the application of calcium in the form of lime has improved yields. Magnesium deficiencies were most likely to occur in acid, coarse textured soils, resulting in reductions in the number of seeds per pod, pods per plant and size of seed (Mahler, Saxena and Aeschlimann, 1986).

Eight other essential micronutrients have been identified for pulses. They are: boron, chlorine, cobalt, copper, iron, zinc, mangenese and molybdenum.

2.2.3 Varieties

Varieties of field peas {Pisum sativum L.} recommended for production in Manitoba at the time of this study were: Century, Titan, Tara, Tipu, Victoria, Trapper and Triumph (Manitoba Agriculture, 1988). Among these Triumph is the only green seeded variety, the others being yellow in colour. It should be noted that the market distinguishes between yellow seeded and green seeded field peas. Varieties may be further categorized into large, medium and small seeded varieties. Titan and Triumph are large seeded. Medium seeded varieties include Century, Tara, Tipu and Victoria. Trapper is the only small seeded variety. Field trials conducted in Manitoba in the 1986-87 crop year showed Victoria to be the highest yielding variety (Manitoba Agriculture, 1988). Other varieties ranked from highest to lowest yield in the same trials were Triumph, Tara, Titan, Century, Tipu and Trapper. Varieties ranked from earliest to longest maturation period were Victoria (90 days), Trapper (95 days), Century, Titan and Tipu (all 96 days), followed by Tara (97 days), and Triumph (99 days).

Since 1988, a number of varieties were added to the field pea variety recommendations for Manitoba. These include: AC Tamor, Bohatyr, Express, Miko, Patriot, Richmond, Topper, Danto, Princeses, Radley, Sirius, Stehgolt and Yellowhead (Manitoba Agriculture, Manitoba Seed Growers Association and Manitoba Cooperator, 1993).

During the period of this study, two types of lentils (Lens esculenta) were grown in western Canada. Chilean, is a large seeded lentil and includes the varieties Laird and Commercial Chilean (Canada Grains Council, 1978). The second type, Persian, is a smaller seeded lentil and includes the varieties Dark-Speckled and Eston. Eston is an earlier maturing variety (95 days) and is reported to be higher yielding than the larger seeded Laird lentil which takes 103 days to mature (Manitoba Agriculture, 1989). The lentil market distinguishes the Eston variety from the Laird. 1993 variety recommendations for lentil production in Manitoba also included a red type of lentil called Rose (Manitoba Agriculture, Manitoba Seed Growers Association and Manitoba Cooperator, 1993).

Commercial varieties of faba beans recommended for production in Manitoba were; Ackerperle, Aladin, Herz Freya, Outlook and Pegasus (Manitoba Agriculture, 1988). The Ackerperle variety (no longer available in Manitoba), although slightly higher yielding than Herz Freya, takes 105 days to mature compared to 101 days for Herz Freya. In 1992, the Orion variety was added to Manitoba Agriculture's list of recommended faba bean varieties.

2.2.4 Nutrient Application

The application of nitrogen fertilizer is not recommended for field pea, lentil and faba bean production, under the assumption that the legume-Rhizobium symbiosis is capable of supplying adequate nitrogen for growth (Manitoba Agriculture, 1988-90). However it should be noted that in the past the application of some nitrogen fertilizer was recommended, presumably to give the plant a better start in early growth prior to the formation of the legume-Rhizobium symbiosis (Ali-Khan and Zimmer, 1980).

Pulses have high phosphorous requirements in the early stages of growth. The availability of phosphate compounds in the soil depends on the solubility of the compound, the soil acidity and soil salinity. Yields respond positively to phosphorous fertilizer particularly when available soil phosphorous is low. For yield maximization, faba beans require slightly more phosphorous than wheat (Ukrainetz, Soper and Nyborg, 1975).

Recommended rates of phosphorous application for pulse production in Manitoba depend upon whether the phosphorous is sidebanded or applied with the seed. In a sideband application, rates of between 27 and 40 pounds per acre are suggested. If applied with the seed, a maximum rate of 18 pounds per acre is recommended (Manitoba Agriculture, 1988).

Potassium fertilizer is recommended for field pea, lentil and faba bean cropping on sandy, sandy loam and organic soils. Pulses have a high susceptibility to fertilizer damage during the germination period. Therefore, production recommendations suggested that the potassium fertilizer should be sidebanded at a rate of 31 to 62 pounds per acre (Manitoba Agriculture, 1988).

For pulse production in Manitoba, the application of sulphur fertilizer at rates of up to 18 pounds per acre is recommended (Manitoba Agriculture, 1988). The higher rates of sulphur application are suggested for production on well drained soils, grey wooded soils or where a sulphur deficiency has been established by a soil test.

2.2.5 Planting Date and Planting Implement

Field peas, lentils and faba beans have a high tolerance to frost in the seedling stage. Early seeding is recommended to allow these crops to make optimal use of the growing season. Recommended planting dates vary slightly for the three crops however. For field peas, planting between May 1st and May 25th is suggested (Manitoba Agriculture, 1988). Lentils are susceptible to frost damage late in the reproductive phase of growth, prior to seed maturation. Therefore it is recommended that lentils be seeded prior to mid-May. Recommended planting dates for faba beans run from April 25th to May 15th.

An important consideration in the selection of a seeding implement for field peas and lentils is the placement of seed at a shallow and uniform depth in the soil. Faba beans require more moisture for germination and therefore should be planted at a lower depth in the soil than either field peas or lentils.

Various seeding equipment may be used for planting pulses. Although the double disc press drill, the discer seeder and the hoe drill are recognized as the most effective (Saskatchewan Agriculture, 1987).

2.3 Summary

Three biological characteristics of pulses must be considered prior to formulating the production function. They are: the growth and developmental characteristics (including the potential for indeterminate growth), the ability to form a nitrogen-fixing symbioses with Rhizobium bacteria, and the plants' broadleaf nature. The growth and developmental characteristics of pulses will determine how yields are effected by weather during the growing season. Fertilizer requirements for pulse production will differ from those for cereal and oilseed production due to the nitrogen-fixing symbioses. The broadleaf nature of pulses determines what management practices can be used to control diseases and pests as well as the placement of pulses in the crop rotation.

Chapter 3. Theoretical Bases and Definitions

3.0 Introduction

The production function is an mathematical representation of the production process. A production function describes the set of technically feasible production possibilities that constrain decision making in a firm. Depending on its specification, three physical relationships can be defined in a production function. They are the input-output, input-input, and output-output transformations. Input-output transformations define the physical relationship between factor inputs of production and output (Beattie and Taylor, 1985). Input-input transformations define the technical interrelationships between factor inputs of production. Output-output transformations define the relationship between different outputs linked through resource constraints (Beattie and Taylor, 1985). As well as defining physical transformations, the production function, also forms the basis for the analysis of economic efficiency.

Although the production function will be defined and subjected to Ordinary Least Squares regression, a complete analysis of economic efficiency will not be undertaken in this study. However, a discussion of economic efficiency is included in this chapter.

In this study, the production of each of the three pulse crops are examined independently. Therefore, this chapter will focus on the input-output relationship.

The problem of economic efficiency is reviewed from the perspective of the individual firm (the pulse crop producer). The assumption is made that perfect competition exists in both the input market and product market. This assumption implies that the individual firm has no control over the price received for the crop, nor the per unit costs of factor inputs.

The final section of this chapter is a brief discussion of the econometric problems that could arise when using Ordinary Least Squares regression to estimate the production function.

3.1 Input-Output Relationship

The production function can be expressed mathematically as

$$Y = f(X_1, X_2, X_3, \ldots, X_n), \tag{3,1}$$

$$\begin{aligned} \textit{where: } Y &= \textit{total physical product (output)}, \\ X_i &= \textit{variable factor input } i, \\ i &= 1,2,3,\ldots,n. \end{aligned}$$

The mathematical expression states that output Y, is a function of variable factor inputs $X_1, X_2, X_3, \ldots, X_n$. Effectively the level of output is dependent on the levels of factor inputs employed in production.

Crop production involves a very large number of inputs. The pulse crop producer has control over how some of these inputs are employed in the production process, i.e., fertilizer and herbicide application. Alternatively, there are a number of inputs that are either fixed or not under the producer's control, i.e., soil type and weather.

The data used in this study contain information on only a limited number of the inputs affecting yields of pulse crops. In turn, the empirical analysis focuses on only a few of those inputs. Therefore to facilitate the analysis of the relationship between output and the inputs we assume that the production process is weakly separable.

The assumption of weak separability implies that the production process can be partitioned into different sub-processes. Each sub-process results in the production of an intermediate input. The intermediate inputs, from the different sub-processes, ultimately combine within the production process to produce the final output (Chambers, 1988).

Under the assumption of weak separability, the production function given in Equation 3,1 is rewritten as,

$$Y = F(f(X_1, X_2, X_3, ..., X_k),\ g(X_{k+1},...,X_n)). \tag{3,2}$$

This equation states that the function, $f(X_1, X_2, X_3,...,X_k)$, describes the production of an intermediate input within the larger production process defined by function F. Likewise the function, $g(X_{k+1},...,X_n)$, also defines the production of an intermediate input.

Average Physical Product (APP_1) is the level of Y divided by the level of X_1, and can be defined in mathematical terms as

$$APP_1 = \frac{Y}{X_1}.$$

Marginal Physical Product (MPP_1) is the change in total output attributable to the addition of one unit of X_1 into production with the other inputs fixed at a constant level.

The MPP_1 is also equal to the partial derivative of Y with respect to X_1 (Henderson and Quandt, 1980). MPP_1 can be mathematically expressed as

$$MPP_1 = \frac{\partial Y}{\partial X_1}.$$

The previous assumption of weak separability described in Equation 3,2 implies that the marginal rate of technical substitution (*MRTS*) between any two inputs in the group, $f(X_1, X_2, X_3,...,X_k)$, is unaffected by changes in the levels of any inputs in the other group, $g(X_{k+1},...,X_n)$, (Henderson and Quandt, 1980). This is mathematically expressed as

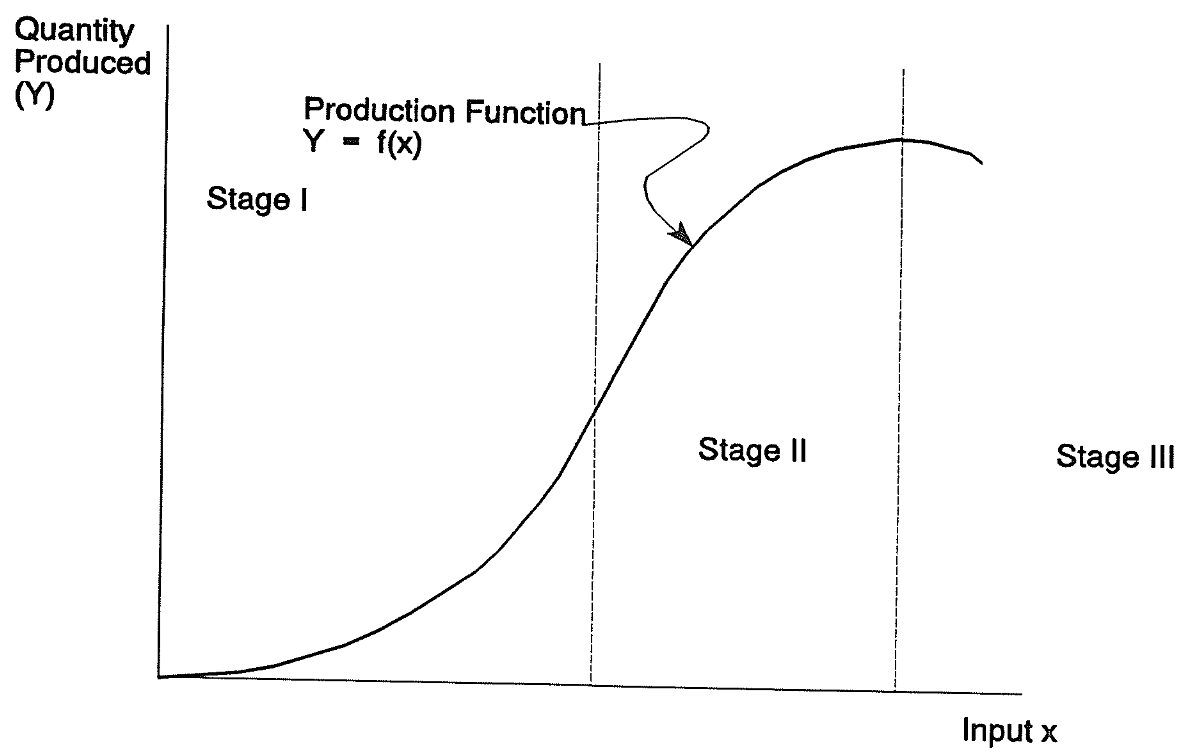
$$\frac{\partial}{\partial X_{k+1}} \frac{\partial Y/\partial X_1}{\partial Y/\partial X_2} = \frac{\partial}{\partial X_{k+1}} MRTS_{12} = 0,$$

$$\textit{where: } MRTS_{12} = \frac{MPP_1}{MPP_2}.$$

This equation states that the technical relationship between inputs X_1 and X_2, does not change when the level of input X_{k+1} increases or decreases.

