

Crop Yield Impacts from Rotations in Manitoba

by

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Abstract

Primary agriculture and agriculture manufacturing, as one of the dominant industries in Manitoba, generates jobs, agricultural products, and boosts economic output. Crop rotation, swapping out different crops over seasons, is an agricultural practice with both economic and ecological benefits for both crop production and the environment. Previous research by Manitoba Agriculture Service Corporation (MASC) studied the relative yield responses of crops grown in Manitoba on large fields using only the previous crop as the influential factor, which might be biased. Thus, there is a need to explore the 'rotation effect' after taking more factors into the crop yield models. The purpose of this research is to explore how crop rotations influence crop yields in Manitoba. A yield model given inputs of fertilizers, climatic and regional factors, seeding dates, regional effects, yearly dummies, soil qualities, and crop rotation effects were developed in the analysis. Yield responses through the coefficients of previous crops were examined through the yield model at both provincial and regional levels. The results were consistent with previous findings that monoculture leads to negative yield potential and rotating crops with soybeans is likely to help boost crop yields. The impacts from the previous crops on yields in this study are more precisely estimated than Kubinec's since it contains more influential factors, which in return helps farmers better estimate their profits. Also, the effects of seeding dates, regional levels, fertilizers, precipitation and temperature on crop yields were identified. These new results provide farmers with a more thorough understanding of crop rotations so they can make better choices about crop selections for production in Manitoba.

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Chapter 1: Introduction

Primary agriculture and agriculture manufacturing are dominant industries in Manitoba, generating jobs, agricultural products, and boosting economic output (Manitoba Agriculture, 2017b). In terms of the economy, crop production has a major impact on the level of farm income and the variation in of farmers' revenues. Crop management decisions such as the choice of tillage applied, crop rotation, seeding date, and the application of fertilizer have been shown to have an impact on the harvest yields of crops (Watson et al., 2013). Risks related to weather conditions and management choices can significantly influence crop yields (USDA, 2019). Canola and spring wheat are the top two crops in Manitoba in terms of area and production and normally generate high profits while offering resistance towards extreme weather (MASC, ndb).

Crop rotation is an agricultural practice involving both economic and ecological benefits for both crop production and the environment. In general crop rotations are the arrangement of crops over time on the same field. The plant species planted last year or over the last several years are expected to impact the yields of crops planted this year and in subsequent crops. Crop productivity changes due to various natural factors and human decisions. Proper arrangement of crop choices for crop rotations can improve the soil organic matter and fertility and boost crop yield for the subsequent season (Liu et al., 2006). Additionally, data from Manitoba Agricultural Services Corporation (MASC) shows lower yield responses to growing the same crop continuously and higher yield responses were found from fields using several crop combinations over time, especially rotations with nitrogen fixing crops (Kubinec, 2018). Planting different crops helps to break disease and pest cycles, caused by monoculture, and reduces production risks (Liu et al., 2006).

Problem:

The relative yield responses of crops grown in Manitoba on large fields, with various previous crops in rotation, were computed by Kubinec from 2010 to 2015 (Kubinec, 2018). As the central diagonal of Table 1 shows, all crops grown after the same crop suffer a lower-than-average yield (100 index). This agrees with findings from the literature about crop rotations in the fields of plant science, soil science, and agricultural economics that state crop rotation choices can generate significant benefits. The table gives farmers a constructive decision aide on how to select crop rotations that will contribute to increased profits from good agronomic choices. According to the author of the first MASC report (Kubinec, 2018), four steps were processed in the methodology. Average yield for all the reported yields of each specific crop type grown on all stubble types were calculated, and then all the yields were separated from contract holders that indicated the specific crops grown on each stubble (residue of previous crop) type. In the next step, a simple ratio was obtained comparing the crop grown on “x” stubble versus all stubble types. Finally, the author looked at the frequency of the different ratios. Note, the methodology of Kubinec’s work (shown in Table 1) considered previous crops as the only factor impacting yields. Previous studies have shown that weather, terrain, soil quality, extreme events such as flooding and drought, seeding dates, pests, and diseases can also boost or damage crop yields. Kubinec’s study could either overestimate or underestimate the crop sequence effects of rotations if omitted variable correlated with the crop choice. We explore the nature of some of these effects. First, there is a need to explore the ‘rotation effect’ after taking more production factors into consideration. Secondly, the analysis of Kubinec’s table covers the yield responses of crops rotations in Manitoba, which assumes the rotation effect from previous crops in the whole province are the same. However, different regions might generate different yield responses to

consequent crop yield potentials, which means the yield responses from crop rotations in different regions would be different. Therefore, yield responses on regions including other factors should be analyzed and compared with Kubinec’s results.

The issue of soil degradation has been an issue on Canadian Prairies since European settlers arrived (Forge, 1998). Repetitive conventional tillage has altered the nutrient reserves of soil organic matter and soil water (Lafond et al., 1991). Risks are involved in crop production. Most importantly, weather plays a critical role in crop seeding and yields. In Manitoba, precipitation and temperature during the growing season determines germination, flowering, and the maturity of crop (County et al., 2014).

Table 1: Yield response (% of 2010 – 2015 average) of Manitoba crops sown on large fields (>120 acres) of various previous crops (stubble) in rotation.

| Previous Crop | Crop Planted | | | | | | | | | | |
|---------------|--------------|--------------|--------|--------|--------|-------|-----------|---------|-----------|-----------|------------|
| | Spring Wheat | Winter Wheat | Oat | Barley | Canola | Flax | Field Pea | Soybean | Navy Bean | Sunflower | Grain Corn |
| Spring Wheat | 85 | 87 | 94 | 95 | 102 | 104 | 103 | 102 | 109 | 103 | 96 |
| Winter Wheat | 72 | 83 | 97 | 106 | 101 | 95 | 107 | 104 | 118 | 107 | 95 |
| Oat | 91 | 84 | 79 | 78 | 95 | 92 | 93 | 100 | 79 | 102 | 99 |
| Barley | 88 | 93 | 90 | 82 | 100 | 102 | 91 | 100 | 83 | 96 | 92 |
| Canola | 100 | 104 | 101 | 103 | 87 | 86 | 98 | 100 | 93 | 92 | 99 |
| Flax | 96 | 104 | 90 | 107 | 103 | 83 | 91 | 98 | NSD | 88 | 85 |
| Field Pea | 102 | 80 | 110 | 106 | 104 | 148 | NSD | 95 | NSD | NSD | 98 |
| Soybean | 107 | 96 | 108 | 107 | 103 | 107 | 90 | 93 | NSD | 103 | 103 |
| Navy Bean | 113 | NSD | 117 | NSD | 116 | NSD | NSD | 122 | 86 | NSD | 110 |
| Sunflower | 102 | NSD | 102 | 106 | 90 | 99 | 85 | 93 | NSD | 82 | 97 |
| Grain Corn | 98 | 66 | 110 | 94 | 110 | NSD | 90 | 101 | 103 | 115 | 88 |
| Potato | 106 | 72 | 93 | 108 | 118 | NSD | NSD | 109 | 107 | NSD | 94 |
| Yield/bc | 50 bu | 64 bu | 101 bu | 65 bu | 36 bu | 21 bu | 38 bu | 35 bu | 1739 lb | 1607 lb | 121 bu |

NSD = Not Significant Data to be used in the analysis

Source: Kubinec, A. (2018). Building a ‘Better’ Crop Rotation.

Objective:

The purpose of this research is to explore how crop rotations influence crop yields in Manitoba. A yield model given inputs of fertilizers, climatic and regional factors, seeding dates, regional effects, yearly dummies, soil qualities, and crop rotation effects will be developed in the analysis. Yield responses through the coefficients of previous crops will be examined through the

yield model both provincial and regional levels. Kubinec's table is widely used in farm extension including having a prominent place in MASC's web site and, if correct, these previous crop choices generate economically important influences on yields. However, here I plan to explore a more thorough yield response table of previous crops by including more related factors than Kubinec's.

Significance of the research:

This study will help explain the impacts of crop rotation, subject to yearly weather effects, on economic returns for farmers, by regions. Compared to Kubinec's results, the effect of the previous crop on crop yield, explained by these models, will help explain rotation effects more thoroughly. Moreover, the coefficients of other influential factors insist agronomists and farmers to understand how much others contribute to crop yield potentials. Given the yield responses from crop rotations for different regions, farmers can identify more profitable rotation choices and make more informed planting decision.

Chapter 2: Background

Introduction of crop rotation:

Crop rotations are an agronomic practice of growing different crops on the same field through consecutive seasons, as opposed to monoculture, which is planting a single plant species year after year. Monoculture can lead to a higher likelihood of pest and disease outbreaks, the depletion of particular nutrients from the soil, poor plant health, and these contribute to lower crop yields (Shipton, 1977; Liu et al., 2006). The application of fertilizers to crop fields enhances crop yields and biomass, which contributes to increased soil organic nutrients and soil productivity. Eventually, monoculture can reduce natural resistance to diseases and pests, which can result in widespread devastation of crops from these pests and diseases (Shipton, 1977). Monoculture can lead to more pesticides and herbicides to ensure healthy crops, which results in water pollution and soil barrenness, and may lead eventually a collapse in methods left to control pests and diseases.

Cyclical rotations make significant contributions to farming systems in terms of the environment, ecology, and economy, whose contributions are known as ‘rotation effects’. Allowing for planting a diversity of crops reduces the dependence on external inputs through internal nutrient cycling and poses stronger resistance towards disease and insect infestations (Liu et al., 2006). Furthermore, the rotations enhance crop yields and soil organic matter, and reduce the need for fertilizers, herbicides, and pesticides. The development and implementation of good crop rotations is key to the success of both organic and non-organic production systems (Watson et al., 2013). As a result, well-managed and well-designed crop rotations reduce production costs and increase farmer profits. The mixture of leguminous and grain crops in a

rotation cycle forms crop rotations where pulse crops enhance nitrogen fertility and supply. General reductions in soil-borne pathogens and root disease severity in crop growth can be partially ascribed to longer crop rotation cycles (Clark et al., 1998). Spillover yields and input effects arise from crop rotations where leftover nutrition from previous crops not only boosts crop yield potential but also decreases the requirement of additional nutrient input, especially added N fertilizer after nitrogen fixing crops (Peterson et al., 1989). Also, switching crops in a rotation cycle could lower the probability of the appearance of certain diseases and insects that would be prevalent in a monoculture.