The relationship between the level of output Y and the level of input X_1 can be graphically illustrated by the total physical product curve, shown in *Figure* 3,1. The total physical product curve depicted in *Figure* 3,1 is a representation of a neoclassical production function. Such a production function can be divided into three sections;

Figure 3,1. Neoclassical Production Function.



Stage I, Stage II and Stage III. Initially in Stage I, both *APP* and *MPP* are increasing. *MPP* is greater than *APP*, and this condition persists throughout Stage I. *APP* increases as higher levels of input X_1 are applied to production. Also MPP_1, which represents the rate of change in Y, is increasing. Maintaining production in this region of Stage I is economically irrational. Each additional unit of input employed in production results in a higher level of output than the previous level of output.

At a point on the production function called the inflection point, still within Stage I, MPP_1 begins to decrease due to the law of diminishing marginal product (Henderson and Quandt, 1980). MPP_1, although decreasing, is still greater than APP_1; therefore production in this region of Stage I is alsoeconomically irrational. Effectively, each additional unit of input employed in production still results in a higher unit of output.

As more of the input is applied in production, MPP_1 continues to decrease until it is less than APP_1. The point at which MPP_1 is equal to APP_1 marks the beginning of Stage II production.

Stage II is the economically rational area of production. Although each additional unit of the input added produces a lower unit of output than that unit of output which was added previously, output is still increasing, albeit at a decreasing rate (Debertin, 1986). MPP_1 continues to decrease until it equals zero, at which point output or Y reaches a maximum. This point marks the end of Stage II, the rational area of production.

In Stage III, MPP_1 is negative and continues to decrease. Effectively, output or Y decreases despite the higher levels of the input applied in production. Production in this area is obviously irrational.

3.2 Input Side - Economic Efficiency

Under perfect competition in the product market, total value product TVP, is the per unit price of the product multiplied by the total physical product Y. Therefore TVP is the value of the output produced (Beattie and Taylor, 1985). In mathematical terms the expression for TVP is

$$TVP = P(Y) = P[\,F(f(X_1, X_2, X_3,\ldots, X_k), g(X_{k+1},\ldots,X_n))\,],$$
$$\textit{where: } P = \textit{per unit price of output.}$$

To facilitate an analysis of the relationship between a particular input X_1, and TVP, the previously made assumption of weak separability is continued. Average physical product (AVP) of X_1 is the TVP divided by the level of X_1 applied to production. It is defined as

$$AVP_1 = \frac{TVP}{X_1}.$$

Marginal value product (MVP) is the rate of change in TVP resulting from a small change in the level of an input applied in production. The MVP of an input is equal to the partial derivative of the *TVP* function with respect to that input (Beattie and Taylor, 1985).

MVP_1, the marginal value product of input X_1 can be defined as,

$$MVP_1 = \frac{\partial(TVP)}{\partial X_1}, \quad or \quad MVP_1 = P(MPP_1). \tag{3,3}$$

In the second expression, MVP_1, the marginal value product for input X_1 is equal to the per unit price P, of the output multiplied by the marginal physical product for input X_1 (MPP_1).

To carry the analysis further the total factor cost (TFC) function must be defined. Assuming the production function is weakly separable, *TFC* can be expressed as,

$$TFC = \sum_1^k r_i X_i + \sum_{k+1}^n r_i X_i + b,$$

$$\begin{aligned} where: \; r_i &= per\ unit\ price\ of\ input\ X_i, \\ X_i &= level\ of\ input\ i, \\ b &= fixed\ costs. \end{aligned}$$

The *TFC* function can also be defined under the assumption that input X_1 is variable with all other inputs held constant at some fixed level. *TFC* can then be written as,

$$TFC = r_1X_1 + \sum_2^k r_iX_i + \sum_{k+1}^n r_iX_i + b,$$

$$\textit{where: inputs } X_2, X_3, \ldots, X_k, \textit{ and } X_{k+1}, \ldots, X_n,$$
$$\textit{are at constant levels.}$$

The marginal factor cost (*MFC*) of an input is the rate of change in total cost when one unit of that input is added to production. The marginal factor cost of input X_1, MFC_1, is equal to the partial derivative of the total cost function with respect to X_1.

$$MFC_1 = \frac{\partial(TFC)}{\partial X_1}. \tag{3,4}$$

Under perfect competition in the input product market, the marginal factor cost of an input will equal the per unit price of that input.

$$MFC_1 = r_1.$$

Profit maximization is achieved when the marginal value product for an input is equal to the per unit price of that input.

$$P(MPP_1) = r_1, \quad or \quad P(MPP_1) = r_1(\frac{1}{MPP_1}),$$

$$where\text{: } P = r_1(\frac{1}{MPP_1}).$$

If MVP_1 is greater than MFC_1, then more of factor input X_1 should be used in production to increase profit. Conversely, if MVP_1 is less than MFC_1, less of factor input X_1 should be applied in production.

If the price of the output exceeds the marginal factor cost of the input, the employment of that factor input in production should be increased, *ceteris paribus*. If the price of the output is less than the marginal cost of the factor input, the employment of that factor input in production should be decreased.

3.3 Profit Maximization

This section is a brief review of the theory of profit maximization of the firm. Three assumptions are made in the following discussion. First, profit maximization is an objective of the pulse crop producer. Second, perfect competition exists in both the input markets and product market. Third, the production function has weak separability.

Profit is equivalent to total value product, TVP, less total factor cost, TFC. The profit function is mathematically expressed as

$$\pi = TVP - TFC,$$

$$where\text{: } \pi = profit.$$

The first-order conditions for maximizing profit require the first derivative of the profit function with respect to the input X_1, to equal zero. This implies

$$\frac{\partial \pi}{\partial X_1} = 0, \ or \ \frac{\partial (TVP)}{\partial X_1} - \frac{\partial (TFC)}{\partial X_1} = 0.$$

The first and second term of this expression were previously defined as MVP_1 and MFC_1 respectively in Equations 3,3 and 3,4. To fulfil the first-order condition for profit maximization, MVP_1 must be equal to MFC_1. This gives

$$MVP_1 = MFC_1.$$

Fulfilment of the first-order condition is a necessary but not sufficient condition for profit maximization. Profit maximization requires that the second-order conditions are also met. The second-order conditions require that the second partial derivative of the profit function with respect to the input X_1 be less than zero. This is represented as

$$\frac{\partial^2 \pi}{\partial X_1^2} < 0.$$

Under the assumption of perfect competition in both the input and product markets, this equation implies that the production function must be strictly concave to the origin in the region where the first-order condition is met (Beattie and Taylor, 1985).

3.4 Potential Econometric Problems

Econometric problems from using Ordinary Least Squares (OLS) regression can occur if one or more of six basic assumptions about the specification of the production function have been violated (Johnston, 1984). These six assumptions are: the functional form is linear in parameters; the expected value of the error term is zero (error term has a zero population mean); all exogenous variables are uncorrelated with the error term; the error terms for different observations are not correlated (no autocorrelation); the error term is homoskedastic (constant variance) and is normally distributed; and, the exogenous variables are not collinear (no multicollinearity).

Biased and inconsistent coefficient estimates will result from OLS regresssion if the true functional form is non-linear, a relevant exogenous variable is omitted from specification, an exogenous variable is measured with error, or an irrelevant variable is included in specification.

If either conditions of autocorrelation or heteroscedasticity exist, then the standard errors of the coefficient estimates will be biased and the coefficient estimates will be inefficient.

If multicollinearity exists, OLS coefficient estimates will be unstable and may change in sign and/or magnitude as observations are added or deleted from the sample.

Chapter 4. Formulation Of The Empirical Production Model

4.0 Introduction

This chapter is divided into three main sections. The first section discusses the formulation of the proposed production model. Information about the data base used in the empirical analysis of this study is given in the second section. The third section details the specification of the empirical production model for field peas, lentils and faba beans that will be analyzed using Ordinary Least Squares regression.

4.1 Formulation of the Production Model

The production model will be tested using pooled time series and cross sectional data. In the proposed production model, yield is a function of a number factor inputs, some of which are under the producer's control while others are not. Therefore, in the production model, yield is defined as a function of management practices under the producer's control and states of nature not under the producer's control.

$$
\begin{aligned}
\textit{yield} = F[&\textit{seedbed preparation, planting method,}\\
&\textit{variety, seed type, cropping regime,}\\
&\textit{nitrogen, soil testing,}\\
&\textit{fertilizer, pest control, soil type,}\\
&\textit{environmental stress,}\\
&\textit{development rate of vegetative growth phase,}\\
&\textit{development rate of reproductive growth phase,}\\
&\textit{interval from maturity to harvesting}]
\end{aligned}
$$

4.1.1 Seedbed Preparation and Planting Method

The management practices used to prepare the field for planting and the method of planting the pulse crop can affect yield. A producer's knowledge and experience with respect to field topography, moisture conditions, soil type and the amount of existing debris from the previous crop will determine the method of cultivation used to prepare the seedbed and subsequent time and method of planting. Management practices involved in planting are: cultivation prior to planting, the timing of planting; the implement used; seed rate; and, planting depth. The affect on yield of using different combinations of seedbed preparation and planting will vary.

4.1.2 Variety

Different varieties of a particular pulse, due to inherent genetic factors, may have different long-term average yields. Certain varieties may be better adapted to particular soil types and climatic factors prevailing in a region. If several varieties of a pulse cultivar are recognized as homogeneous in the product market, then cropping of the variety best adapted to local conditions reflects good management on the part of the producer.

The different varietal types of the particular pulse crop could be represented by a variety yield index; where each variety is assigned an index value that reflects the relative long-term average yield of the variety. A varietal yield index would be derived from yield data obtained through repeated field variety trials.

4.1.3 Seed Type

The quality of the seed planted will affect yield. Higher rates of germination and emergence as well as better resistance to certain diseases will result from the use of pedigree seed as opposed to commercial seed. Consequently, yields from the use of quality seed can be expected to be higher and have less variability than those from poorer quality seed.

4.1.4 Cropping Regime

The placement of the pulse crop in the crop rotation can affect yield. An agronomically unsound crop rotation could result in lower yields. For example, planting a pulse in a field that was in flax, canola, sunflower or pulse production in the previous year, may result in lower yields due to the occurrence of disease.

The practice of summerfallowing can also affect yield. Higher soil moisture, fewer weed problems and a low incidence of disease would be expected in a crop planted in a field that had been summerfallowed in the previous year. Therefore, planting a pulse or any other crop, in a field that was summerfallowed in the previous year could result in higher yields, than planting in a field that is maintained under a continuous cropping regime. However, among many Manitoba producers, summerfallowing has fallen into disfavour, as the practice has been recognized to contribute to soil erosion.

Alternatively, a pulse producer with superior crop management skills, who maintains fields under a continuous cropping regime with a well planned and agronomically sound crop rotation, might expect yields comparable to those achieved by a producer who is summerfallowing. In addition, over the longer term, the use of a continuous cropping regime may be more economically viable than intermittent summerfallowing.

4.1.5 *Nitrogen*

Producers have four alternative ways of providing a pulse crop with a source of nitrogen for growth and development. A producer may: inoculate the seed with Rhizobium prior to planting; inoculate and apply nitrogen presumably to achieve a starter effect; apply nitrogen fertilizer without inoculation; or, neither inoculate nor apply any nitrogen thereby depending on nitrogen reserves in the soil and/or naturally occurring soil-borne Rhizobium. A positive effect on yield will be achieved through inoculation with Rhizobium alone or in combination with lower amounts of nitrogen fertilizer (under 18 pounds per acre). The application of higher rates of nitrogen fertilizer (18 pounds per acre or higher) will also positively effect yields, particularly when the pulse crop is under conditions of stress.

4.1.6 *Soil Testing*

The management practice of testing the nutrient levels existing in the soil and subsequently using the resulting information to plan the type and amount of fertilizer to apply to a field can have a positive effect on yield. Any nutrient deficiencies would be detected by a soil test and thereafter the producer could correct that deficiency by the application of the appropriate type and level of fertilizer.

In addition, the information resulting from soil test could preclude an unnecessary application or over-application of a given fertilizer. If the soil test provides an accurate profile of the soil nutrient levels that exist in a field and the producer uses that information properly, a soil test could indirectly contribute to economic efficiency in production.

4.1.7 Fertilizer

In general, the application of non-nitrous fertilizers i.e., phosphorous, potassium and sulphur will have a positive effect on yield. Yield increases would be realized by higher levels of application of these nutrients up to a maxima, and thereafter decline.

4.1.8 Pest Control

Abatement of weed, insect, and fungal infestations will have a positive effect on yield. Lichtenberg and Zilberman (1986), showed that the effect of pesticides on yield would be overestimated if a pesticide parameter was included a standard linear production function similar to the one proposed in this study. To accurately determine the effects of pesticides on yields, an abatement function defining the proportion of the target pest killed by the application of a given level of the pesticide would have to be constructed. The abatement function must define the rapidly declining productivity of the pesticide at high rates of application. Due to the possibility of the pest developing resistance to the pesticide, the specification of the abatement function must also be dynamic to reflect the decreasing effectiveness of the pesticide over time. Interactions between the pesticide and pest prevalence, weather and other parameters must also be considered.

4.1.9 Soil Type

The soil is an integral factor of production. Inherent soil characteristics such as: texture, organic matter content, parent material, drainage capacity, topsoil depth, salinity, erosion and topography can be determining factors of yield. As cross sectional data, representing producers located on different soil types in various locations in Manitoba, will be used for regression analysis, the effects of different soils on yield must be considered in the model specification.

To accurately represent the various combinations of qualitative and quantitative elements inherent in soils across Manitoba, soils must be categorized into a number of soil classes or groups. Each soil class or group would represent a distinct state of nature and reflect the soil's productive capacity irrespective of any management practices employed by a producer.

The categorization of soils could be based on a nominal measure, where soils with common characteristics are aggregated into a number of soil types or groups, or an ordinal measure such as an index that reflects the relative productivity of soil classes. Of the two types of classification systems, the soil productivity index would impart a greater measure of causality to the model. For the soil categorization to be a valid measure of yield potential, each individual soil group, whether defined by a nominal or ordinal classification system, must be heterogeneous with respect to its capacity for production of the pulse. If the soil productivity categorization is an index (an ordinal measure), the ranking of soil classes or groups must reflect the relative capacity for production of the pulse.

4.1.10 Environmental Stress

During the growing season the pulse crop may be subjected to number of different environmental shocks or stresses. These include; hail, frost, excessive heat, drought, lodging, and biological pests for which there are no abatement measures. The occurrence of one or more of these environmental stresses will have a negative effect on yield.

4.1.11 Development Rate

The rate of development of the pulse can be a determinant of yield. A high development rate, equivalent to a shortened duration of growth, will be accompanied by a relatively high growth rate. Conversely, a low development rate, equivalent to a lengthened duration of growth, will be accompanied by a lower growth rate. The rate of development will be affected by temperature and moisture conditions during the growing season. For varieties of pulses showing photoperiodism, the length of photoperiod during growth will also effect the development rate.

The development rate during the vegetative phase of growth could have an impact on observed yields. Production of pods and seeds, the components of yield, is part of reproductive growth. Reproductive growth has a strong sink activity, thereby drawing heavily on the vegetative components for photosynthesates and other metabolites. A high development rate during the vegetative growth phase could result in a plant with smaller or fewer vegetative structures and consequently have a limited capacity to sustain reproductive growth. Alternatively, a very low development rate during the vegetative growth phase could delay reproductive development, possibly into non-optimal growth conditions late in the season.

In inoculated pulse crops, dependent solely on the legume-Rhizobium symbiosis for nitrogen, a high development rate during vegetative growth could further decrease yield potential. A diminished capacity to produce the carbohydrates required as an energy source for nitrogen-fixation could limit reproductive growth.

The development rate of a pulse crop is equivalent to the inverse of the number of days required for the crop to reach a certain stage of development. A negative relationship is expected between yield and both the development rates during the vegetative growth phase and the reproductive phase.

Development rates for both growth phases are strongly influenced by weather conditions. Therefore the development rate during the vegetative growth phase and the development rate during the reproductive growth phase implicity represent the effects of weather on pulse yield in the production model. Given a set of weather conditions during a specific growing season within a locality, the development rates of the growth phases will also be influenced by the date the crop was planted. The development rates therefore also implicitly represent the effects of a management decision on pulse yield in the production model.

4.1.12 Interval from Maturity to Harvest

The length of the interval from crop maturity to harvest can have an effect on yield. Delayed harvesting may be due to adverse weather conditions or the result of a management decision (priorities) by the producer, or a combination of the two. In the time period between maturity and harvest the crop can be exposed to weather conditions or pest infestations that diminish yield. Therefore a lengthening interval between maturity and harvesting could result in decreasing yields.

4.2 The Data

The data used in this study are a self-selected sample taken from the Manitoba Crop Insurance Corporation (MCIC) records for insured producers. The data include all field pea, lentil and faba bean producers in the province that had purchased crop insurance through the MCIC. During the 1981 to 1986 period, the MCIC survey retained a fairly consistent format. Prior to 1981 the questionnaire was less comprehensive in the survey of management practices used by producers. A copy of the " Definitions and Instructions " given to insured producers completing the MCIC production survey in the 1981 to 1986 period is provided in Appendix A.

Later in the study, when data for the 1987 crop year became available, 1987 data were incorporated in the analysis. The 1987 data had a slightly different structure, notably information on weed problems was deleted in favour of more detailed data on tillage practices.

To prepare for regression analysis of the production function developed in section 4.3, the MCIC data were examined to determine whether the information required to construct the exogenous variables was available. Univariate statistics on the factor inputs and management practices under investigation were compiled and evaluated to determine whether the MCIC data accurately and reliably presented the information necessary to proceed with regression analysis.

4.3 Empirical Production Model

The empirical production model that will be subjected to Ordinary Least Squares regression analysis for each pulse crop has the following specification:

$$
\begin{aligned}
YIELD = {} & a_0 + a_1 DDPD + a_2 DS + a_3 HOE + a_4 AIRS \\
& + a_5 VRTY + a_6 PDGR\_SD + a_7 CNTCRPG \\
& + a_8 SOIL\_TST + a_9 LO\_NITRO \\
& + a_{10} PHOSP + a_{11} POTAS + a_{12} SULPH \\
& + a_{13} GRSSHBCD + a_{14} BRLFHBCD + a_{15} INSCTCD + a_{16} FUNGCD \\
& + b_1 SOIL\_TYP + b_2 ENVR\_STS \\
& + c_1 \ln VEGSPAN + c_2 \ln REPSPAN .
\end{aligned}
$$

In this equation, a_i coefficients are associated with variables under the producer's control, b_i coefficients denote parameters representing states of nature over which the producer has no control. The c_i coefficients are linked to parameters reflecting the combined effects of a management decision and a state of nature.

The effects of using one of four different planting implements on pulse yield are represented by the following dummy variables: *DDPD* (double disc press drill), *DS* (discer seeder), *HOE* (hoe drill), and *AIRS* (air seeder). These parameters, as well as representing the use of a particular type of seeding implement, to some extent also reflect different preplanting cultivation practices. Analysis of the MCIC pulse data for 1987 showed that 66 percent of producers using a double disc press drill cultivated their fields in spring prior to planting. Only 47 percent of producers using a discer seeder, hoe drill or air seeder reported spring cultivation. In contrast, 26 percent of producers using a discer seeder, hoe drill or air seeder harrowed their fields prior to planting, compared with 12 percent for producers using a double disc press drill. Coefficient estimates for each of the *DDPD*, *DS*, *HOE* and *AIRS* dummy variables are expected to have a positive sign.

The particular variety of field pea, lentil or faba bean planted by the producer are represented by the *VRTY* dummy variables in the empirical production model. The MCIC data included information on the particular variety of field pea, lentil or faba bean seeded by the producer.

Percentage frequency distributions for the varieties of field peas lentils and faba beans seeded in the 1981 to 1987 sample are given in ***Table* 4,1**. Only the Century variety of field pea was reported with a sufficiently high frequency to allow for regression analysis. Approximately 90 percent of producers in the sample planted the Century variety of field pea. Therefore the need for a *VRTY* dummy variable in the regression of the model for field peas is precluded.

Initially, three varieties of lentil were reported with sufficiently high frequency to be considered in the analysis. These varieties were; Eston, Laird and Chilean. However, as information required to approximate the values for the vegetative growth phase and reproductive growth phase variables (*VEGSPAN* and *REPSPAN* discussed below) was available only for the Eston and Laird varieties, it was decided to focus on producers planting the Eston and Laird varieties exclusively. Therefore, the *VRTY* dummy variable will represent planting the Eston variety in regression of the model for lentils. As noted previously in sub-section 2.2.3 of this study, Eston lentils were reportedly higher yielding than the Laird variety. Hence a positive sign is expected for the *VRTY* coefficient estimate.

For faba beans, due to the reported frequency of planting in the sample (shown in *Table* 4,1) and the availability of information needed to estimate the values for the durations of the vegetative and reproductive growth phase variables, only two varieties, Herz Freya and Ackerperle, could be considered in regression analysis. As noted in sub-section 2.2.3., the Ackerperle variety was reported to be slightly higher yielding than Herz Freya faba beans. Therefore the *VRTY* dummy variable will represent planting the Ackerperle variety in regression of the model for faba beans. The coefficient estimate for the *VRTY* variable is expected to have a positive sign.

The reported planting of pedigree seed (Certified, Registered, Foundation, Select or Breeder) is represented by the ***PDGR_SD*** dummy variable in the empirical model. A positive sign is expected for the ***PDGR_SD*** coefficient, due to higher rates of germination and a lower incidence of disease resulting from planting cleaner and better quality seed.

The frequency distribution of field pea, lentil and faba bean producers in the sample using a continuous cropping regime or summerfallowing is given in ***Table* 4,2**. Nineteen percent of field pea producers, 27 percent of lentil producers and 33 percent of faba bean producers planted into fields that had been summerfallowed in the previous year or two to five years previously. Alternatively, 81 percent of field pea producers,

Table 4,1. Frequency and percentage distribution of reported seeding of varieties of field peas, lentils and faba beans in the MCIC data, 1981 to 1987.

Field Pea

Variety	Frequency	Percent of sample
Century	6,717	89.9
Tara	60	0.8
Trapper	142	1.9
Triumph	45	0.6
B.C. Blue	105	1.4
Sterling 58	37	0.5
Victoria	37	0.5
other	329	4.4

Lentil

Variety	Frequency	Percent of sample
Eston	385	29.5
Laird	360	27.6
Chilean	341	26.1
Dark Speckled	125	9.6
other	95	7.2

Faba bean

Variety	Frequency	Percent of sample
Herz Freya	284	44.8
Ackerperle	140	22.0
Aladin	52	8.2
Diana	48	7.6
Outlook	14	2.2
other	97	15.2

Table 4,2. Frequency and percentage distribution of reported cropping regime used by field pea, lentil and faba bean producers in the MCIC data 1981 to 1987.

Field Pea

Cropping regime	Frequency	Percent of sample
Continuous Cropping	6,090	81
Summerfallowed (previous year)	120	2
Summerfallowed (2 to 5 years previously)	1,262	17

Lentil

Cropping regime	Frequency	Percent of sample
Continuous Cropping	956	73
Summerfallowed (previous year)	58	5
Summerfallowed (2 to 5 years previously)	292	22

Faba bean

Cropping regime	Frequency	Percent of sample
Continuous Cropping	425	67
Summerfallowed (previous year)	24	4
Summerfallowed (2 to 5 years previously)	186	29

73 percent of lentil producers and 67 percent of faba bean reported planting into fields kept continuously under a crop.

As noted in sub-section 4.1.4, higher yields might be expected from planting the pulse crop in fields which had been summerfallowed in the previous year, than in fields maintained under a continuous cropping regime. Alternatively, a producer who is maintaining a continuous crop regime; employs an agronomically sound crop rotation, uses adequate pest weed control measures and otherwise has superior crop management skills, might achieve yields equivalent to, or higher than a producer who is summerfallowing. Therefore the coefficient for the *CNTCRPG* dummy variable (representing that the field is maintained under a continuous cropping regime) might be expected to have a positive sign.