The agricultural industry in Manitoba:

Agriculture is one of the dominant income generating industries in Manitoba. Up to 13.5 million acres are suitable for sustained annual production of cultivated crops (Honey et al., 2006). In addition to primary agriculture, agricultural manufacturing has been thriving and makes a significant contribution to economic development in Manitoba. Food manufacturing industries contributed 2.1% to provincial Gross Domestic Production and 24% to manufacturing sales in 2016 (Manitoba Agriculture, 2017b). Canola and wheat are the primary crops grown and exported out of the province. The main destinations for exported agricultural products are the United States, China, Japan, and Mexico (Manitoba Agriculture, 2018). Canola plays a dominant role in crop production, followed by spring wheat, and soybeans. However, ecological pollution, especially water pollution, and soil erosion have been long-term issues in many agricultural regions (Forge, 1998). Herbicides, pesticides, and fertilizers are some of the major sources of environmental contaminants. These environmental problems could be partly attenuated with the reduced application of herbicides, pesticides, and fertilizers partially facilitated from crop rotations. In addition, crop rotations can have a positive influence on crop yields and reduce

input supply requirements. Therefore, the crop rotation system is worth considering as an extension question for farmers because of its environmental and economic benefits.

Crop choices of rotations for farmers in Manitoba:

Planting grains, oilseed, and pulses in rotation has been proven to offer benefits on both private and public levels. In Manitoba, wheat (a grain) and canola (an oilseed), are frequently grown in rotation by farmers. From the summary of approximately 50,000 fields in Manitoba for 15 years from data supplied by MASC for this study, the highest ranked crop rotations were ‘spring wheat and canola’ or ‘spring wheat, canola and soybean’ in most municipalities. For farmers, the choice of which crops to plan for in subsequent years relies heavily on: profits (yield, price and cost), and disease risks in the rotation interval, (Simonot, 2019). Canola, soybean, corn, and sunflowers are high-value crops in Manitoba with a potential for high profits (Simonot, 2019). Wheat, barley, and oats are often grown as offset oilseed crops in the rotation, which can reduce disease and pest risks (Simonot, 2019).

Canola has become the most popular crop in the Canadian Prairies. Both canola seed and canola oil are nutritionally and economically valuable, and canola oil is deemed to be one of the healthiest oils due to its low saturated fat level (Manitoba Agriculture, 2017a). Higher market prices relative to yield for canola than that of other crops leads canola to be more profitable and popular as a crop with farmers. Huge internal and international markets such as China are accessible to the canola industry, an industry that is responsible for millions of jobs in Canada (Canola Sector, Manitoba Agriculture, 2017a).

Wheat was the mainstay crop for western Canadian farmers for more than a century. Spring wheat remains the largest crop in terms of tonnes produced for most years and is the

largest in terms exported tonnes (Statistics Canada, 2019). A variety of uses for wheat was one of the reasons why wheat was and continues to be popular. Wheat is processed into “flour, cereal food, feed, pasta, bread, and bakery products. It comprises a large component of food processing in Manitoba (Manitoba Agriculture, 2017c). A significant domestic and international market makes wheat appealing. The majority of provincial wheat exports are in an unprocessed form, and over 70 countries import Manitoba wheat, including the United States, Iran, Japan, and Mexico. Canadian spring wheat is recognized throughout the world as a high-quality wheat (Manitoba Agriculture, 2017c). Finally, the durable nature of wheat explains why it is so widespread. Wheat is capable of surviving through severe growing conditions, such as different kinds of tillage systems, frost, and drought, and still produce a profitable yield.

Soybean, a nitrogen-fixing crop, enhances soil fertility and offsets disease cycles from other crops. This leads to benefits for the crop planted in the next year. High market prices for soybean along with good yields have appealed to Manitoba farmers and they have recently increased their area seeded to soybeans.

Literature review (Crop Rotations)

Crop rotations have a long history of usage in Europe. As early as the Roman Empire, Romans created a crop rotation system called ‘food, feed, fallow’ in which farmers rotated crops to plant food crops such as wheat, feed grain such as barley or oats for livestock, and then fallow in three sequential years (Ralls, 2013). The concept of rotating wheat, barley, a root crop, and a nitrogen-fixing crop was introduced in Great Britain by Viscount Charles ‘Turnip’ Townshend in the mid-1700s (Ralls, 2013). In the U.S., George Washington established a seven-year crop rotation of grain and legume crops, along with carrots, cabbage, peas, potatoes, pumpkins, and

turnips in the 1700s to enhance soil quality on his Mount Vernon farm (USDA, 2017). Crop rotation was used to demonstrate a constructive agricultural application that benefitted soil fertility and organic matter to local farmers (USDA, 2017). Currently, crop rotations have been implemented by many farmers across North America. USDA data shows continuous cropping of corns, wheat, and soybeans in recent years is rare compared to crop rotations (Wallander, 2013). On the Canadian prairies, Simonot (2019) suggested a typical crop rotation included cereals (e.g., wheat, barley, oats), oilseed (e.g., canola, flax, sunflowers), and legumes (e.g., pulses, field peas, beans, lentils, chickpeas), with a base of a 3-year or 4-year cycle.

Guillermo and Hernan (2000) tested the differences of soil organic matter content after crop and tillage selection. Their study concludes that residues returned to the soil may be increased by including crops in the rotation with high above-ground biomass-production, and through fertilization, thus attenuating soil organic carbon decrease (Guillermo, 2000). Wu, Babcock, and Lakshminarayan (1996) conducted a joint analysis of the economic and environmental impacts of conservation tillage, rotation, and soil nitrogen testing, which are considered as best management practices (BMPs) for the central Nebraska corn area. The polychotomous-choice selectivity model is applied to the empirical estimations. The authors highlight that farmer with more farming experience are more willing to adopt crop rotations because crop rotations are believed to generate long-term benefits (Wu et al., 1996). In addition, they observed that farmers who adopted both conservation tillage and rotations had much lower soil erosion rates than farmers who adopted only one of them (Wu et al., 1996). Furthermore, Helmers et al. (1986) studied the profitability and risk associated with crop rotation systems in east-central Nebraska. Two approaches were used to measure risks in the research: (1) both variability and dispersion of returns; and (2) the probability of losses. These were severe enough

to place farms in financial difficulty (Helmets et al., 1986). The coefficient of variation of net incomes and skewness of incomes are important because the distribution of negative deviations of net incomes can be as important as the overall level of dispersion. Helmets et al. (1986) conclude that row crop rotations have substantially higher returns than continuously grown row crops, and soybeans play a significant position in the yield increase.

Literature review (Yield Models)

Yield models have been created by using climatic factors which are related to crop growth. A two-piece empirical equation using the non-linear Quasi-Newton method has been applied to yield estimations (Prasad et al., 2006). Corn and soybean yields in Iowa are predicted by means of the Normalized Difference Vegetation Index (NDVI), surface temperature, precipitation, and soil moisture (Prasad et al., 2006). Crop yield for these two crops is largely governed by a model in which explanatory variables were selected as those that resulted in a model with a significant R^2 to predict for corn and soybean yield (Prasad et al., 2006). Schlenker and Roberts (2009) conducted an analysis of the link between crop yields and weather for three crops (corn, soybean, and cotton) in the US. They pair a panel of county-level yields for three crops with a fine-scale weather dataset and incorporates the whole distribution of temperatures within each day and across all days in the growing season. The most relevant conclusion that would apply to Manitoba is that both precipitation and temperature have a statistically significant inverted-U shape impact on yield and they estimated yield maximising temperatures and precipitations for each of the three crops.

A crop yield model designed by Cortus et al. (2011) was anchored on the theory of water use to water demand ratio with growing season precipitation (GS) as a proxy for water use and

growing degree days (GDD) as a proxy for water demand. An analysis of yield for twelve predominant crops in California was evaluated by Lobell, Cahill, and Field (2007). Two appropriate weather variables (GS&GDD) significantly impacted crop physiological growth.

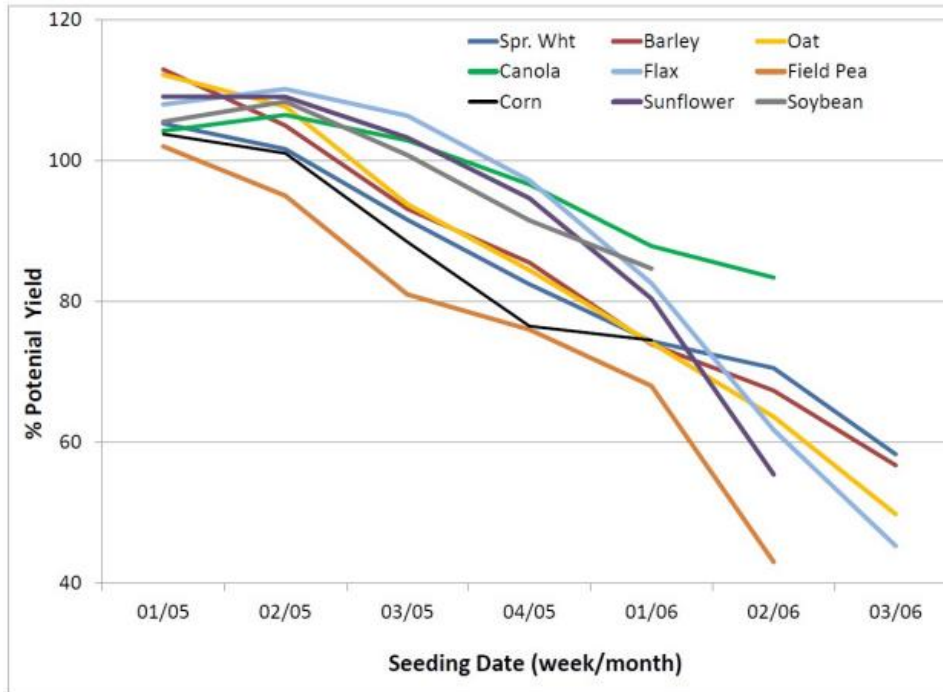
Including too many variables can easily lead to a model that has poor prediction accuracy due to over-fitting, resulting in higher interpretation difficulty. A second order polynomial regression is required because most weather elements often have a non-monotonic effect on yields.

Chapter 3: Study Area

The study area for this research covers all agricultural activities in Manitoba. Climate, weather, soil classes, terrain, and hydrology differ depending on local conditions through a diversity of municipalities. The region of Manitoba north of Lake Winnipeg and Lake Manitoba generally lacks crop production due to the cold climate and poor ground conditions for crop growth. Therefore, the research area is condensed to regions in the southern half of Manitoba with some modest data on the production in Swan River.