A soil test provides the producer with data on the nutrient levels that exist in the soil on a field. Incorporation of this data into the crop management plan, enables the producer to make informed decisions on the specific type and amount of fertilizer to apply when growing a particular crop on a particular field. This means, that the nutrient levels required to achieve adequate or high yields for a particular crop on a particular field can be met. Effectively, an over-application or under-application of fertilizer can be avoided. The use of a soil test is represented by the *SOIL_TST* dummy variable in the empirical production model. As a soil test provides important information to the producer in making management decisions, the coefficient for the *SOIL_TST* variable is expected to have a positive sign.

As mentioned in sub-section 4.1.5, producers have four alternatives ways of ensuring a pulse crop has an adequate source of nitrogen for growth and development. These are: inoculation with Rhizobium; inoculation and application of some nitrogen fertilizer; application of nitrogen fertilizer without inoculation; or, neither inoculate nor apply any nitrogen fertilizer. Unfortunately, the MCIC data did not contain a reliable indicator of whether or not the producer inoculated the pulse seed prior to planting. Therefore it was not possible to construct a parameter representing the condition where the producer had inoculated the seed.

As an alternative, the *LO_NITRO* variable was constructed to represent the producer's method of ensuring a nitrogen supply for the pulse crop. If a producer reported using no nitrogen fertilizer or reported applying low amounts of nitrogen, at a rate less than or equal to 17 pounds per acre, a value of " 1 " is assigned to the *LO_NITRO* dummy variable. The alternative condition, where producers were applying nitrogen fertilizer at rates in excess of 17 pounds per acre, the *LO_NITRO* dummy variable is assigned a value of " 0 ".

The rationale for using a rate of 17 pounds per acre as the point of delineation between low nitrogen users and high nitrogen users was based on the studies of Mahler, Saxena and Aeschlimann (1986), and Dean and Clark (1980), discussed in section 2.1.2.3 of this study. These studies suggested that biological nitrogen-fixation was inhibited by applications of nitrogen fertilizer at rates in excess of 17 pounds per acre. The frequency, percent distribution and mean nitrogen fertilizer application for low and high nitrogen users is given in *Table* 4,3. Seventy-five percent of field pea producers, 78

Table 4,3. Frequency, percentage distribution and mean rates of application of field pea, lentil and faba bean producers using low and high rates of nitrogen fertilizer. MCIC data, 1981 to 1987.

Field Pea Producers

Range of N applied (lbs/acre)	Producer frequency	Percent of sample	Mean N applied (lbs/acre)
$0 \leq N \leq 17$	5361	75	3
$N \geq 17$	1763	25	47

Lentil Producers

Range of N applied (lbs/acre)	Producer frequency	Percent of sample	Mean N applied (lbs/acre)
$0 \leq N \leq 17$	998	78	4
$N \geq 17$	281	22	44

Faba Bean Producers

Range of N applied (lbs/acre)	Producer frequency	Percent of sample	Mean N applied (lbs/acre)
$0 \leq N \leq 17$	425	71	4
$N \geq 17$	175	29	51

percent of lentil producers and 71 percent of faba bean producers either used no nitrogen fertilizer or applied nitrogen at rates below or equal to 17 pounds per acre. Mean rates of nitrogen application for the low nitrogen users were substantially below those for producers using in excess of 17 pounds of nitrogen per acre. As noted above, the *LO_NITRO* parameter was assigned a value of " 1 " to represent low condition. The sign of the *LO_NITRO* coefficient is therefore expected to be negative, indicating that lower yields correspond with low nitrogen fertilizer use.

To examine the effects of phosphorous application on yield, the variable *PHOSP*, representing phosphorous fertilizer application in pounds per acre is included in the empirical model. The sign of the coefficient for the *PHOSP* parameter is expected to be positive.

The *POTAS* and *SULPH* variables, representing potassium fertilizer and sulphur fertilizer application in pounds per acre respectively, are included in the empirical model. The signs of the parameter coefficients for both *POTAS* and *SULPH* are expected to be positive.

The use of herbicides to control weeds in field peas, lentils and faba beans is represented by two dummy variables, *GRSSHBCD* and *BRLFHBCD*, in the empirical model. The *GRSSHBCD* parameter represents the reported use of herbicides that control grassy weeds, such as, wild millet, wild oats and quackgrass. Specific herbicides included in the *GRSSHBCD* variable are: trifluralin (Treflan, Rival or Triflurex), diclofop methyl (Hoe Grass 284), sethoxydim (Poast), trichloroacetic acid (TCA), triallate (Avadex BW), and dalapon (Basafapon, Dalapon or Dowpon). A positive sign is expected for the *GRSSHBCD* coefficient, indicating that the yield diminishing effects of grassy weeds have been mitigated.

The *BRLFHBCD* parameter represents the reported use of herbicides that control broadleaf weeds, such as Lamb's quarters, wild buckwheat, wild mustard, red root pigweed and smartweed. Specific herbicides included in the *BRLFHBCD* variable are: metribuzin (Lexone or Sencor), methyl chlorophenoxy acetic acid (MCPA), bentazon (Basagran), and a methyl chlorophenoxy acetic acid and methyl chlorophenoxy butyrate mixture (Tropotox). The *BRLFHBCD* coefficient is expected to have a positive sign.

The primary insect pests of pulses are aphids. The *INSCTCD* dummy variable therefore represents the reported use of insecticides that control aphids in pulses. These insecticides are: carbofuran (Furadan), chloropyrifos (Lorsban), malathion and dimethoate. A positive sign is expected for the *INSCTCD* coefficient in regression analysis.

The use of fungicides to control fungal diseases in pulses is represented by the *FUNGCD* dummy variable. This parameter was derived from information about producer fungicide use contained in the chemical code variables in the MCIC data base. Cases where seed was purchased in a pre-treated form are not represented by the *FUNGCD* variable. Fungicides included in this variable are: Captan, Thiram and Vitavax. The coefficient for the *FUNGCD* parameter is expected to be positive.

The MCIC classifies all arable soils in Manitoba using a soil productivity index. Ten classes of soil are identified. Each class of soil is designated with a letter ranging from " A " to " J ". Soil type A is rated as the most productive, J the least. The basis for the classification system resulted from thirty-five years of observations of wheat, oats and barley yields on representative " benchmark " soil types. By relating the soil texture, organic matter content, parent material, drainage capacity, topsoil depth, salinity, erosion and topography of other soils to the benchmark soils, each quarter section was given a soil productivity classification.

If the MCIC soil index is a valid measure of the capacity for pulse production two assumptions about the productivity index must hold. First, each soil type must be heterogeneous with respect to its capacity for production of the pulse. Second, the ranking of soil types must reflect the relative capacity for production of the pulse.

In preliminary analysis of the MCIC data, the fourteen year (1974 to 1987) mean field pea yields were established for soil classes A through I (there were only three observations for soil class J). Upon initial examination, it was observed that the magnitudes of the mean yields for soil classes did not consistently reflect the ranking of relative productivity suggested by the MCIC. Contrary to the MCIC ranking system, the respective mean yields for soil classes C, B and D, were all greater than the mean yield for soil class A. The mean for soil class C was also higher than that for class B. A third observed anomaly, was that the mean yield for soil class I was greater than that for class H.

To more rigorously examine the relationship between field pea mean yield and soil class, a statistical procedure known as " Duncan's Multiple Range Test " was utilized (Duncan, 1955). A discussion of the underlying assumptions and application of Duncan's Test is provided in Appendix B.

Results from the application of Duncan's Test to the field pea data are presented below. Mean yields not significantly different from one another have a common underscore.

```
29.49  29.09  28.87  28.70  26.76  26.05  23.23  22.39  21.74
  C      B      D      A      E      F      G      I      H
  ________________________    __________________________
                                            _______________
```

Inferences about the ranking of the respective mean yields of the soil class populations, μ_i, where i = (A,B,C,...I), may be summarized by the following five statements.

1. The mean yields of populations of soil classes A, B, C and D may not be ranked according to magnitude.

$$\mu_A = \mu_B = \mu_C = \mu_D$$

2. The mean yields of populations of soil classes E, F, G and I may not be ranked according to magnitude.

$$\mu_E = \mu_F = \mu_G = \mu_I$$

3. The mean yields of populations of soil classes G, H and I may not be ranked according to magnitude.

$$\mu_G = \mu_H = \mu_I$$

4. Each of the mean yields of populations of soil classes A, B, C and D may be ranked as having a higher magnitude than the mean yields of populations E, F, G, H and I.

$$[\mu_A, \mu_B, \mu_C, \mu_D] > [\mu_E, \mu_F, \mu_G, \mu_H, \mu_I]$$

5. Both of the mean yields of populations of soil classes E and F may be ranked as having a higher magnitude than the mean yield of population H.

$$[\mu_E, \mu_F] > \mu_H$$

The results of Duncan's Test did not support the assumption that each soil class was heterogeneous with respect to its capacity for field pea production. The assumption that the ranking of soil classes by MCIC reflected the relative productivity for field pea cropping was also not supported by the results. However the classification system had some relevance for field pea cropping. Individually and as a group, mean yields on soil classes A, B, C and D were shown to be higher than those for the other soil classes.

Based on the results of Duncan's Test, the *SOIL_TYP* dummy parameter was constructed for inclusion in the empirical production model. If the producer planted into soil class A, B, C or D, the *SOIL_TYP* variable was assigned a value of " 1 ".

Alternatively, if the producer planted into soil class E, F, G, H or I, the *SOIL_TYP* variable was assigned a value of " 0 ". The coefficient for the *SOIL_TYP* is expected to have a positive sign, indicative of the greater capacity for pulse production of soil classes A, B, C and D.

The occurrence of environmental shocks and/or the prevalence of adverse growing conditions, over which the producer has no control, are represented by the *ENVR_STS* dummy variable. Preliminary univariate analysis of the data indicated that extended periods of heat, the incidence of frost, excess moisture over the growing season, and hail were the most frequent environmental stresses experienced by pulse producers during the period covered by this study. The yield diminishing effects of these stresses is expected to cause a negative sign for the *ENVR_STS* coefficient.

As noted in sub-section 4.1.11, the development rates of the pulse crop during the vegetative and reproductive growth phases will be determined by the date of planting and the subsequent weather conditions during the growing season. The development rates therefore implicitly represent the effects of the planting date and weather on the yield of a particular pulse variety. A negative relationship is expected to exist between the development rates and yield. The development rate during a growth phase is equivalent to the inverse of the number of days it takes the crop to reach a certain stage of development, i.e., flowering or maturity. A positive relationship is therefore expected between yield and the durations of the growth phases.

Given a set of weather conditions in an average growing season within a Manitoba locality, early planting will generally increase the length of the growth phases. A positive relationship between yield and the durations of the growth phases would therefore also reflect a positive relationship between yield and early planting dates.

The interval between seeding and flowering could be used as an approximation of the length of time the pulse crop was in the vegetative growth phase. Similarly the interval between flowering and crop maturity approximated the duration of reproductive growth.

Information on the week in which the producer seeded the crop was available in the MCIC data. However, the time of flowering and the time of maturity had to be approximated for producers who seeded their crops at different times and in various localities in the 1981 to 1987 period. The method developed and applied for this purpose is detailed in Appendix C. Values for the *VEGSPAN* and *REPSPAN* variables, representing the number of weeks a crop was in the vegetative and reproductive growth phase respectively, were estimated for the following pulse varieties; Century field peas, Eston lentils, Laird lentils, Ackerperle faba beans and Herz Freya faba beans.

Very low development rates, equivalent to signficantly lengthened growth phases, could delay development and crop maturity, possibly into non-optimal growth conditions late in the season. Therefore the relationship between the length of each of the two growth phases and yield could be non-linear. Although a positive relationship between yield and the length of each growth phase would be expected, the rate of increase in yield could decrease as the length the growth phases increased. To represent this condition the values of the *VEGSPAN* and *REPSPAN* variables were converted to natural logarithms. The transformed variables, *lnVEGSPAN* and *lnREPSPAN*, were then included in regression analysis of the empirical production model. As the duration of a growth phase is equivalent to the inverse of the development rate; and a negative relationship exists between yield and the development rate; the coefficients for the *lnVEGSPAN* and *lnREPSPAN* variables are both expected to have a positive sign.

As noted in sub-section 4.1.11 of this chapter, the rates of development (and therefore the length of each growth phase) will be affected by moisture conditions as well as temperature. However, in this study, only temperature (Growth Degree Days) is used to approximate the length of each growth phase, *VEGSPAN* and *REPSPAN*. This raises the possibility that the *VEGSPAN* and *REPSPAN* variables are measured with error. Errors of measurement in an exogenous variable can cause that variable to become correlated with the disturbance term, and can cause other coefficient estimates to be inconsistent (Johnston, 1984).

In the preliminary analysis of this study an attempt was made to quantify the effects of weather on field pea, lentil and faba bean yields. This approach involved linking each municipality with a proximal weather reporting station on the Environment Canada Monthly Weather Summary. Monthly precipitation was identified for municipalities in each year in the 1981 to 1986 period.

The monthly data for each year were examined for multicollinearity. Monthly values for precipitation were collinear within each year of the 1981 to 1986 period. In addition monthly values for precipitation were colinear with mean monthly temperature values. To avoid introducing multicollinearity, inclusion of the monthly precipitation parameters in the production model was not considered. This decision was made in order to avoid producing unstable parameter estimates (Johnston, 1984).

As noted earlier in sub-section 4.1.12 of this chapter, the length of the interval from crop maturity to harvest could have an effect on yield. Whether harvesting is delayed due to adverse weather conditions or a producer's decision, a lengthened interval between crop maturity and harvesting could result in reduced yields. A variable representing this interval was not available for inclusion in the empirical production model. The lack of this variable in specification could potentially cause estimation problems in Ordinary Least Squares regression.

In Ordinary Least Squares regression the omission of a relevant exogenous variable from model specification can result in biased and inconsistent estimates. However under the assumption that the production function is weakly separable (discussed in Chapter 2 of this study), the empirical model that will be subjected to regression analysis represents the production process of a specific intermediate input within the larger production process. In spite of the lack of a variable representing the interval from maturity to harvest and/or a variable reflecting moisture or precipitation, the assumption that the larger production function is weakly separable facilitates the analysis of the empirical production model using Ordinary Least Squares regression.

Chapter 5. Empirical Results

5.0 Introduction

In this chapter the results from Ordinary Least Squares regression of the empirical production model developed in Chapter 4 are presented and discussed. As the model was run separately for each of field peas, lentils and faba beans, empirical results for each crop are presented in separate sections with an accompanying discussion.

5.1 Field Peas - Model Results and Discussion

The production model was tested using data on Century field pea producers for the 1981 to 1987 period. A sub-sample of 5,378 producers from across the province was segregated from the larger Manitoba Crop Insurance Corporation (MCIC) data base. In addition to seeding the Century variety, all producers in the sub-sample reported planting dates between the third week of April and the second week of June. As only the Century variety was included in the analysis, the need for a *VRTY* dummy variable in specification was precluded.

The unit of measure of the dependent variable *YIELD*, for the field pea data was bushels per acre. Results from regression analysis are given in ***Table*** 5,1.

Table 5,1. Results from Regression of Field Pea Yield, MCIC Data 1981 to 1987.

Variable	Coefficient Estimate	Standard Error
INTERCEPT	-34.32	2.91*
DDPD	3.01	0.75*
DS	2.75	0.74*
HOE	3.36	0.93*
AIRS	2.21	1.75
VRTY	-	-
PDGR_SD	-0.67	0.29*
CNTCRPG	2.40	0.36*
SOIL_TST	0.11	0.41
LO_NITRO	-1.92	0.29*
PHOSP	0.03	0.01*
POTAS	-0.01	0.02
SULPH	-0.07	0.04
GRSSHBCD	1.83	0.33*
BRLFHBCD	1.59	0.26*
INSCTCD	3.42	0.70*
FUNGCD	1.66	1.18
SOIL_TYP	2.52	0.31*
ENVR_STS	-8.33	0.32*
lnVEGSPAN	24.09	1.01*
lnREPSPAN	5.15	1.04*

* Indicates significance at the 5 percent level

Mean yield = 30.3 bushels per acre

n = 5,378

F = 85.46

$\bar{R}^2 = 0.23$

Of the four planting implements included in model specification, three had statistically significant coefficient estimates. As expected, the coefficients for the double disc press drill (*DDPD*), discer seeder (*DS*) and hoe drill (*HOE*) all had a positive sign. Among the three seeders, the coefficient estimate for the hoe drill had the largest magnitude, followed by the double disc press drill and the discer seeder. Many producers using a hoe drill for planting also reported harrowing their fields in the spring prior to planting. The larger magnitude of the *HOE* coefficient therefore suggested that preparation of the seedbed by harrowing followed by planting with a hoe drill produced higher field peas yields than other combinations of seedbed preparation and planting implements. The estimate for the *AIRS* variable, was not statistically significant; indicating that yields on fields planted with an air seeder did not differ significantly from those planted with a double disc drill or chisel drill, etc.

Contrary to expectation, the coefficient estimate for the pedigree seed variable, *PDGR_SD*, had a negative sign. This suggested that field pea yields resulting from pedigree seed (Certified, Registered, Foundation or Breeder), produced lower yields than commercial seed.

The continuous cropping variable (*CNTCRPG*), coefficient had a positive sign. In general, producers employing a continuous cropping regime were appreciating higher field pea yields than those summerfallowing their fields. The positive *CNTCRPG* coefficient suggested that producers practicing continuous cropping were also maintaining agronomically sound crop rotations and otherwise using superior crop management practices.

The estimate for the soil test variable *SOIL_TST*, was not statistically significant. However, the non-significant coefficient did not imply that soil test data is irrelevant to the field pea producer when making management decisions. Information from a soil test, when used to achieve an efficient application of fertilizers, could have a substantial affect on the economics of pulse production.

A statistically significant coefficient with a negative sign was observed for the *LO_NITRO* variable. The *LO_NITRO* dummy variable represented the condition where the producer had either not applied any nitrogen or had applied nitrogen at a rate less than or equal to 17 pounds per acre. The negative sign of this coefficient estimate was expected. It indicated that producers not using nitrogen fertilizer or applying low rates of nitrogen were achieving lower yields than producers applying nitrogen at high rates. This result suggested that field pea producers would achieve higher yields by either applying high rates of nitrogen or inoculating the seed and applying nitrogen, than by relying on inoculation alone.

The sign of the *PHOSP* variable, representing the application of phosphorous fertilizer in pounds per acre was positive. As expected, the application of phosphorous fertilizer had a positive effect on field pea yield. The estimated magnitude of the effect of phosophorous application on yield is most accurate for producers achieving mean yields using the mean level of phosphorous fertilizer. Field pea producers in the sample were applying phosphorous fertilizer at an average rate of 19 pounds per acre and achieving mean yields of 30.3 bushels per acre. Therefore the coefficient estimate suggested that increasing the rate of phosphorous fertilizer by an additional pound to 20 pounds per acre would produce an additional 0.03 bushels of field peas per acre.

Statistically significant estimates were not obtained for neither the*POTAS* variable (representing potassium application in pounds per acre), nor the ***SULPH*** variable (representing sulphur application in pounds per acre). Although both potassium and sulphur fertilizer application were recommended by Manitoba Agriculture for field pea production, the empirical results suggested that neither had an effect on yield.

The positive coefficient for the *GRSSHBCD* variable indicated that the yield diminishing effects of grassy weeds, such as, wild millet, wild oats and quackgrass, were mitigated by the application of: trifluralin, diclofop methyl, sethoxydim, trichloroacetic acid, triallate or dalapon. Similarly, the positive sign of the *BRLFHBCD* variable indicated that the application of metribuzin, methyl chlorophenoxy acetic acid, bentazon, or a mixture of methyl chlorophenoxy acetic acid and methyl chlorophenoxy butyrate, decreased the yield diminishing effects of broadleaf weeds in field peas.

Of all chemical pest control measures represented in the model, insecticide application had the largest effect on yield. The estimate for the *INSCTCD* coefficient indicated that the use of one of carbofuran, chloropyrifos, malathion or dimethoate, to control aphid pests increased field pea yields by an average of 3.42 bushels per acre. In contrast to insectide use, the estimate for the fungicide variable *FUNGCD*, representing the use of fungicides to control diseases, was not statistically significant.

As expected, regression results were consistent with those of Duncan's Test with respect to soil productivity for field pea cropping. The positive sign of the *SOIL_TYP* variable indicated that the MCIC soil classes A, B, C and D, had a greater relative capacity for field pea production than MCIC soil classes E through J. Producers located on A, B, C or D soil classes achieved yields that were 2.52 bushels per acre higher, on average, than producers located on soil classes E through J. This result suggested that for the purposes of field pea production there is no economic basis for land values to be higher for soil class A land than soil class D land. Similarly, for field pea cropping, there is no basis for soil class E land to have a higher value than soil class J land.

Environmental shocks and/or adverse growing conditions had the expected negative effect on yield as indicated by the sign of the *ENVR_STS* coefficient. Of all parameters included in model specification, the *ENVR_STS* dummy variable had the largest effect on yield. The occurrence of hail, frost and excessive heat or moisture during the growing season decreased mean field pea yields by 8.33 bushels per acre.

Consistent with a priori expectations, positive coefficient estimates were observed for *lnVEGSPAN* and *lnREPSPAN*, the logarithmically transformed variables representing the durations of the vegetative and reproductive growth phases, respectively. These results supported the hypothesis that field pea yield increased, at a decreasing rate, as the duration of each growth phase lengthened. As the duration of a growth phase is equivalent to the inverse value of the rate of development, this result was consistent with previous studies where a negative relationship between the rate of development and yield was established.

Values for the length of the vegetative growth phase and the reproductive growth phase were logaritmically transformed in model specification. To determine the effect, on yield, of increasing the length of a growth phase by one unit of measure, the parameter estimate must be divided by the mean value of the non-transformed variable. The mean length of each of the vegetative and reproductive growth phases was seven weeks. Therefore if the length of the vegetative growth phase is increased by one week, one would expect yield to increase by 3.44 bushels per acre (24.09 divided by 7). Similarly, by increasing the length of the reproductive growth phase by one week, one would expect yield to increase by 0.74 bushels per acre (5.15 divided by 7).

The length of each growth phase is determined by two factors, the planting date and the subsequent weather conditions during the growing season. In this study, producers that planted in, or between, the third week in April and the second week in June were included in analysis. The empirical results suggest that Manitoba field pea producers should plant at the earliest opportunity, within that time frame. With established probabilities for weather conditions over the growing season for certain geographic areas, it might also be possible to determine optimal planting dates for some field pea varieties.

5.2 Lentils - Model Results and Discussion

In the case of lentils, the model was tested using data on producers growing the Eston and Laird varieties during the 1981 to 1987 period. A sub-sample of 394 lentil producers from various areas of the province was segregated from the larger MCIC data base. All producers in the sub-sample reported planting between the third week of April and the second week of June inclusive. Results from regression analysis are given in *Table 5.2*. The unit of measure of the dependent variable *YIELD*, for the lentil data was pounds per acre.

The frequency of reported insecticide use in the lentil sub-sample was too low to allow for the *INSCTCD* variable to be included in regression analysis. Unstable and inconsistent parameter estimates, due to multicollinearity, would have resulted if the *INSCTCD* parameter had been included in specification.

Results from regression analysis of the model with the lentil production data were poor when compared to those observed for field peas. Most of the coeffient estimates were not statistically significant. In general, the empirical model developed in Chapter 4 did not accurately describe the lentil production process. However, a discussion of some of the statistically significant estimates follows.

The coefficient for the *VRTY* dummy variable, representing the planting of the Eston lentil variety was positive as expected. Eston lentils were shown to be higher yielding than the Laird variety.

As was the case for field peas, the practice of continuous cropping, represented by the *CNTCRPG* coefficient had a positive sign. Lentil producers employing a continuous cropping regime were appreciating higher yields than producers who were summerfallowing their fields.

Table 5,2. Results from Regression of Lentil Yield, MCIC Data, 1981 to 1987.

Variable	Coefficient Estimate	Standard Error
INTERCEPT	-101.82	626.23
DDPD	92.17	187.32
DS	121.06	197.23
HOE	118.02	268.16
AIRS	164.23	238.92
VRTY	273.57	68.32*
PDGR_SD	71.19	77.04
CNTCRPG	233.53	76.61*
SOIL_TST	214.62	80.58*
LO_NITRO	-194.60	79.81*
PHOSP	5.41	2.25*
POTAS	-4.05	3.06
SULPH	-20.21	15.73
GRSSHBCD	179.74	76.40*
BRLFHBCD	139.01	73.12
INSCTCD	-	-
FUNGCD	298.93	249.04
SOIL_TYP	131.39	72.30
ENVR_STS	-432.82	88.20*
lnVEGSPAN	602.40	242.85*
lnREPSPAN	-424.86	274.42

* Indicates significance at the 5 percent level

Mean yield = 1125.6 pounds per acre

n = 394

F = 6.72

$\overline{R}^2 = 0.22$

The *SOIL_TST* variable, consistent with a priori expectations but inconsistent with the result for field pea producers, had a positive sign. This indicated that lentil producers, appreciated higher yields by incorporating the information gained from a soil test into their crop management strategy.