Cold winters greatly reduce exposure to some of the crop diseases more commonly found in warmer climates (Manitoba Agriculture, nda). However, the frost-free period in different areas of Manitoba restricts the seeding dates and agricultural crops that can be grown. The average frost-free period is the shortest near Riding Mountain at 75 days, while the longest (125 to 135 days) is in the Morden, Portage la Prairie, and Selkirk areas (Manitoba Agriculture, nda). Southern and southwest Manitoba enjoy the longest growing seasons while northwest areas have the shortest growing seasons. Soybean and grain corn require longer growing seasons in contrast to barley, canola, and spring wheat. Heat accumulation is another main factor which allows plants and insects to grow, develop, and emerge because each crop has a base temperature below which no growth or development will occur (Manitoba Agriculture, nda). Grain corn and soybeans have higher requirements for heat accumulation than wheat. Average yearly precipitation in different areas in Manitoba are fairly similar, at approximately 20 inches.

Figure 1: Crop yield responses to seeding dates (2005-2013)

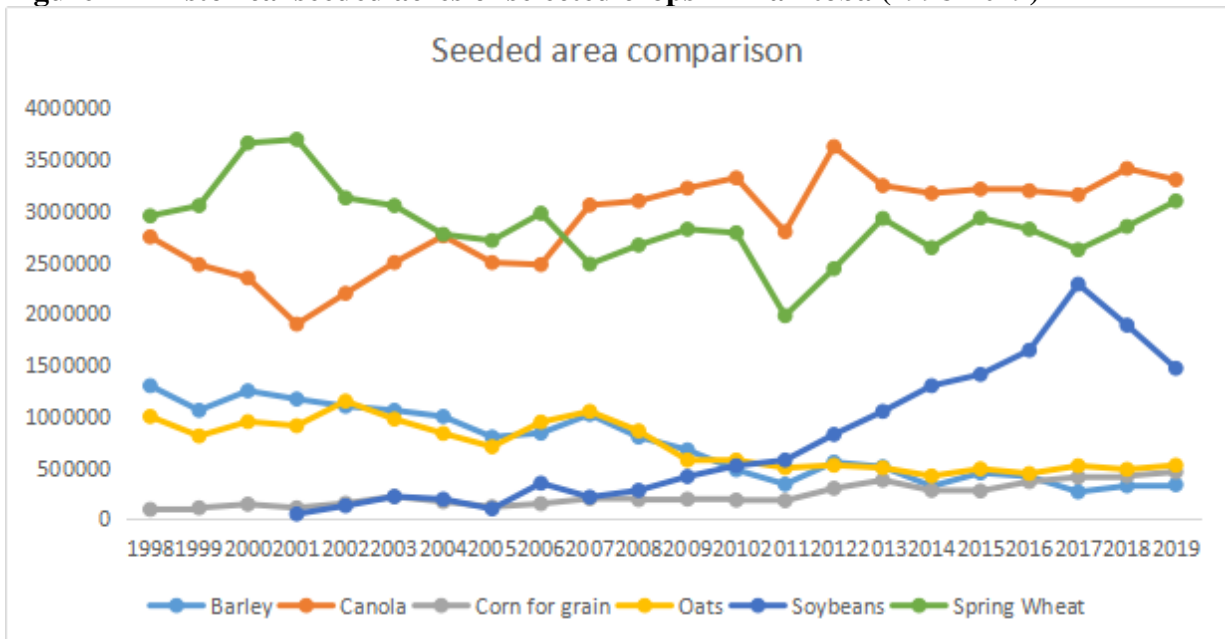


Source: Manitoba Agriculture (ndc). Reward Versus Risk: Seeding Early In Manitoba

Figure 1 above demonstrates the fundamental connections between seeding dates and yield potentials for a plethora of crops containing spring wheat, canola, corn, barley, flax, sunflower, oats, field pea, and soybeans in Manitoba. The x-axis shows seeding dates by week from first of May to the third week of June while y-axis shows yield potentials for nine crops. In general, data from the figure proves the earlier crops are seeded, the more yield potential generated. Exceptionally, the second week of May leads to the highest yield production in terms of flax, soybean, and canola. Manitoba Agriculture illustrates several reasons why earlier seeding results in increased yield potential (Manitoba Agriculture, ndc). Firstly, earlier seeding enables crops better to utilize available soil moisture through the growing season (Manitoba Agriculture, ndc). Secondly, the influx of weed and insect or disease damage could be avoided with early seeding because faster crop establishment, growth, and development is more likely to arrive

earlier than the period when ideal weather conditions for weeds, insects, and diseases exist (Manitoba Agriculture, ndc). Thirdly, “crop development is driven by accumulation of heat and moisture, if a crop can flower/head earlier than when peak high temperatures occur in mid-July, yield reductions can be avoided” (Manitoba Agriculture, ndc). Finally, “early seeding usually translates into early maturity and harvest as in most years, weather conditions in August and into September are drier and more favourable for harvest, also fall frost could be avoided that can cause yield and quality reductions” (Manitoba Agriculture, ndc).

Figure 2 – Historical seeded acres of selected crops in Manitoba (1998-2019)



Source: Statistics Canada, 2019 (1998-2019)

Figure 2 above gives the general trend of seeded area in acres for spring wheat, canola, barley, oats, soybean, and grain corn in Manitoba from 1998 to 2019. Data is from Statistics Canada and the figure is created by the author. Wheat was the dominant crop for many years in Manitoba, with the greatest seeded area of all crop types (Statistics Canada, 2019) until 2007. Canola has ranked as number one since 2007 in Manitoba (Canola Council, 2017). Canola area

increased from 1,600,000 acres in Manitoba in 1992 to 3,307,800 acres in 2019 (Statistics Canada, 2019). Soybeans have been the third most common crop since 2011 (Statistics Canada, 2019), reflecting the profitability of this newer crop. Barley, oats, and grain corn are popular with Manitoba farmers also, though their seeded acreages have remained low during the recent decade. Crop rotation combinations in Manitoba will most likely consist of the most common (canola, spring wheat, and soybean) and selective (barley, oats, and grain corn) crops and these will generate a variety of economic outputs.

Risk Areas are agricultural divisions for the purpose of identifying regions with similar production risks to determine insurance premiums consistent with the production risks of the area (2016a). Risk areas explore common agricultural production areas based on the criteria that group areas with similar soils, and climate into a common group (Wilcox, nd). Farmlands in Manitoba are classified into 15 Risk Areas after these criteria. All the Risk Areas included in the map in Figure 3 do not represent the whole province, but they do represent the arable area of the province. Wheat, barley, and oats are scattered and widespread in most Risk Areas. Cropping of grain corn is only in southern Risk Areas, where there are more growing degree days and longer frost-free periods; however, in recent years, grain corn has been grown among most Risk Areas. Soybean growth followed a similar path as grain corn, grain corn, originally grown in southern and warmer regions before expanding into most areas in Manitoba. Risk Area 12 is located in the Red River Valley, an area with high soil productivity, moisture, and heat units, which enables production of a wide range of crops. As for Risk Area 14, the elevation is higher with moderate productivity and it connects flat prairies to more hilly terrain. Further to the north and northwest, the soil is less productive and growing seasons are shorter. In the southern Risk Areas 1, 2, and 3 lying on the south and west side of the Assiniboine River, where it is drier and elevation is higher.

Although it is assumed that similar soils and climate areas are grouped into the same area, in practice, each Risk Area still has multiple soil classes and climates. In table 2, a variety of soil zones are generated relying on MASC cropping data. The benchmark soils were then placed in one of ten classes (A-J) with the soils having the highest yields classed as ‘A’, and lowest productive soils classed as “J” (Wilcox, nd). It should be noted that a “C” soil in Risk Area 12 may not have the same productivity as a “C” soil in Risk Area 6 due to climatic differences (Wilcox, nd). The analysis of area allocations should be dependent on 15 Risk Areas in conjunction with up to 10 soil classes, and founded on which accurate economic evaluations of crop rotations could be captured.

Table 2: Soil zones in 16 Risk Areas in Manitoba.

| Risk Area | Soil classes | Risk Area | Soil classes |
|------------------|---------------------|------------------|---------------------|
| 1 | D-J | 9 | B-J |
| 2 | C-J | 10 | C-J |
| 3 | C-J | 11 | A-J |
| 4 | B-J | 12 | B-J |
| 5 | B-J | 14 | C-J |
| 6 | B-J | 15 | C-J |
| 7 | B-J | 16 | C-J |
| 8 | A-J | | |

Source: Manitoba Agriculture Service Corporation (2016).

Risk Areas consist of a range of rural municipalities (RM). Only when at least 70% (approximately) of a municipality is thought to be within the boundary of one Risk Area will the region be considered in the Risk Area. A municipality with 50% to 70% of its area in one Risk Area will be deemed to be half included in the Risk Area. Overall, municipalities of Risk Areas are generated and shown in table 3.

Table 3: Municipalities in 16 Risk Areas.

| Risk Area | Municipalities |
|-----------|--|
| 1 | Two borders |
| 2 | Grassland, Brendawaskada, Deloraine-Winchester, Boissevain-Morton, Killarney-Turtle Mountain. |
| 3 | Ellice-Archie, Wallace - Woodworth, Pipestone (1/2), Sifton (1/2) |
| 4 | Riverdale, Whitehead, Cornwallis, Oakland-Wawanesa, North Cypress-Langford, Glenbore-South Cypress (1/2) |
| 5 | Prairie Lakes (1/2), Argyle, Louise, Pembina, Lorne, Victoria (1/2), Norfolk-Treherne (1/2) |
| 6 | Hamiota, Oakview, Minto-Odanah, Clanwilliam-Erickson, Harrison Park, Yellowhead (1/2), Elton (1/2) |
| 7 | Prairie-View (1/2), Yellowhead (1/2), Rossburn |
| 8 | Swan Valley West, Minitonas-Bowsman, Mountain (1/2) |
| 9 | Hillsburgrobin-Shell River, Grandview, Ethelbert, Gilbert Plain, Dauphin, Mossey River, Lakeshore, Ste. Rose, Alonsa, Mountain (1/2) |
| 10 | North Norfolk (1/2), Grey (1/2) |
| 11 | Westlake-Gladstone, Portage La Prairie, Woodlands, Rockwood, Glenella-Lansdowne (1/2) |
| 12 | Dufferin (1/2), Thompson, Roland, Stanley (1/2), Rhineland, Montcalm, Morris, MacDonald, Cartier (1/2), Rosser, West St. Paul, East St. Paul, Winnipeg, Spring Field (1/2), Tache, De Salaberry, Ritchot, Emerson-Franklin (1/2) |
| 14 | St. Clements, Brokenhead, Ste. Anne, La Broquerie, Stuartburn, Piney, Reynolds, Whitemouth, Pinawa, Alexander, Lac Du Bonnet, Hanover (1/2) |
| 15 | Grahamdale, West Interlake, Coldwell, St. Laurent, Armstrong, Gimli, Fishier, Bifrost-Riverton |
| 16 | Kelsey |

Source: Manitoba Agriculture Service Corporation (2016).