Similar to the result observed for field peas, the *LO_NITRO* coefficent had a negative sign. Lentil producers not using nitrogen fertilizer or applying nitrogen fertilizer at rates of 17 pounds or less per acre were achieving lower yields than producers applying higher rates of nitrogen.

The application of phosphorous fertilizer was also shown to have a positive effect on yield. Lentil producers in the sub-sample were applying phodphorous fertilizer at a mean rate of 26 pounds per acre and achieving mean yields of 1125.6 pounds per acre. The coefficient estimate for the *PHOSP* variable indicated that the average lentil producer would appreciate an 5.41 pound per acre increase in yield from the application of one additional pound of nitrogen.

Of the two dummy variables representing herbicide use, only the*GRSSHBCD* coefficient was statistically significant. Similar to the results observed for field pea producers, a positive effect on yield was appreciated by lentil producers who used herbicides for the control of grassy weeds.

Environmental shocks and/or adverse growing conditions, i.e., hail, frost and excessive heat or moisture, had the expected negative effect on lentil yield. The large negative sign for the *ENVR_STS* coefficient was also observed in the analysis of the model for field pea producers.

The positive coefficient for the tranformed duration of vegetative growth parameter, ***lnVEGSPAN*** supported the hypothesis that lentil yield increased with a lengthening vegetative growth phase. As was the case for field pea production, this result suggested that early planting of lentils had a positive effect on yield. The mean length of the vegetative growth phase was approximately 7 weeks. Therefore if the mean duration of the vegetative growth phase was lengthened by one week, lentil yield would be expected to increase by 86 pounds per acre (602.40 divided by 7).

5.3 Faba Beans - Model Results and Discussion

For faba beans, the model was tested using data on producers growing the Ackerperle and Herz Freya varieties during the 1981 to 1987 period. A sub-sample of 132 faba bean producers from various areas of the province was segregated from the larger MCIC data base. All producers in the sub-sample reported planting between the third week of April and the second week of June inclusive. Results from regression analysis are given in ***Table* 5,3**. Faba bean yield was measured in hundred-weight per acre.

Compared with the results for field peas and lentils, the empirical model did not provide a good description of faba bean production. At 13 percent, the value for the adjusted coefficient of determination, $\overline{R}^2$, was well below the results observed in the analyses of field pea producers and lentil producers. In addition, only three parameter estimates, *PHOSP*, *SOIL_TYP* and *ENVR_STS* were statistically significant. It should

Table 5,3. Results from Regression of Faba Bean Yield, MCIC Data, 1981 to 1987.

Variable	Coefficient Estimate	Standard Error
INTERCEPT	41.21	28.71
DDPD	2.62	8.33
DS	6.64	7.99
HOE	-	-
AIRS	-0.69	11.24
VRTY	-2.25	3.22
PDGR_SD	3.00	3.01
CNTCRPG	-4.19	3.09
SOIL_TST	-2.09	3.11
LO_NITRO	-0.26	3.28
PHOSP	0.18	0.08*
POTAS	-0.71	0.56
SULPH	0.88	0.67
GRSSHBCD	-1.70	3.38
BRLFHBCD	3.21	2.86
INSCTCD	17.08	14.41
FUNGCD	-	-
SOIL_TYP	7.44	2.94*
ENVR_STS	-11.96	3.64*
lnVEGSPAN	-2.48	10.38
lnREPSPAN	-13.53	9.97

* Indicates significance at the 5 percent level

Mean yield = 20.6 hundred-weight per acre

$n = 132$

$F = 2.06$

$\bar{R}^2 = 0.13$

be noted however that the sign of the coefficient estimate for each of these three parameters was consistent with a priori expectations.

Chapter 6. Summary and Conclusions

6.1 Summary

The goal of this study was to enhance the level of knowledge about pulse crop management practices for the further development of a crop management strategy for Manitoba pulse producers. A two stage process was designed to achieve this goal. First, a production model for pulse crops was developed using available scientific and agronomic information. Second, the production model was subjected to Ordinary Least Squares regression analysis to estimate the marginal physical product of certain factor inputs and determine which factor inputs had the greatest effect on yield.

A production model was developed for field pea, lentil and faba bean producers. This model was tested using Manitoba Crop Insurance Corporation (MCIC) data and other information sources. The model was subjected to Ordinary Least Squares regression, with the objective of determining the positive and negative effects of certain management practices on yield.

Results of the empirical analysis suggested that the planting date had a substantial effect on the yield of field peas and lentils. The results also indicated that field pea and lentil producers who were applying higher rates of nitrogen fertilizer to sustain their crops were achieving higher yields than producers applying lower amounts of nitrogen fertilizer and/or Rhizobium inoculation.

6.2 Conclusions

The first main conclusion of this study is that the time of planting has a significant effect on the yield of field peas and lentils. Within the field pea and/or lentil producer's decision framework, the time of seeding will have an effect on the environmental conditions the crop will be exposed over the growing season. Environmental conditions such as temperature, soil moisture and in some cases photoperiod will determine when the crop flowers or effectively switches from the vegetative to the reproductive growth phase.

In this study, the duration of the vegetative growth phase and the duration of the reproductive growth phase were approximated using the accumulation of heat units (Growth Degree Days) from the reported time of seeding. A positive logarithmic relationship was then established, empirically, between the duration of the vegetative growth phase and the yields of field peas and lentils. Similarly, a positive log-linear relationship was observed between the duration of the reproductive growth phase and field pea yield.

The second conclusion of this study was that producers who applied high rates of nitrogen fertilizer to their field pea and lentil crops, appreciated a positive effect on yield. Although this management practice was in conflict with pulse crop production recommendations for Manitoba (which recommend inoculation rather than nitrogen application), over 60 percent of field pea, lentil and faba bean producers in the sample applied some nitrogen fertilizer to their crops in the 1981 to 1987 study period.

Many field pea, lentil and faba bean producers were using nitrogen fertilizer above the 17 pound per acre rate known to have an inhibitory effect on the nitrogen-fixing Rhizobium-pulse symbiosis. Twenty-five percent of field pea producers, 22 percent of lentil producers and 30 percent of faba bean producers applied nitrogen at rates above 17 pounds per acre. A final conclusion of this study regards the quality of the MCIC data base as a general information source for production economics research. The experience of this study suggests that the MCIC data base has limited value for any comprehensive empirical research in the area of crop production economics. In certain cases, important information about certain production practices is not available in the MCIC data. In some other instances, the MCIC data that is available is unreliable or incomplete.

Examples of the type of information, not included in the MCIC data, that would be valuable to research in crop production economics are: the date the crop was harvested; the use of pre-harvest dessicants; and the specific crop that was produced on a field in the previous year. Information about the specific crop grown on a particular field in the previous year would be particularly useful to research examining the crop rotations used by Manitoba producers.

The seed treatment variable on the MCIC data is one example of a situation where information is included in the MCIC data but is unreliable. Although producers are queried on the MCIC survey as to whether or not they used a seed treatment; specific questions are not asked about the particular type of treatment applied to the seed, i.e., fungicidal or Rhizobium inoculation. Therefore, in an empirical analysis, it is not possible to establish parameters that reliably reflect that the producer has either treated the seed with a pesticide or, in the case of a pulse or other legume crop, inoculated pulse seed with Rhizobium bacteria.

A second example of where the MCIC data does not provide a complete set of information about producers' management practices regards the pesticide variables. Although the data indicates the use of a particular herbicide or insecticide, there is no indication of what specific weed or insect pest the producer is attempting to control. Nor does the data indicate whether the producer is using the pesticide prophylactically to prevent an infestation, or reactively in response to an infestation. This incomplete information complicates the interpretation of the effectiveness of pesticides in empirical analysis.

6.3 Suggestions for Further Research

The results of this study suggested that the duration of the vegetative growth phase had a significant affect on the yield of both field peas and lentils. Field pea yield was also affected by the duration of the reproductive growth phase. Further research examining the relationships between pulse yield and the lengths of the growth phases should be conducted under controlled or field conditions. In such cases the time of flowering, i.e., the transition from the vegetative to the reproductive growth phase, and time of maturity could be observed. This would allow the time durations of the two growth phases to be measured accurately. In field or controlled experiments the effects of soil moisture and photoperiod (for pulse cultivars on that display photoperiodism) on the length of the vegetative growth phase and yield could also be studied.

A study examining the frequency of inoculation with Rhizobium and nitrogen fertilizer use among pulse producers should be undertaken. The scientific literature suggests that the nitrogen-fixing pulse-Rhizobium symbiosis provides the crop with an adequate supply of nitrogen for growth and development. If some producers are applying nitrogen fertilizer at high per acre rates rather than, or in conjunction with Rhizobium inoculation, a condition of economic inefficiency may be present. Alternatively, other sources in the scientific literature suggest that a beneficial yield effect is achieved by the application of low rates of nitrogen fertilizer in conjunction with Rhizobium inoculation. A study should be undertaken to determine the most economically efficient method a Manitoba pulse crop producer can use to ensure that a developing pulse crop has a nitrogen source. Such an economic study should be based on data from field experiments (conducted at a number of different Manitoba locations), that measure the physical effects of nitrogen-fixation, nitrogen fertilizer application, and combined nitrogen-fixation and fertilizer application on pulse yield.

Cropping recommendations suggest that a pulse be included in a rotation only once every three to five years and not precede or follow another pulse, canola, flax or sunflowers. Any expansion of the area devoted to pulse crop production means that other crops will be displaced in crop rotations. On a given acreage, a pulse would effectively replace, a cereal crop, an oilseed or a different pulse in the crop rotation. Due to their broadleaf physiology, pulses are susceptible to a number of plant diseases common to canola, flax and sunflowers. If pulses are incorporated into rotations indiscriminately, the incidence of plant disease among pulses and oilseeds alike could increase. Research should be undertaken to determine if producers are including pulses in their crop rotations in an agronomically sound manner.

Bibliography

Aitken, Y. " Flower initiation in relation to maturity in crop rotation in crop plants. IV, sowing time and maturity type in pea (*Pisum sativum L.*) in Australia. " Australian Journal of Agricultural Research. vol. 17, no. 1. (1978): 983-1001.

Ali-Khan, D.C. and R.C. Zimmer. Production of Field Peas in Canada. Publication 1710, Agriculture Canada. (1980)

Askin, D.C., White, J.G.H. and P.J. Rhodes. " Nitrogen fixation by peas and their effect on soil fertility. " in The Pea Crop. eds. P.D. Hebblethwaite, M.C. Heath, T.C.K. Dawkins. Butterworths, London. (1985): 421-430.

Beattie, B.R. and C.R. Taylor. The Economics of Production. John Wiley and Sons, New York. (1985).

Bernier, C. " Diseases of pulse crops and their control. " in Oilseed and Pulse Crops in Western Canada. Modern Press, Saskatoon, Sask. (1975): 439-453.

Canada Grains Council. Pulse Crop Report. Report: Working Group on Pulse Crops. (1978).

Chambers, R.G. Applied Production Analysis. Cambridge University Press, New York. (1988).

Debertin, D.L. Agricultural Production Functions. Macmillan Pub. Comp., New York. (1986).

Dean, J.R. and K.W. Clark. " Effect of low level nitrogen fertilizer on nodulation, acetylene reduction and dry matter in fababeans and three other legumes. " Canadian Journal of Plant Science. 60 (1980): 121-130.

Duncan, D.B. " Multiple range and multiple F Tests. " Biometrics. (1955): 1-42.

Edey, S.N. Growing Degree-Days and Crop Production in Canada. Publication 1635, Agriculture Canada. (1977).

Elkan, G.H. " Taxonomy and metabolism of Rhizobium and its genetic relationships. " in Biological Nitrogen Fixation, Ecology, Technology and Physiology. ed. M.Alexander, Plenum Press, New York. (1984): 1-38.

Hadley, P., Summmerfield, R.J., and E.H. Roberts. " Effects of temperature and photoperiod on reproductive development of selected grain legume crops. " in Temperate Legumes. eds. D.G. Jones and D.R. Davies, Pitman Publishing Inc., London. (1983): 19-41.

Hardwick, R.C. and M.O. Kelly. " Senescence in pulse crops. " in World Crops: Cool Season Food Legumes. (1986): 923-930.

Headley, C.L. and M.J. Ambrose. " The application of plant physiology to the development of dried pea crop plants." in The Pea Crop. eds. P.D. Hebblethwaite, M.C. Heath, T.C.K. Dawkins. Butterworths, London. (1985): 95-104.