Table 4: Top 4 most common crops planted in 16 Risk Areas in Manitoba (2014-2018).

| Risk Area | 1st | 2nd | 3rd | 4 th |
|-----------|----------|----------|----------|-----------------|
| 1 | S. Wheat | Canola | Soybean | Oats |
| 2 | Canola | S. Wheat | Soybean | Oats |
| 3 | Canola | S. Wheat | Soybean | Barley |
| 4 | S. Wheat | Canola | Soybean | Barley |
| 5 | Canola | S. Wheat | Soybean | Barley |
| 6 | Canola | S. Wheat | Barley | Soybean |
| 7 | Canola | S. Wheat | Barley | Oats |
| 8 | Canola | S. Wheat | Soybean | Oats |
| 9 | Canola | S. Wheat | Soybean | Oats |
| 10 | Soybean | Canola | S. Wheat | Oats |
| 11 | Canola | S. Wheat | Soybean | Barley |
| 12 | Soybean | S. Wheat | Canola | Grain Corn |
| 14 | Soybean | S. Wheat | Canola | Grain Corn |
| 15 | Canola | S. Wheat | Soybean | Oats |
| 16 | Canola | S. Wheat | Soybean | Oats |

Source: Manitoba Agriculture Service Corporation (2021).

Seeded area data measured on municipalities from MASC (ndb) provides us with a foundation of the prevalent crops from 2014 to 2018 in all Risk Areas. The four most dominant crops (potatoes were excluded because it is not common outside of a few municipalities) are shown on Table 4. It is indicated that for most Risk Areas, spring wheat, canola, and soybean take the top three positions, followed by oats, barley, and grain corn in some Risk Areas. Risk Area 12 and 14 have the same crop selection of ‘Soybean – Canola – S. Wheat – Grain Corn’ because both of them are warmer and more humid. ‘Canola - S. Wheat – Soybean’ are the three most dominant crops in Risk Area 2, 3, 5, 8, 9, 11, 15, 16.

Chapter 4: Methodology

The research goal of this proposal research is to explore the yield responses from crop rotations in each Risk Area in Manitoba. To increase economic impacts from crops, crop yields are deemed to be critical and worth exploring in the analysis. Before running a yield model including multiple variables, a yield response exploration using a linear regression with ordinary least squares (OLS) will be conducted and compared to Kubinec's results using the same MASC data. The second stage of the research will focus on building a crop yield model, at both a provincial level and a Risk Area level, based on environmental criteria and other factors that explain how the previous crop influences the yield for the following season by observing the coefficients for previous crops. These yield models help us not only understand how different Risk Areas contribute to yield productions but also explain rotation effects from a new dataset and method. Regional yield models indicate yield responses based on regions, which provides farmers with more specific crop rotation methods.

Yield exploration: Linear model

The linear regression for the relationship between crop yields, as dependent variables, and previous crops, as independent dummy variables, will be modeled. Maximum Likelihood Estimators (MLE) are applied to non-linear and discrete distributions (Greene, 1997). OLS is suitable for regressions of linear models. The simple linear regression is as below:

$$Y_t = \alpha_0 + \alpha_1 C_1 + \alpha_2 C_2 + \alpha_3 C_3 + \alpha_4 C_4 + \alpha_5 C_5 + \varepsilon_t \quad (1)$$

Model explanation:

The model represents a simple linear model of yield for a given crop (Y_{ti}) in year t and field i including only previous crops as dummy variables. The only factor considered in the model is the effect from previous crops, called rotation effect and random shocks. One previous crop variable needs omitting based on the theory of application of dummy variables in econometrics. In the model, α_0 is the constant, which is supposed to be equal to the average yield with the omitted crop as the previous crop. C_j represents the j th previous crop other than omitted crop. α_j is the coefficient of the j th previous crops, which imply yield changes in response to the planting of previous crops compared to omitted variables. Omitted crops are consistent with those in yield model including all variables. The final impact is a random shock E_{ti} for each year and field.

Compared to Kubinec's method of calculating yield responses, the linear yield model catches not only the significance of yield responses from previous crops but also the Adjusted R^2 of the yield models which represents how much the previous crops explain crop yields. A new yield response table attached to coefficients of previous crops will be shown from a linear model. A comparison between the new yield response table from MASC and the yield response table from Kubinec will be illustrated.

Yield Model including all variables in Manitoba:

A series of ecological and farm management elements have the ability to interact with growth and crop yields, including soil quality, seeding dates, precipitation outside growing season before seeding, temperature and precipitation during the growing season, pests and diseases, the inputs of fertilizers, pesticides and herbicides, as well as rotation effects. Among

these factors, the occurrence of crop diseases and pests are a challenge to model because their incidence and extent of damage is more difficult to assess and measure compared to some other influences. In addition, monitoring and managing crops properly by farmers is vital to crop yields. Crop decisions, e.g., tillage methods, crop selection, soil nutrition complements, and pesticide choices make an enormous difference on crop yields. However, only inputs of fertilizers, seeding dates and crop choices among human operating factors could be tracked in the available data.

Precipitation, rain and snow, prior to the growing season provides soil moisture at the time of seeding (Manitoba Agriculture, nda). However, data for soil moisture in the past 15 years is lacking. The Manitoba Soil Survey has grouped and classified soils based on morphological features. The benchmark soils were then placed in one of ten classes (A-J) with the soils having the highest yields classed as “A”, and the lowest yielding soils classed as “J” (Wilcox, nd). The effects of seeding date (MASC, nd) towards main crop yields are such that generally the earlier crops are planted, the greater the yield potential (based on 1989 -2008 yield analysis). Appropriate precipitation and temperature in the growing season and at specific stages (seeding, germination, flowering, and maturity) favor crop growth and yield potential significantly.

Growing degree days (GDD) and growing season precipitation (GS) are measures of accumulated heat units and precipitation, respectively, during crop growing season. They are two applicable explanatory variables to be used in the crop yield model. During the growing season (roughly spring to August 30), precipitation (GS) varies from about 230 mm to 270 mm (Manitoba Agriculture, nda). Adequate temperature accumulation is essential for plants and insects to grow and develop. Growing degree days (GDD), a measure of heat accumulation, is used to predict plant and pest development. Each crop has a base temperature that is required for

plant growth, so the GDD is the accumulated average minimum, above the base, and maximum daily temperature above the base (Miller et al., 2001).

Crops require different volumes of water and heat in separate development stages, but we do not have data to demonstrate fragments of crop growth. Crop rotation directly affect the yields of following crops. Production inputs and human management are assumed to be optimally applied in crop operations. It is assumed that plant nutrition and agricultural machines are near-optimal for farms to obtain good cropping management and high profits. In summary, fertilizer components (N, P, K, S), soil classes, Risk Areas, seeding dates, crop rotation effects, yearly dummies, GDD, and GS are available to be used in our yield model. The model can also be specified to account for yearly differences.

A panel data yield model incorporating nutrient values of fertilizers (N, P, K, S) and climatic factors which represent time series effects, crop rotation effects, seeding dates, Risk Areas, and soil qualities as the fixed effects is targeted to examine the influences from natural conditions and human cropping operations, to project crop yields given simulated exogenous variables. A model proposed for the six crops is the following:

$$\begin{aligned}
 Y_{i,t} = & \alpha_0 + \rho_1 N_{i,t} + \rho_2 P_{i,t} + \rho_3 K_{i,t} + \rho_4 S_{i,t} + \\
 & \beta_1 GS_{i,t} + \beta_2 (GS_{i,t})^2 + \beta_3 GDD_{i,t} + \beta_4 (GDD_{i,t})^2 + \beta_5 (GS_{i,t} GDD_{i,t}) + \\
 & \gamma_1 R_2 + \gamma_2 R_3 + \gamma_3 R_4 + \dots + \gamma_{15} R_{16} + \gamma_{16} B + \gamma_{17} C + \gamma_{18} D + \dots + \gamma_{25} J + \\
 & \theta_1 D_1 + \theta_2 D_2 + \theta_3 D_3 + \dots + \theta_7 D_7 + \\
 & \alpha_1 C_1 + \alpha_2 C_2 + \dots + \alpha_5 C_5 +
 \end{aligned}$$

$$\delta_1 T_1 + \delta_2 T_2 + \dots + \delta_{12} T_{12} + \mu_{ijt} \quad (2)$$

The calculation of GDD and GS is:

$$GDD = \sum_{i=1}^n \left(\frac{T_{\max}^i + T_{\min}^i}{2} - T_{base} \right) \quad (3)$$

$$GS = \sum_{i=1}^n P_i \quad (4)$$

Model explanations:

Y_{it} is the same as the linear model. α_0 is the intercept of the model. $\rho_{(1-4)}$ represent coefficient effects from fertilizer inputs on yields. As described above, GS_{it} and GDD_{it} represent growing season precipitation and growing degree days, respectively, in Risk Area i (1-16, there is no Risk Area 13) for the year t . β_i shows the contributions from temperature and precipitation to yield effects. R_i is a dummy variable for Risk Area i (1 to 16 (13 is missing) and B-J is a dummy variable for soil zone B to J. For some Risk Areas, there only are some of soil classifications in the data set. γ_i is the yield effects from a certain soil zone and Risk Area. Here soil zone “A” and Risk Areas 1 deemed to be omitted variables. The following part of the model indicates impacts from dummy variable ‘seeding dates (D)’, in which seeding dates are aggregated weekly from the last week of April to the 3rd week of June (8 weeks). The week with the highest average yields would be omitted among dummy variables in each Risk area. C_i stands for the previous crop planted in the same field, and the coefficients ‘ α_i ’ are ‘rotation effects’ under different Risk Areas. We only consider the six most common crops in each Risk Area: spring wheat, canola, soybean, oats, barley and grain corn. For crops, canola and spring wheat will be considered as omitted variables for previous crops since they are most common crops in

this province (Table 5). Yearly dummy variables ‘ T_i ’ are used to show structural technical variations for each year. Year 2018 is omitted from the yearly dummies. Finally, μ is the error term which includes for all unmeasured factors.

Table 5: Omitted crops for previous crops in the yield models for each crop modeled.

| | Crop in the yield model | | | | | |
|-------------------------|-------------------------|---------|------------|--------|----------|---------|
| | Barley | Canola | Grain Corn | Oats | Soybeans | S.Wheat |
| Previous Crop (omitted) | Canola | S.Wheat | Canola | Canola | Canola | Canola |

Fertilizers including N (nitrogen), P (phosphorus), K (potassium), S (sulphur) are necessary nutrients for nourishing crop growth and boosting yield potentials. Fertilizer use is very expensive and can harm the environment if not used correctly (Dejoia, 2015). If too little is added, crops will not produce as much as they should (Dejoia, 2015). If too much is added, or at the wrong time, excess nutrients will run off the fields and pollute streams and groundwater (Dejoia, 2015). Therefore, the appropriate amount of fertilizers at the right time is required to avoid potential negative effects to the environment (Dejoia, 2015). Quadratic items for all the fertilizer inputs are supposed to be added to the model based on the principle as described above, however, excess quadratic items could lead to an econometric problem with multicollinearity. Consequently, the model is restricted to linear or ln linear version of inputs of fertilizers. If ln linear of N, P, K, S is applied, at least fifteen percent of missing data of N, P, K, S yields smaller than applicable dataset, which causes less significant regression results compared to single linear regression. Eventually, simple linear application of N, P, K, S was deemed to be the appropriate form in the model.

Generally, plants grow faster with an increasing air temperature and rainfall up to an optimal point, while extreme heat will slow growth and increase moisture loss, and excess water reduces the amount of oxygen in the soil, resulting in root loss or injury (County et al., 2014). That is the reason why quadratic items are included for GS and GDD in the model. As for the fixed effects and technical change sections, one option needs omitting due to the nature of how dummy variables work in a regression.

Yield model including all variables Risk Area by Risk Area:

Another set of yield estimates were also developed to demonstrate how crop yields are influenced by natural and human factors within a Risk Area. A yield model given inputs of fertilizers, soil zones, seeding dates, crop rotation effect, and yearly dummies will be developed in the analysis. The reasons why growing season precipitation (GS) and growing degree days (GDD) are abandoned is that multicollinearity occurs between GS & GDD and yearly dummies. A model proposed for the six crops is the following:

$$\begin{aligned}
 Y_{i,t} = & \alpha_0 + \rho_1 N_{i,t} + \rho_2 P_{i,t} + \rho_3 K_{i,t} + \rho_4 S_{i,t} + \\
 & \gamma_1 B + \gamma_2 C + \dots + \gamma_9 J + \\
 & \theta_1 D_1 + \theta_2 D_2 + \theta_3 D_3 + \dots + \theta_7 D_7 + \\
 & \alpha_1 C_1 + \alpha_2 C_2 + \dots + \alpha_5 C_5 + \\
 & \delta_1 T_1 + \delta_2 T_2 + \dots + \delta_{12} T_{12} + \mu_{ijt} \quad (5)
 \end{aligned}$$

The explanations of variables are the same as those in yield model for Manitoba but Y here is for a single Risk Area. As for omitted variables for soil zones, seeding weeks, and yearly

dummies, soil zones, seeding weeks, and yearly dummies are the same as those in yield model for the whole province.

Chapter 5: Data

Dataset from MASC:

Field level data on 51,433 fields during the period from 2004 to 2018 was shared in a data sharing contract from the MASC. Through the process of data collection, crop varieties, crop yields, Risk Areas, soil class, and seeding dates for each parcel and year were captured. The crop planted in the previous year was extracted based on the same land code. Data for 37585 fields extracted from the whole dataset was applied in the analysis because only data relevant to 6 common crops (spring wheat, canola, soybean, oats, barley, grain corn) were complete enough to be used in this study. Additionally, the time span is shortened to 2006-2018, to identify the previous crop and Risk Area 13 is excluded from the dataset. An example from MASC data is shown in Table 6.

Table 6: Crop data from a MASC contract.

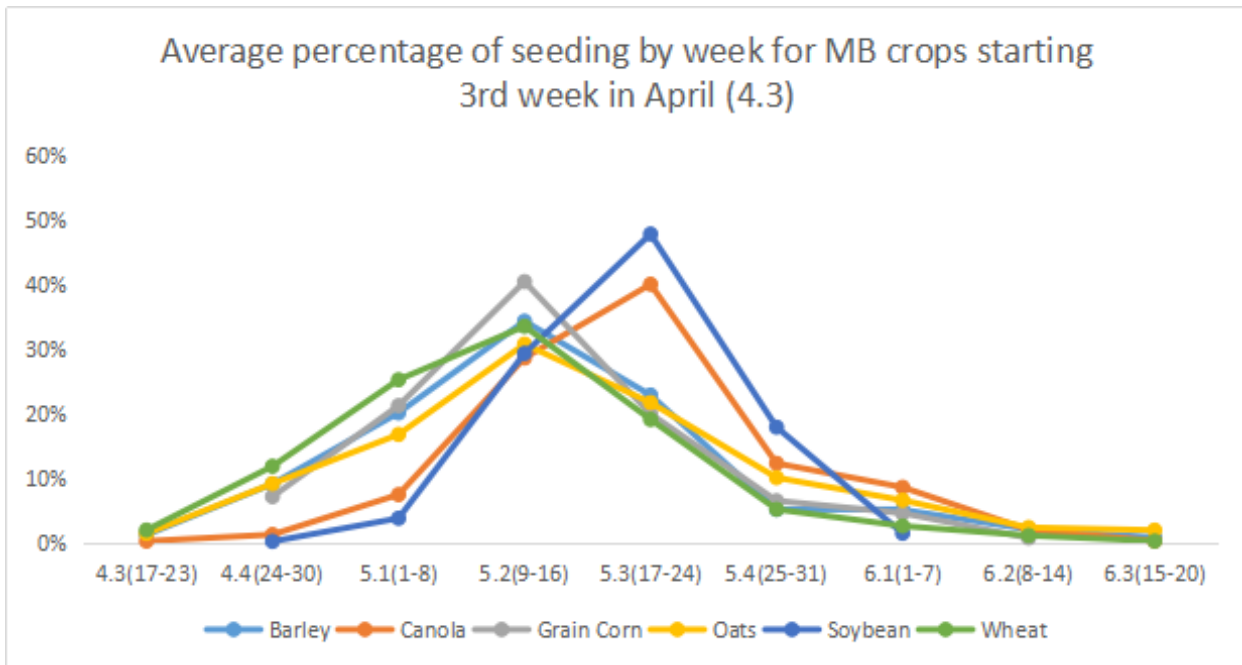
| Year | Crop | RA | Soil class | Previous Crop | Seeding Month | Seeding Date | Landcode | Yield (bu) |
|--------------|--------------|--------------|--------------|---------------|---------------|--------------|----------|------------|
| 2018 | Canola | 12 | B | Soybean | 5 | 4 | xxx | 64.42 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |
| N (Pound) | P (Pound) | K (Pound) | S (Pound) | | | | | |
| 150 | 50 | 0 | 15 | | | | | |
| ... | ... | ... | | | | | | |

Source: Manitoba Agriculture Service Corporation (2021).

Based on the full dataset from MASC, data of both dependent and independent variables regarding the six common crops, spring wheat, canola, soybean, oats, barley, and grain corn, would be considered and applied in this analysis. Other minor crops and fallow are excluded from the research because it is unlikely significant estimates can be measured from the low number of the yield fluctuations observed. Potatoes are also out of consideration of the research

because potato operations need special equipment and again they are small crop relative to the six crops considered. Yearly dummies in the yield models range from 2006 to 2018 which represent the year when the crop was planted.

Figure 4: Seeding dates for selected crops by week in Manitoba (the third week of April to the third week of June) (2006-2018).



Source: Manitoba Agriculture Service Corporation (2021).

MASC gives seeding dates for all the landcodes ranging from April 1st to June 20th.

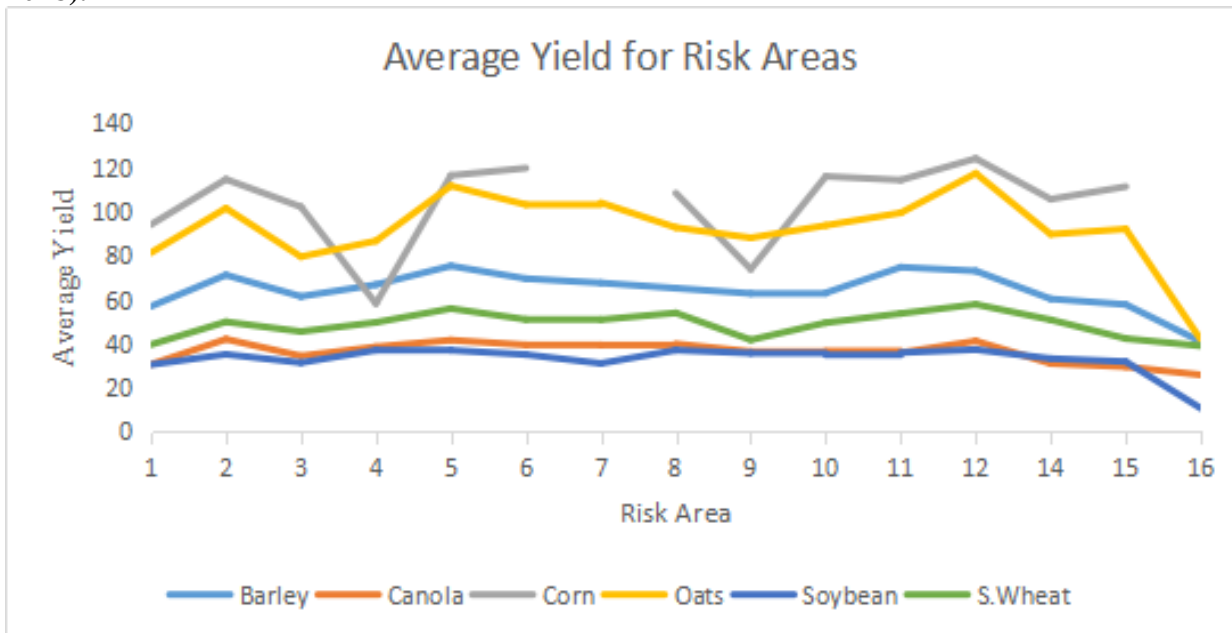
Figure 4 shows the percentage of seeding dates for the six crops by week in Manitoba.

Percentages of seeding weeks for six crops are aggregated in y-axis and compared among six crops. 26 data points are beyond consideration owing to the scarcity of their presence in the first two weeks of April. The absence of seeding weeks of the third week of April for soybeans and grain corn explains shortage of seeding for grain corn and soybeans in Figure 4. It is indicated from the table that more than 80 percent of seeding dates are concentrated in May because of suitable weather, soil moisture, and temperature. The seeding dates of grain crops such as barley,

oats, and wheat are spread out over various weeks, because barley, oats, and wheat have stronger resistance towards risks from extreme weather conditions or market prices. Canola is not supposed to be grown before May for biological reasons; canola could be killed by frost in April-early May and would need to be reseeded. 99% of soybean is seeded in May, especially mid and late May. Soybeans are more sensitive to changes in soil temperature.