Henderson, J.M. and R.E. Quandt. Microeconomic Theory. McGraw-Hill Inc. New York. (1980).

Hunter,J.H., Sexsmith,J.J.P., Keys,C.H. and W.O.Chubb. " Weed control in oilseeds and pulse crops. " in Oilseed and Pulse Crops in Western Canada. (1975): 375-397.

Jardim Freire, J.R. " Important limiting factors in soil for the Rhizobium-Legume symbiosis. " in Biological Nitrogen Fixation, Ecology, Technology, and Physiology. ed. M. Alexander, Plenum Press, New York. (1984): 51-74.

Johnston, J. Econometric Methods. 3d ed. McGraw-Hill Book Comp. New York. (1984): 428-430.

Lichtenberg, E. and D. Zilberman. " The Econometrics of Damage Control: Why Specification Matters. " American Journal of Agricultural Economics. (May 1986): 261-273.

Langille, J.E., MacLeod, J.A., Bubar, J.S. and R.W. Jones. " Victoria Field Pea. " Canadian Journal of Plant Science. 66 (1986): 785-786.

Lehninger, A.E. Principles of Biochemistry. Worth Pub. Inc., New York. (1982): 637.

Mahler,R.L., Saxena,M.C. and J.Aeschlimann. " Soil fertility requirements of pea, lentil, chickpea and faba bean. " in World Crops: Cool Season Food Legumes. (1986): 280.

Manitoba Agriculture. " Field Pea Production in Manitoba." (1986).

_____. " Lentil Production in Manitoba. " (1986).

Manitoba Agriculture. " Field Crop Facts: Faba Bean Production." (1987).

_____. " Guide to Chemical Weed Control." (1987).

_____. " Field Crop Production Guide for Manitoba." (1988).

_____. " Field Crop Variety Recommendations for Manitoba." (1988).

_____. " Manitoba Insect Control Guide." (1988).

_____. " Guide to Crop Protection 1993. "(1993).

_____, Manitoba Seed Growers Association and Manitoba Cooperator. " Variety Recommendations and Growers Directory. " (1993).

McVetty, P.B.E., Evans, L.E. and J. Nugent-Rigby. " Response of faba bean (Vicia faba L.) to seeding date and seeding rate. " Canadian Journal of Plant Science. 66 (1986):39-44.

Planquaert, P. and J. Desbureaux. " The agronomic effects of peas in rotation with winter wheat and oilseed rape - a progress report. " in The Pea Crop. 1985: 19-29.

Rennie, R.J. " Selection for Captan tolerance in the *Rhizobium phaseoli - Phaseolus vulgaris L.* N_2 fixing symbiosis. " Canadian Journal of Soil Science. 66 (1986):143-150.

Richards, J.E. and R.J. Soper. " Effect of N fertilizer on yield, protein content and symbiotic N fixation in fababeans. " Agronomy Journal. 71 (1979): 807-811.

Robson, A.D. " Nutrient requirements of pulses. " in World Crops: Cool Season Food Legumes. (1986): 869-881.

Saskatchewan Agriculture. Soils and Crops Branch. " Soil Improvement with Legumes." (1987).

Saxena, M.C., Saxena, N.P. and A.K. Mohamed. " High temperature stress." in World Crops: Cool Season Food Legumes. (1986): 845-856.

Slinkard,A.E. Interview by author, July 1988.

_____. "Breeding pulse crops in Western Canada." in Oilseed and Pulse Crops in Western Canada. (1975): 223-228.

Slinkard, A.E., Drew, B.N. and F.A. Holm. " Lentil Production in Western Canada. " University of Saskatchewan, Publication Number 413. (1988).

Sprent, J.I., Stephens, J.H. and O.P. Rupela. " Environmental effects on nitrogen fixation. " in World Crops: Cool Season Food Legumes: Proceedings of the International Legumes Research Conference on Pea, Lentil, Faba Bean and Chickpea. ed. R.J. Summerfield. Kluwer Academic Publishers, Dordrecht, Boston and London. (1986): 801-810.

Steel, R.G.D. and J.E. Torrie. Principles and Procedures of Statistics. 2d ed. McGraw-Hill Inc. New York. (1980).

Summerfield, R.J. and E.H. Roberts. " Photo-thermal regulation of flowering in pea, lentil, faba bean and chickpea. " in World Crops: Cool Season Food Legumes. (1986): 911-922.

Ukrainetz, H., Soper, R.J. and M. Nyborg. " Plant nutrient requirements of oilseed and pulse crops. " in Oilseed and Pulse Crops in Western Canada. (1975): 325-374.

University of Manitoba. Production of Fababeans. Research Report, 1975-76. Faculty of Agriculture. A report submitted to the Canada Grains Council. (August 9, 1976).

Van Dobben, W.H. " Influence of temperature and light conditions on dry-matter distribution, development rate and yield in arable crops. " Netherlands Journal of Agricultural Science. Vol. 10, No. 5 (1962).

Vessey,J.K. " The Effect of Plant Development on N_2 Fixation in Two Varieties of Field Pea. " A scientific paper presented at Manitoba Agri-Forum. (January, 1991).

Appendix A

The following is a copy of the "Definitions and Instructions" given to insured producers completing the MCIC production survey. These instructions accompanied the survey used in the 1981 to 1986 period. In 1987, the survey format was changed; questions about weed problems were deleted and detailed questions on tillage practices were added.

" DEFINITIONS & INSTRUCTIONS "

UNCULTIVATED ACRES

- includes native hay and pasture, bushland and waste areas.

CULTIVATED ACRES

- includes cropland, fallow, and tame hay (reported in yield section), tame pasture and breaking.

FALLOW ACRES

- includes summerfallow but does not include new breaking or land worked up from a perennial crop.

PASTURE

- indicate only tame pasture in this column. Native pasture and hay to be included in Uncultivated Land.

BREAKING

- includes land broken out of bush or perennial crop.

CROP VARIETY

- eg. Barley (Bedford).

PEDIGREE

- indicate " Y " if seed used was Certified, Registered, Foundation, Select or Breeder.
- indicate " N " if commercial seed was used.

TREATED

- indicate " Y " if seed treatment used.
- indicate " N " if no seed treatment used.

CROP PRACTICE

- indicate year since summerfallowed.
- indicate " C " if continuous (more than 5 years since last summerfallowed).
- indicate " Z " if zero tillage.

SEEDING DATE

- 1st digit = week 2nd digit = month
  (exact date not required, eg. May 10 = 2-5)

SEEDING METHOD

- Double disc drill	01
Double disc press drill	02
Discer seeder	03
Hoe drill	04
Broadcast - ground applicator	05
Broadcast - by aircraft	06
Zero-Till Disc Drill	07
Zero-Till Hoe or Chisel Type Drill	08
Zero-Till PTO Drill eg. John Deere	09
Grass Seeder eg. Brillion	10
Air Seeding eg. Super Seeder	11
Other (specify)	

SOIL TEST

- Y = yes
  N = no

FERTILIZER INPUTS

- indicate the actual pounds added per acre plus pounds of trace elements if added.
- indicate Copper - Cu, Zinc - Zn.

WEED PROBLEMS

- W.O. - wild oats
  W.B. - wild buckwheat
  G.F. - green foxtail (wild millet)
  C.T. - Canada Thistle
  Q.G. - quack grass

  circle code if weed present

WEED AND HERBICIDE CODES

- for information see local Crop Insurance Agent

CONTROL

- refers to the growers assessment of weed control achieved on the field.
  (0) - poor control (1) - fair control
  (2) - good control (3) - excellent control

OTHER CHEMICALS

- If other chemicals used for insect or plant disease control please indicate. Do not include seed treatment or herbicides in this column.

MOISTURE

- refers to general moisture supply for the total growing season.
  (0) - very low (1) - low
  (2) - average (3) - above average
  (4) - excessive

YIELD

- yield per acre in Imperial units, i.e., pounds, bushels, cwt., tons.

MAJOR STRESS

- (if any) refers to any major limiting factor which prevented the crop from reaching maximum yield.
  eg. drought, heat, frost, hail, insects, herbicide damage, deep seeding, etc.

Appendix B

To examine the relationship between field pea mean yield and the Manitoba Crop Insurance Corporation soil productivity index, Duncan's Multiple Range Test was utilized. In Duncan's Test, the arithmetic difference between sample means is compared with a corresponding shortest significant range. If the arithmetic difference between sample means exceeds the the shortest significant range, the difference is declared statistically significant. If the arithmetic difference between means is less than the shortest significant range the difference between the means is not considered significant. An exception to this rule is that the difference between two means is not considered significant if both means are contained in a sub-set of means for which a non-significant range has been previously declared (Duncan, 1955).

A shortest significant range (R_P) is calculated by multiplying the significant studentized range (q_α) by the standard error of the mean ($S_{\overline{Y}}$).

Duncan's Test consists of performing a " family " of independent tests, each with its own null hypothesis. The Type I error rate for the family of independent tests (α) is the probabilty of concluding that at least two of the means are not equal, when in truth all of the means are equal (Steel and Torrie, 1980).

Duncan's Test accounts for the fact that as the number of means in the range being tested increases, the probability of finding two or more means which are different increases. This is achieved by using a level of significance (α') that is dependent on the number of means involved at a certain stage of independent testing (Steel and Torrie, 1980). The relationship between α, the family-wise error rate, and α', the error rate for an independent test, can be mathematically expressed by the following equation.

$$\alpha = 1 - (1 - \alpha')^K,$$
$$\textit{where: } K = \textit{the number of means} \in \textit{the range being tested less } 1.$$

Two assumptions about the field pea data were necessary for the test results to be valid. The first necessary assumption of Duncan's test was that the sample of observed means have been drawn independently from their respective normal populations.

$\overline{Y}_i$ are drawn independently from $N(\mu_i, \sigma_i^2/n_i)$

where: $\overline{Y}$ = mean yield of sample

μ = mean yield of population

n_i = size of population i

σ_i^2 = variance of population i

σ_i^2/n_i = variance of μ_i

i = soil class (A,B,C,...,I)

The second necessary assumption was that the respective means of populations as defined by each soil class, had a common variance, σ^2/n.

$$\sigma^2/n = \sigma_i^2/n_i = \sigma_{i'}^2/n_{i'},$$
$$where:\ n = \sum_A^T n_i,\ i \neq i'.$$

This assumption was plausible in that; if each soil class accurately reflected a distinct capacity for field pea crop production; and, capacity between soil classes differed by uniform increments; then the variances of means of populations as defined by soil class should have been equivalent.

Both of the necessary assumptions were considered to be true for the data, therefore the pooled standard deviation, S_P, could be used as an estimate of the true standard deviation $\sigma/\sqrt{n}$.

$$S_P = \sqrt{\frac{[\sum_A^T \sum_1^r (Y_{ij} - \overline{Y}_{i\cdot})^2]}{(n-t)}}$$

where: Y_{ij} = observed yield in sample from population i

$\overline{Y}_{i\cdot}$ = mean yield of sample from population i

r_i = size of sample from soil class i

n = sum of r_i

i = soil class (A,B,C,...,I)

j = observations (1,2,3,...,r_i)

t = the number of soil classes

The standard error of the mean, $S_{\bar{Y}}$, necessary for the calclation of the shortest significant range, could then determined. Due to an unequal number of observations among soil class populations, a correction formula was used for determining the standard error of the mean (Steel and Torrie, 1980).

$$S_{\bar{Y}} = S_P \sqrt{1/2\left(\frac{1}{r_i} + \frac{1}{r_{i'}}\right)}$$

The shortest significant ranges, R_P, were then determined by multiplying $S_{\bar{Y}}$, by values for the significant studentized ranges, q_α. The values for q_α were taken from a table entitled " Significant studentized ranges for 5 percent and 1 percent level new multiple range test " (Steel and Torrie, 1980). Testing was conducted with infinite degrees of freedom, at the 1 percent level of significance, implying a family-wise error rate (α) equal to 0.01.

The field pea data necessary for this test are presented in ***Table B,1***. Mean yields for each soil class are presented in order of the observed rank as required by the testing procedure. ***Table B,1*** also shows the calculation of the pooled standard deviation of the means, S_P, and lists the tabular values for the significant studentized ranges, $q_{0.01}$. An example of the application of an independent test for the comparison between two mean yields is also given in ***Table B,1***, complete with the determination of the appropriate shortest significant range, R_P.