Figure 5 gives the average yield comparisons of six selected crops (Barley, Canola, Corn, Oats, Soybean, Spring wheat) between 15 Risk Areas. There are corresponding average yields for each crop in each Risk Area calculated by MASC data for thirteen years. Risk Area 12 produces the highest average yields for corn, oats, soybean, spring wheat. Barley grows better in Risk Area 5, 11, and 12. Risk Area 16, northern Manitoba, has the poorest growing conditions and thus produces the lowest yields for barley, canola, oats, soybean, and spring wheat. Grain corn was not grown in Risk Area 8 and 16.

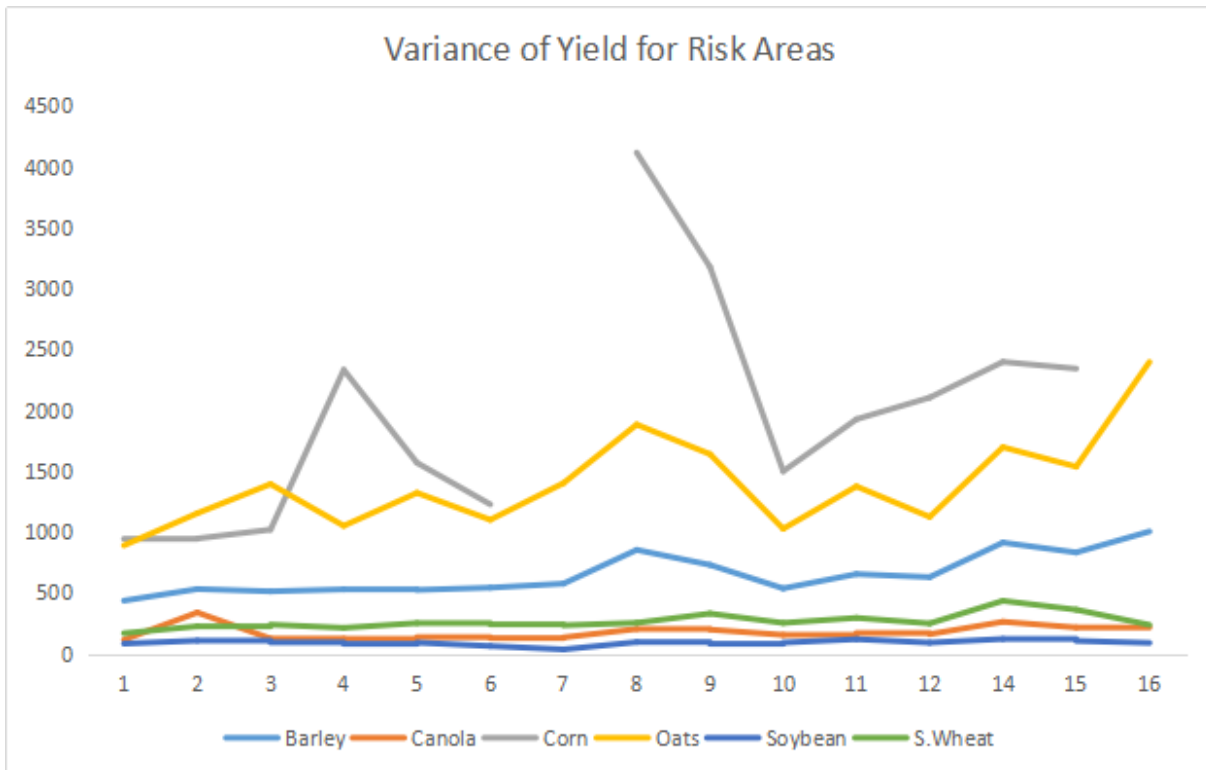
Figure 5: Average yield (Bushel/acre) for selected crops in Risk Areas in Manitoba (2004-2018).



Source: Manitoba Agriculture Service Corporation (2021).

Figure 6 gives the yield variation (bu./ac)² comparisons of 6 selected crops (Barley, Canola, Corn, Oats, Soybean, Spring wheat) for the 15 Risk Areas based on MASC data for thirteen years. The corresponding variance to each Risk Area is shown in y-axis. Risk Area 1 has the lowest crop yield fluctuations for barley, canola, corn, oats, and spring wheat. The result for corn might not be precise since the data for corn is lacking (no data in Risk Areas 7 and 16). The variances for soybean, spring wheat, and canola in different Risk Areas are quite stable and low.

Figure 6: Variance of yields (bu./ac)² for selected crops in Risk Areas in Manitoba (2004-2018).



Source: Manitoba Agriculture Service Corporation (2021).

Data from Environment and Natural Resources:

128 weather stations in Manitoba are used to gather data by Environment Natural Resources Canada where daily maximum and minimum temperatures from May 1 to September

30 and precipitation from May 15 to September 30 are available. 128 weather stations were classified into the 16 Risk Areas according to the criterion through which municipalities were assigned to Risk Areas. The existence of data length from 2005 to 2018 for temperature and precipitation varies from station to station, so in the case of missing data from some stations, nearby stations' data would be averaged and used. Base temperatures for various crops Manitoba Agriculture are shown in Table 7.

Table 7: Base temperatures for six selected crops.

| Crop | Canola | Corn | Spring Wheat | Soybean | Oats | Barley |
|-----------------------|--------|------|--------------|---------|------|--------|
| Base temperature (°C) | 5 | 10 | 4.7 | 10 | 4.7 | 4.7 |

Source: Manitoba Agriculture (2016).

In terms of growing degree days (GDD), the term from June 1 to September 30 is applied to the growth of grain corn and soybean since they are considered as longer and later growing season crops. But growing degree days for barley, canola, oats, and spring wheat use the period of May 1 to August 30, since they are planted and harvested earlier. In terms of growing season precipitation (GS), the sum of precipitation from May 15 to August 30 is included into the calculation of barley, canola, oats, and spring wheat, which satisfies the growing periods of these crops. However, precipitation from May 15 to September 30 is considered as the growing season for soybean and grain corn.

Chapter 6: Results

Results from the Linear Model:

Ordinary least squares estimation (OLS) was applied in the linear regression. Assumptions of this type of model - homoscedasticity, non-autocorrelation, normality, and non-multicollinearity were tested and satisfied for the OLS regressions of six yield models. Frequencies of previous crops on current crops in Manitoba are shown in Appendix A. Regression results from Stata are shown in Appendix B1 to B6. The regression results have an adjusted R^2 for barley, canola, grain corn, oats, soybeans, and spring wheat of 0.045, 0.019, 0.034, 0.042, 0.009, and 0.057 respectively, which are considered low in econometrics and justify the low robustness of variables. Based on t-statistics, most previous crop coefficients are significant except grain corn for the barley regression, oats and spring wheat for the grain corn regression, soybeans for the barley regression, and grain corn for soybeans regression.

Table 8 illustrates the coefficients and t-statistics of regression results from MASC data with only previous crops as dummy variables. Coefficients explain gaps between crop yields while planting previous crops in bushel compared to crop yields with omitted crops as previous crops. For example, barley yield while planting barley as a previous crop (coefficient) is less than barley yield with a previous crop of canola (omitted crop) by 15.11975 bushels. Table 9, partially derived from Table 8, displays 95% confidence intervals for coefficients of previous crops from linear regressions.

Table 8: Coefficients (t-statistics) of previous crops compared to canola in linear models with only previous crops as exogenous variables in Manitoba (2006-2018).

| | | Crop planted | | | | | |
|---------------|------------|---------------------|--------------------|-------------------|--------------------|--------------------|---------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -15.119 (-18.42) | -1.110 (-8.51) | -9.443 (-3.78) | -10.333 (-6.71) | -0.531 (-1.62) | -8.376 (-16.95) |
| | Canola | 0 | -4.146 (-29.93) | 0 | 0 | 0 | 0 |
| | Grain Corn | -1.152 (-0.55) | 4.312 (-16.97) | -6.312 (-3.42) | 9.021 (-3.56) | 0.924 (-3.05) | 1.099 (-1.11) |
| | Oats | -12.369 (-11.60) | -2.814 (-16.53) | -4.039 (-1.39) | -25.619 (-8.15) | -1.046 (-3.80) | -9.231 (-18.78) |
| | Soybeans | 5.383 (-6.1) | 3.177 (-19.25) | 10.566 (-7.72) | 8.266 (-8.15) | -1.879 (-10.35) | 8.957 (-45.32) |
| | S.Wheat | -5.093 (-8.89) | 0 | 3.194 (-1.7) | -6.575 (-6.05) | 0.729 (-4.64) | -12.202 (-45.82) |

Table 9: Coefficients (95% confidence intervals) of previous crops compared to canola in linear models with only previous crops as exogenous variables in Manitoba (2006-2018).

| | | Crop planted | | | | | |
|---------------|----------|--|-------------------------------------|--------------------------------------|--|-------------------------------------|--|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -15.119 (-16.73 - -13.51) | -1.110 (-1.37 - -0.85) | -9.443 (-14.34 - -4.55) | -10.333 (-13.35 - -7.32) | -0.531 (-1.17 - 0.11) | -8.376 (-9.34 - -7.41) |
| | Canola | 0 | -4.146 (-4.42 - -3.87) | 0 | 0 | 0 | 0 |
| | G.Corn | -1.152 (-5.25 - 2.94) | 4.312 (3.81 - 4.81) | -6.312 (-9.93 - 2.70) | 9.021 (4.05 - 13.99) | 0.924 (0.33 - 1.52) | 1.099 (-0.85 - 3.05) |
| | Oats | -12.369 (-14.46 - -10.28) | -2.814 (-3.15 - 2.48) | -4.039 (-9.72 - 1.64) | -25.619 (-29.35 - -21.89) | -1.046 (-1.59 - 0.51) | -9.231 (-10.20 - -8.27) |
| | Soybeans | 5.383 (3.65 - 7.11) | 3.177 (2.85 - 3.50) | 10.566 (7.88 - 13.25) | 8.266 (6.28 - 10.25) | -1.879 (-2.24 - -1.52) | 8.957 (8.57 - 9.34) |
| | S.Wheat | -5.093 (-6.22 - -3.97) | 0 | 3.194 (-0.48 - 6.87) | -6.575 (-8.71 - -4.45) | 0.729 (0.42 - 1.03) | -12.202 (-12.72 - -11.68) |

Table 10 shows the average yield for crops with omitted variables as previous crops, e.g., the average yield for barley after canola – omitted crop, sorted from the original data is 74.487987 bushels. Moreover, the average yields for crops are shown in Table 11, e.g., the average yield for barley aggregated by the original data is 72.083 bushels.

Table 10: Average yields for crops with omitted crops as previous crops (2006-2018). Canola is used as the omitted crop for all other crops except canola, in which case spring wheat is used.

| Crop | Barley | Canola | G.Corn | Oats | Soybeans | S. Wheat |
|--------------------|--------|----------|---------|---------|----------|----------|
| Omitted Crop | Canola | S. Wheat | Canola | Canola | Canola | Canola |
| Average Yield (Bu) | 74.487 | 39.801 | 118.277 | 104.626 | 35.874 | 53.080 |

Source: Manitoba Agriculture Service Corporation (2021).

Table 11: Average yields for crops in Manitoba (2006-2018).

| Crop | Barley | Canola | G.Corn | Oats | Soybeans | S.Wheat |
|--------------------|--------|--------|---------|---------|----------|---------|
| Average Yield (Bu) | 72.083 | 39.477 | 121.092 | 103.752 | 35.687 | 53.090 |

Source: Manitoba Agriculture Service Corporation (2021).

After basic interpretations of the coefficients of previous crops and average yields for crops with varying previous crops, adjusted average yields after previous crops with confidence intervals can be calculated by the addition of coefficients of previous crops to the average yields of crops while previous crops are omitted, e.g. the adjusted average yield for barley after barley is the addition of the coefficient of barley in the yield model of barley and the average yield of barley with canola being a previous crop, $-15.119 + 74.487 = 59.368$ bushels. The adjusted average yields for crops based on coefficients are shown in table 12.

Table 12: Adjusted average yields based on coefficients of previous crops compared to canola in linear regressions on crop rotations (2006-2018).

| | | Crop planted (Bu) | | | | | |
|------------------|----------|-----------------------------|-----------------------------|--------------------------------|--------------------------------|--------------------------------|-----------------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 59.368 (57.76- 60.98) | 38.690 (38.43- 38.95) | 108.833 (103.94- 113.73) | 94.292 (91.28- 97.31) | 35.342 (34.70- 35.98) | 44.704 (43.74- 45.67) |
| | Canola | 74.487 | 35.655 (35.38- 35.93) | 118.277 | 104.626 | 35.874 | 53.080 |
| | G.Corn | 73.335 (69.24- 77.43) | 44.114 (43.61- 44.61) | 111.964 (108.35- 115.58) | 113.648 (108.68- 118.62) | 36.799 (36.20- 37.39) | 54.180 (52.23- 56.13) |
| | Oats | 62.118 (60.03- 64.21) | 36.986 (36.65- 37.32) | 114.237 (108.56- 119.92) | 79.007 (75.28- 82.74) | 34.827 (34.28- 35.36) | 43.849 (42.88- 44.81) |
| | Soybeans | 79.871 (78.14- 81.60) | 42.978 (42.65- 43.30) | 128.843 (126.16- 131.53) | 112.892 (110.91- 114.88) | 33.994646 (33.63- 34.35) | 62.037 (61.65- 62.42) |
| | S.Wheat | 69.394 (68.27- 70.52) | 39.801 | 121.471 (117.80- 125.15) | 98.050 (95.92- 100.18) | 36.6041 (36.29- 36.90) | 40.878 (40.36- 41.40) |

Yield responses in percent change are calculated in the ratio of the adjusted average yield of crop rotations (Table 12) over average yield (Table 11) shown in table 13, e.g., yield response of barley after barley is $59.368 / 72.083 = 82.40\%$.

Table 13: Yield responses (% change) and 95% confidence intervals of yield responses in rotations based on MASC data (2006-2018).

| | | Crop planted | | | | | |
|---------------|----------|-----------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 82.40% (80.1% - 84.6%) | 98.00% (97.3% - 98.7%) | 89.90% (85.8% - 93.9%) | 90.90% (97.2% - 100.8%) | 99.00% (97.2% - 100.8%) | 84.20% (82.4% - 86.0%) |
| | Canola | 103.30% | 90.30% (89.6% - 91.0%) | 97.70% | 100.80% | 100.50% | 100.00% |
| | G.Corn | 101.70% (96.1% - 107.4%) | 111.70% (110.5% - 113.0%) | 92.50% (89.5% - 95.4%) | 109.50% (101.4% - 104.8%) | 103.10% (101.4% - 104.8%) | 102.10% (98.4% - 105.7%) |
| | Oats | 86.20% (83.3% - 89.1%) | 93.70% (92.8% - 94.5%) | 94.30% (89.6% - 99.0%) | 76.10% (96.1% - 99.1%) | 97.60% (96.1% - 99.1%) | 82.60% (80.8% - 84.4%) |
| | Soybeans | 110.80% (108.4% - 113.2) | 108.90% (108.0% - 109.7%) | 106.40% (104.2% - 108.6%) | 108.80% (94.2% - 96.3%) | 95.30% (94.2% - 96.3%) | 116.90% (116.1% - 117.6%) |
| | S.Wheat | 96.30% (94.7% - 97.8%) | 100.80% | 100.30% (97.3% - 103.3%) | 94.50% (101.7% - 103.4%) | 102.60% (101.7% - 103.4%) | 77.00% (76.0% - 78.0%) |

Table 13 shows the yield responses and confidence intervals in terms of percentage converted from coefficients of previous crops. Firstly, it is consistent with the agronomic theory of monoculture that there are negative effects on the following year's crops while the previous crop is the same as that in the following year. Secondly, data from table 13 proves the effectiveness of soybeans as a nitrogen fixing crop, which helps boost yields for crops in the consequent year. Thirdly, the yield responses to previous crops range from 75% to 120%.

Table 14: Yield responses (% of 2010 - 2015 average) of Manitoba crops sown on large fields (> 120 acres) of various crops (stubble) in rotation. (Kubinec's).

| | | Crop planted | | | | | |
|---------------|---------|--------------|--------|--------|------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 85% | 104% | 92% | 90% | 101% | 90% |
| | Canola | 102% | 86% | 99% | 101% | 100% | 101% |
| | G.Corn | 96% | 112% | 89% | 111% | 102% | 98% |
| | Oats | 78% | 95% | 99% | 77% | 100% | 93% |
| | Soybean | 108% | 104% | 103% | 108% | 94% | 108% |
| | S.Wheat | 96% | 102% | 98% | 98% | 101% | 85% |

Source: Kubinec, A. (2018). Building a 'Better' Crop Rotation.

Kubinec's research of yield responses for the six crops in rotations is shown in Table 14, which is part of Table 1 in the first Chapter. The yield responses with data from MASC and Kubinec's research are mostly consistent and satisfy theories of negative effects from monoculture and positive effects from soybeans. Confidence intervals of rotation effects do not deviate yield responses significantly in general. However, there are still some differences between the two Table 13 and Table 14, for instance, grain corn prior to barley and spring wheat, and barley prior to canola and soybeans. Different datasets lead to inconsistent yield responses.

Yield responses calculated from the only the rotation effect in MASC data (2006 - 2018) ignore other factors including climatic factors, regional factors, influences from soil quality and seeding dates, fertilizers, and yearly shocks. Moreover, the low Adjusted R² for crops is more evidence that previous crops solely do not have a strong enough influence to explain yield for crops. Expanded data available from MASC and Environment and Natural Resources Canada helps us explore the influences from identified factors to crop yields. In the meantime, the yield responses from crop rotations excluding other factors will be examined.

Panel data yield model results:

Panel data contains both cross sectional and time series level data. There are three main advantages of panel data. The first advantage is the increased precision in estimation because of an increase in the number of observations owing to combining or pooling several periods of data for each individual (Cameron et al., 2005). The second advantage of panel data is the possibility of consistent estimation of the fixed effects model, which allows for unobserved individual heterogeneity that may be correlated with regressors (Cameron et al., 2005). The third advantage of panel data is its capability to learn more about the dynamics of individual behavior than is possible from a single cross section (Cameron et al., 2005).

The panel data model explores how some exogenous variables, in terms of some individuals over time, influence the endogenous variables, for example, exploring the effect of different levels of education on income with data in different regions over time. A panel data model takes the form below:

$$y_{it} = \alpha_{it} + X'_{it} \beta_{it} + u_{it} \quad i = 1, \dots, N, t = 1, \dots, T. \quad (6)$$

Panel data models contain three kinds of models: a pooling model, fixed effects, and random effects model. The pooled model is the most restricted model. It specifies constant coefficients where regressors are uncorrelated with errors, e.g., $\alpha_{it} = \alpha$ (Cameron et al., 2005). The individual-specific effects model allows each cross-sectional unit to have a different intercept term though all slopes are the same, e.g., $\alpha_{it} = \alpha_i$ (Cameron et al., 2005). When an unobserved individual effect (α_i) is potentially correlated with the observed regressors (X_{it}), the model is defined as a fixed effect (FE) model. On the other hand, when an unobserved individual

effect (α_i) is distributed independently of the regressors (X_{it}), the model is called a random effect (RE) model (Cameron et al., 2005).

The Hausman test for panel data models is designed to examine whether the panel data model is a fixed or random effect model. Based on the results of a Hausman test, all six crop yield estimates are assumed to be fixed effect models. However, a fixed effect model can be assessed with five estimators: a within or fixed effects estimator, a first-differences estimator, a conditional ML estimator, a Least-Squares Dummy Variable Estimator, or a covariance estimator (Cameron et al., 2005). The most popular methodology for fixed effect models is a within or fixed effect estimator. The main interest of within and fixed effect estimators lies solely in the coefficients of time series variables since it measures the association between individual-specific deviation of regressors from their time-averaged values and the individual-specific deviations of the dependent variable from its time-averaged value (Cameron et al., 2005). The within model is generated through the subtraction of the time-averaged model $\bar{y}_i = \alpha_i + \bar{X}_i' \beta + \bar{\varepsilon}_i$ from the original model (Cameron et al., 2005). Specifically, the within model is displayed below:

$$y_{it} - \bar{y}_i = (X_{it} - \bar{X}_i)' \beta + (\varepsilon_{it} - \bar{\varepsilon}_i), i = 1, \dots, N, t = 1, \dots, T. \quad (7)$$

In the within model, the fixed effect α_i is eliminated through subtraction. The within estimator is the OLS estimator which generates coefficients as below:

$$\hat{\beta}_w = \left[\sum_{i=1}^N \sum_{t=1}^T (X_{it} - \bar{X}_i)(X_{it} - \bar{X}_i)' \right]^{-1} \sum_{i=1}^N \sum_{t=1}^T (X_{it} - \bar{X}_i)(y_{it} - \bar{y}_i) \quad (8)$$

In any panel model, $\hat{\beta}_w$ would be consistent. A major limitation of within estimation is that the coefficients of time-invariant regressors are not identified in the within model (Cameron

et al., 2005). The First-Difference estimator is less efficient than the within estimator for $T > 2$ (Cameron et al., 2005). The Least-Squares Dummy Variable Estimator (LSDV) is designed to generate the coefficients of both time-invariant and time variant variables (Cameron et al., 2005). The resulting estimator β from LSDV turns out to equal to the within estimator which is a special case of the Frisch-Waugh Theorem for a subset regression (Cameron et al., 2005). The Least-Squares Dummy Variable Estimator (LSDV) is based on using the Ordinary Least Square (OLS) simultaneously estimating α and β (Cameron et al., 2005). Assuming the $T \times 1$ vectors over all N individuals to yield the fixed effects dummy variable model:

$$\begin{bmatrix} y_1 \\ \dots \\ y_N \end{bmatrix} = \begin{bmatrix} e & 0 & 0 \\ 0 & \dots & 0 \\ 0 & 0 & e \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \dots \\ \alpha_N \end{bmatrix} + \begin{bmatrix} X_1 \\ \dots \\ X_N \end{bmatrix} \beta + \begin{bmatrix} \varepsilon_1 \\ \dots \\ \varepsilon_N \end{bmatrix} \quad (9)$$

Least-Squares Dummy Variable (LSDV) estimator is the transformation of OLS. So LSDV estimator is below:

$$\begin{bmatrix} \hat{\alpha}_{LSDV} \\ \hat{\beta}_{LSDV} \end{bmatrix} = \begin{bmatrix} \bar{Y} - \bar{X} \hat{\beta}_w \\ [X'X - \bar{X}'\bar{X}]^{-1} (X'y - \bar{X}'\bar{y}) \end{bmatrix} \quad (10)$$

In the meantime, $\hat{\beta}_{LSDV} = \hat{\beta}_w$; $\hat{\alpha}_{LSDV} = \hat{\alpha}_{FE}$ (Cameron et al., 2005).