Table B,1.
Data and Worksheet for Duncan's Test
(Field Pea Mean Yields by Soil Class, 1974 to 1987)

OBSERVED RANK	SOIL CLASS	r_i	$\sum (Y_{ij} - \overline{Y}_i)^2$	$\overline{Y}_i$
1	C	3,546	420,597	29.49
2	B	1,029	121,892	29.09
3	D	4,274	513,982	28.87
4	A	518	63,273	28.70
5	E	1,823	238,010	26.76
6	F	385	61,397	26.05
7	G	331	51,932	23.23
8	I	46	4,801	22.39
9	H	132	16,642	21.74

$$n = \sum_A^I r_i = 12{,}084 \qquad \sum_A^I \sum_1^r (Y_{ij} - \overline{Y}_i)^2 = 1{,}492{,}526$$

Pooled Standard Deviation (S_P):

$$S_P = \sqrt{\frac{1{,}492{,}526}{(12{,}084 - 9)}} = 11.118$$

Table B,1 continued.

Significant Studentized Ranges (q_α):

α = 0.01, degrees of freedom = ∞
P = number of means for range being tested

P:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$q_{0.01}$:	3.64	3.80	3.90	3.98	4.04	4.09	4.14	4.17

Sample Calculation of Shortest Significant Range (R_P):
(Comparison of $\overline{Y_B}$ and $\overline{Y_F}$)

Standard error of the mean with correction for unequal sample sizes.

$$S_{\overline{Y}} = S_P \sqrt{1/2\left(\frac{1}{r_i} + \frac{1}{r_{i'}}\right)} = 11.118 * \sqrt{1/2\left(\frac{1}{1{,}029} + \frac{1}{385}\right)}$$

$$S_{\overline{Y}} = 0.47$$

Shortest significant range for comparison of $\overline{Y_B}$ with $\overline{Y_F}$.

$$R_P = q_\alpha S_{\overline{Y}} = 3.98 * 0.47 = \underline{1.87}$$

Observed Difference between $\overline{Y_B}$ and $\overline{Y_F}$:

$$\overline{Y_B} - \overline{Y_F} = 29.09 - 26.05 = \underline{3.04}$$

Result:

$$\overline{Y_B} - \overline{Y_F} > R_P$$

Therefore the difference between the mean yields is statistically significant.

Appendix C

The method used to compute values for the parameters representing the length of the vegetative and reproductive growth phases (VEGSPAN and REPSPAN respectively), is detailed below. This method was used to estimate values for the VEGSPAN and REPSPAN variables for the following pulse varieties: Century field peas, Eston lentils, Laird lentils, Ackerperle faba beans and Herz Freya faba beans.

Determination of Heat Flowering Constant and Heat Reproductive Constant

The method developed to estimate the time of flowering and the time of maturity was based on the related concepts of the Growth Degree Day, GDD, and the Heat Maturity Constant, HMC. There are two assumptions underlying the concept of the GDD. First, that plant growth is directly related to average daily temperature. Second, that there is a cultivar specific temperature below which plant growth does not occur (Edey, 1977).

A GDD is a thermal unit equal to the average daily temperature minus a cultivar specific base temperature value, t_B.

$$GDD = \frac{(\text{max.}\ \mathit{daily\ temp.}\ -\ \text{min.}\ \mathit{daily\ temp.})}{2} - t_B.$$

If the base temperature for a certain cultivar has not been determined under experimental conditions a base temperature of 5^0 Celsius may be considered valid (Edey, 1977).

A Heat Maturity Constant, HMC, is a cultivar specific requirement for total heat accumulation through the growing season to reach maturity.

$$HMC = \sum_{1}^{D} GDD_i$$

$$\begin{aligned} \textit{where: } i &= \textit{day } (1,2,3,\ldots,D), \\ D &= \textit{number of days to reach maturity.} \end{aligned}$$

The HMC was partitioned into two elements: the total heat accumulation required for the crop to flower, the Heat Flowering Constant, (HFC); and the total heat accumulation between flowering and maturity, the Heat Reproductive Constant, (HRC).

$$HMC = HFC + HRC,$$

$$\begin{aligned} \textit{where: } HFC &= \sum_{1}^{F} GDD_i, \\ HRC &= \sum_{F+1}^{D} GDD_i, \\ F &= \textit{number of days from emergence to flowering}, \\ D - F &= \textit{number of days from flowering to maturity.} \end{aligned}$$

The total heat accumulation required for flowering was estimated for Century field peas, and each of the Eston and Laird varieties of lentils using data from the Agronomic and Climatic Data from the 1987 Manitoba Crop Variety Trials and temperature data from the Environment Canada Monthly Weather Report. The Manitoba Crop Variety Trial data provided the date of seeding and time of flowering. Although the date of harvest was also given, it did not accurately represent the actual date the crop reached maturity and was therefore not used to estimate the HFC and HRC.

As the data included records for only three sites, (Winnipeg, Waskada and Dauphin) for only one year, the use of regression analysis was precluded. By using information on planting and flowering dates from the Manitoba Crop Variety Trials and data on prevailing mean daily temperatures for Dauphin, Waskada and Winnipeg, the HFC for each variety was be estimated using the following calculation,

$$HFC = \sum_{i}^{F} (t_i - t_B).$$

$$\begin{aligned} \textit{where: } t_i &= \textit{mean daily temperature on day } i, \\ i &= 1,2,3,\ldots,F, \\ t_B &= \textit{base temperature } (5^0\ \textit{Celsius}). \end{aligned}$$

This calculation was performed separately for Century field peas, Eston lentils and Laird lentils, for each of the three sites in 1987. Data for Ackerperle and Herz Freya faba beans was only available for two sites Dauphin and Winnipeg. The average for the sites was then taken to represent the accumulated heat requirements for flowering of the particular variety. In the case of Century field peas the average HFC was approximately 630^0 Celsius. The average HFC for each of the Eston and Laird variety of lentil was 615^0 Celsius and 655^0 Celsius respectively. For Ackerperle and Herz Freya faba beans the average HFC was 640^0 Celsius and 639^0 Celsius respectively. These values of HFC, for each of Century field peas, Eston and Laird lentils, and Ackerperle and Herz Freya faba beans, were subsequently used to estimate the time of crop flowering.

As mentioned above, the date of harvesting provided in the 1987 Manitoba Crop Variety Trials data did not accurately reflect the date of crop maturity. Therefore the date of maturity was estimated as follows. The average maturation period for production of Century field peas in Manitoba was given as 96 days in the Field Crop Variety Recommendations for Manitoba (Manitoba Agriculture, 1988). The same source listed the average maturation period for the Eston and Laird varieties of lentils as 95 days and 103 days respectively, and 105 days for Ackerperle faba beans and 101 days for Herz Freya faba beans. It was then assumed that each variety of pulse at each of the sites required the average maturation period, specific to that variety, to reach maturity. The date of maturation of the varieties at each site was then approximated by adding the variety's average maturation period to the reported date of planting. For example, Century field peas were planted at the Waskada site on April 29th. Therefore, the date of maturity was approximately August 4th, or 96 days after planting.

With the approximate dates of maturation, the *HRC* was estimated for each variety at each of the three sites using the following calculation.

$$HRC = \sum_{F+1}^{D} (t_i - t_B).$$

$$\begin{aligned} \textit{where: } t_i &= \textit{mean daily temperature on day } i, \\ i &= F+1, F+2, F+3, \ldots, D, \\ t_B &= \textit{base temperature } (5^0 \textit{ Celsius}). \end{aligned}$$

The average *HRC* determined for Century field peas on the three sites was 571^0 Celsius. For each of the Eston and Laird lentil varieties the average *HRC* was 601^0 and 607^0

Celsius respectively. In the case of the faba bean varieties, the average *HRC* was 669^0 Celsius for Ackerperle and 638^0 Celsius for Herz Freya. The value of the *HRC*, for each of Century field peas, Eston and Laird lentils, and Ackerperle and Herz Freya faba beans were subsequently used to estimate the time of crop maturity.

Determination of the Week of Flowering and Maturation, and Computation of the VEGSPAN and REPSPAN Variables

The MCIC data provided information about the week of seeding rather than the day of seeding. Therefore the probable week of flowering and the week of crop maturity were estimated rather than the day of flowering and day of maturity. The probable week of flowering and week of maturation for different possible seeding weeks, were determined for each of nine Environment Canada weather stations in Manitoba (Beausejour, Cartwright, Glenlea, Graysville, Morden, Plum Coulee, Plumas, Portage la Prairie and Winnipeg) for Century field peas, Eston and Laird lentils, and Ackerperle and Herz Freya faba beans for each year in the 1981 to 1987 period.

Each seven day period in April through to September, was assigned an integer value (*WK*) corresponding to the number of weeks that had elapsed since the end of March. For example the third week in April was assigned a *WK* value of 3, the second week in June was assigned a *WK* value of 10, the second week in August was assigned a *WK* of 19, etc. The *GDD* accumulated in each week were then calculated by summing the mean daily temperature less a base temperature of 5^0. The first week in which the accumulated GDD, given a specific seeding week, were equal to or greater than the HFC, indicated the week the crop was in flower.

$$\textit{If } HFC \leq \sum_{WK_S}^{WK_F} GDD_i < \sum_{WK_S}^{WK_{F+1}} GDD_i\,,$$
$$\textit{then a crop seeded in } WK_S, \textit{ is in flower in } WK_F,$$

$$\begin{aligned} \textit{where: } GDD_i &= \textit{accumulated GDD in week } WK_i, \\ i &= 1,2,...,S,...,F,F+1,...,n., \\ WK_S &= \textit{week (WK) of seeding}, \\ WK_F &= \textit{week (WK) of flowering}. \end{aligned}$$

The variable $VEGSPAN$, representing the approximate length of the vegetative growth phase, in weeks, could then be derived by subtracting the value of the week of seeding, WK_S, from the week the crop was in flower, WK_F;

$$VEGSPAN = WK_F - WK_S\ .$$

Values for the $VEGSPAN$ parameter were computed for Century field peas, Eston and Laird lentils, and Ackerperle and Herz Freya faba beans, for each of the nine weather stations, for possible seeding weeks ranging from the third week in April to the second week in June in each year from 1981 to 1987 inclusive.

The variable $REPSPAN$, representing the duration of the reproductive growth phase was determined using a similar method. The first week in which the accumulated GDD, given the estimated week of flowering, WK_F, were equal to or greater than the HRC, indicated the week the crop was mature.

$$\text{If } HRC \le \sum_{WK_{F+1}}^{WK_M} GDD_i < \sum_{WK_{F+1}}^{WK_{M+1}} GDD_i ,$$

then a crop seeded in WK_S *and*

flowering in WK_F*, is mature in* WK_M,

$$\begin{aligned} \text{where: } GDD_i &= \text{accumulated GDD in week } WK_i , \\ i &= 1,2,...,S,...,F,F+1,...,M,M+1,...,n. , \\ WK_F &= \text{week (WK) of flowering} , \\ Wk_M &= \text{week (WK) of maturity}. \end{aligned}$$

A value for *REPSPAN* was then determined by subtracting the week the crop was in flower, WK_F, from the week the crop was

mature, WK_M;

$$REPSPAN = WK_M - WK_F .$$

Values for the *REPSPAN* parameter, were computed for Century field peas, Eston and Laird lentils, and Ackerperle and Herz Freya faba beans, for the range of flowering weeks at each of the nine weather stations, in each year from 1981 to 1987 inclusive.

Each computed value for the *VEGSPAN* variable had a corresponding value for the *REPSPAN* variable. Both variables corresponded to a variety, specific seeding week, a locality (weather station) and year. In the next step, the *VEGSPAN* and *REPSPAN* variables were linked to producers that reported growing Century field peas, Eston or Laird lentils, Ackerperle or Herz Freya faba beans, in the MCIC data according to the corresponding variety, week of seeding, year and location in a municipality that contained or was proximal to one of the nine weather stations. *Table C,*1 details the specific municipalities that were linked to each of the Environment Canada weather stations. Therefore each producer who was growing Century field peas, Eston lentils or Laird lentils, Ackerperle or Herz Freya faba beans and was located in one of the municipalities listed in *Table C,*1 was assigned values for the *VEGSPAN* and *REPSPAN* variables that corresponded to the variety, year and week of seeding as reported on the MCIC data.

Table C,1. Environment Canada weather stations linked with producers' reported municipality on MCIC data.

Environment Canada weather station	Municipalities
BEAUSEJOUR (2)	Brokenhead
CARTWRIGHT	Louise
GLENLEA	Desalaberry MacDonald
GRAYSVILLE	Thompson
MORDEN	Pembina Stanley
PORTAGE LA PRAIRIE	North Norfolk Portage la Prairie
PLUM COULEE	Montcalm Morris Rhineland Franklin
PLUMAS	Westbourne
WINNIPEG (INTL.)	Cartier