The purpose of step two of the research is to obtain not only the coefficients of the time series variables (N, P, K, S, GS, GDD, D, C, T) but also the coefficients of time invariant variables (R, S), therefore, the Least-Squares Dummy Variable Estimator (LSDV) will be adopted in all the model regression. Regression results from Stata are shown in Appendix C1 to C6. The results in Appendix C1 to C6 illustrate the effects to the yields of barley, canola, grain corn, oats, soybeans, and spring wheat from: inputs of fertilizers (N, P, K, S), precipitation,

temperature, previous crop, seeding week, soil zones, Risk Areas, and constants. For dummy variables in the yield model, soil zone A, previous crops of canola and spring wheat, the third week of April for barley, oats, and spring wheat models, the fourth week of April for canola, the first week of May for grain corn, the third week of May for soybeans, the year 2018, and Risk Area 1 are omitted to avoid dummy variable multicollinearity. Before the regressions of panel data models, Breusch-Pagan test, DF Fuller test, and Durbin Watson test are applied to test for heteroskedasticity, unit root, and auto-correlation and the model for spring wheat has heteroskedasticity. As a result, robust standard error is imposed on the regression of spring wheat. The Adjusted R^2 for models of barley, canola, grain corn, oats, soybeans, and spring wheat are 0.378, 0.438, 0.378, 0.394, 0.264, and 0.481 respectively. The adjusted coefficient of determination for the six models, adjusted R^2 , which indicates the extent of the relationship of independent variables and dependent variables, fluctuate around 0.4, which infers the elements (fertilizers, climatic factors, regional factors, rotation effect, and yearly shocks) in yield models drive yield to a larger extent than previous crop alone.

The aim of the yield models for six crops is to examine rotation effects to yields with consideration of fertilizers, climatic, regional factors, seeding influences, crop rotations, and yearly shocks. The regression results indicate a series of plausible explanations of the selected factors. In terms of fertilizers, some coefficients are significant and most of them are positive but small, whereas P in the barley model, canola model, and grain corn model, and S of the soybean model show negative signs but all of them are insignificant. Crops typically respond positively to the application of fertilizers, especially N (Roser et al., 2015). The coefficients of precipitation and temperature, similar to fertilizers, are relatively small, but most significant. Growing season precipitation (GS) and growing degree days (GDD) play roles in enhancing crop yield potentials

based on the data. The coefficients of quadratic items for GS and GDD are supposed to be negative due to the theory that plants grow faster with an increasing air temperature and rainfall up to an optimal point, while extreme heat will slow growth and increase moisture loss, and excess water reduces the amount of oxygen in the soil, resulting in root loss or injury (County et al., 2014). Fortunately, most coefficients of GS^2 and GDD^2 are negative. The coefficients of soil zones from B to I or J show a decreasing trend, still, some of which are insignificant. Additionally, all of them are negative effects compared to soil zone A. The differences between the effect of soil zone B and J vary from 8 to 20 bushels according to different crops. It is rational that the coefficients of soil zones follow a decreasing trend as soil zone A to J are defined from the higher yielding soil quality and the lower yielding soil quality. Among the coefficients of previous crops, the positive signs of coefficients of previous crops mean more positive contributions to the yield of current crops than the omitted variables; however, the negative coefficients of previous crops represent negative yield responses relative to the effects of the omitted previous crops. Most of the coefficients for seeding weeks are significant and negative versus the omitted variables (third week of April, the first week of May, the third week of May). Moreover, previous research shows the earlier week is, the higher coefficients of the weeks are. For seeding weeks, the general trend shows the earlier in the season crops are planted, the higher yield potentials are, which is consistent with the agronomic theory we mentioned for seeding dates in Chapter 3. Eventually, the coefficients of Risk Areas are as we expected and Risk Area 5, 10, 11, and 12 have larger coefficients while Risk Area 16 is the lowest crop growth location, which identifies Risk Area 5, 10, 11, 12 offer the superior crop growth environment while Risk Area 16 is ranked as the lowest quality land for cropping. It is not surprising that most coefficients for Risk Area are significant based on the t-statistics. In the study area section, we

have described that Risk Area 12 has higher productivity due to enough volume of moisture and heat units, however, weather conditions for Risk Area 16 are cold.

Table 15: Coefficients (t-statistics) of previous crops compared to canola in the panel data model in Manitoba (2006-2018).

| | | Crop planted | | | | | |
|--------------------|------------|--------------------|--------------------|-------------------|--------------------|-------------------|--------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -9.094 (-13.89) | -0.171 (-1.69) | -1.308 (-0.63) | -6.007 (-4.63) | -0.609 (-2.11) | -3.100 (-8.37) |
| | Canola | 0 | -3.228 (-29.53) | 0 | 0 | 0 | 0 |
| | Grain Corn | -1.094 (-4.40) | 1.720 (-8.24) | -5.282 (-3.30) | -0.903 (-0.42) | 0.776 (-2.79) | 1.294 (-1.64) |
| | Oats | -7.254 (-8.58) | -1.426 (-10.76) | -3.741 (-1.57) | -12.719 (-8.25) | -0.147 (-0.59) | -3.690 (-9.89) |
| | Soybean | 0.803 (-1.07) | -0.216 (-1.59) | 2.036 (-1.710) | 2.443 (-2.58) | -1.613 (-9.65) | 2.025 (11.87) |
| | S.Wheat | -2.716 (-5.89) | 0 | 2.855 (-1.83) | -1.732 (-1.93) | 0.221 (-1.57) | -5.119 (-26.83) |
| Average Yield (Bu) | | 72.083 | 39.477 | 121.093 | 103.753 | 35.687 | 53.09 |

Table 16: Average yield for the six crops with omitted previous crops in Manitoba (2006-2018).

| | | Crop Planted (Bu) | | | | | |
|---------------------------------------|--------|-------------------|---------|---------|--------|----------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybeans | S.Wheat |
| Previous Crop | Canola | S.Wheat | Canola | Canola | Canola | Canola | Canola |
| Average Yield with Omitted Crops (Bu) | 74.487 | 39.801 | 118.277 | 104.626 | 35.874 | 53.080 | |

Source: Manitoba Agriculture Service Corporation (2021).

Coefficients representing the effect of the previous year's crop on the following year's yield are demonstrated in Table 15. It is necessary to calculate the average yield of six crops with

omitted previous crops because the coefficients represent the changes of the yield of current crops based on the previous crop and not when the previous crop is omitted. For example, the coefficient when the previous crop before barley was barley's yield model is -9.093, which means the average yield for barley if the previous crop was barley will be less than the average yield for barley when the previous crop is canola by -9.093 bushel. The mean yield for barley with a previous crop of canola (omitted crop) is 74.487 bushel, so the average yield for barley with the previous crop barley could be assumed as $74.487 - 9.093 = 65.394$ bushel. Through the same process, a new table based on the coefficients of previous year crops and means of yields with omitted previous year crops is formed and named Table 17.

Table 17: Adjusted average yield (Bushel) based on coefficients of previous crops compared to canola in panel data yield models on crop rotations (2006-2018).

| | | Crop Planted (Bu) | | | | | |
|---------------|---------|-------------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 65.394 | 39.630 | 116.969 | 98.619 | 35.265 | 49.981 |
| | Canola | 74.488 | 36.573 | 118.277 | 104.626 | 35.874 | 53.081 |
| | G.Corn | 73.394 | 41.521 | 112.995 | 103.723 | 36.651 | 54.374 |
| | Oats | 67.234 | 38.376 | 114.537 | 91.907 | 35.727 | 49.390 |
| | Soybean | 75.291 | 39.585 | 120.313 | 107.069 | 34.261 | 55.106 |
| | S.Wheat | 71.772 | 39.801 | 121.132 | 102.894 | 36.095 | 47.962 |
| Average Yield | | 72.083 | 39.477 | 121.093 | 103.753 | 35.687 | 53.090 |

According to Kubinec's calculation, a simple ratio was obtained of the average yield of crops grown on previous crops versus the overall average yield of crops. A similar yield response table using the same methodology as Kubinec can be obtained and compared. For example, the adjusted average yield for barley after barley as a previous crop, 65.395, divided by the average yield for barley, 72.083, is 90.70% approximately. Other yield response ratios are calculated through the same method and shown in table 18.

Table 18: Yield responses (% change) of Manitoba crops of previous crops in rotations (2006-2018).

| | | Crop Planted | | | | | |
|------------------|---------|--------------|---------|---------|---------|---------|---------|
| | | Barley | Canola | G. Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 90.70% | 100.40% | 96.60% | 95.10% | 98.80% | 94.10% |
| | Canola | 103.30% | 92.60% | 97.70% | 100.80% | 100.50% | 100.00% |
| | G. Corn | 101.80% | 105.20% | 93.30% | 100% | 102.70% | 102.40% |
| | Oats | 93.30% | 97.20% | 94.60% | 88.60% | 100.10% | 93.00% |
| | Soybean | 104.50% | 100.30% | 99.40% | 103.20% | 96.00% | 103.80% |
| | S.Wheat | 99.70% | 100.80% | 100.00% | 99.20% | 101.10% | 90.30% |

Table 18 demonstrates the ratio of yield responses relying on the regression results including the full available data for other variables. Compared with Kubinec’s table, generally, the results claim similar trends towards crop yields. However, there are four inconsistent results: the previous crop of grain corn for barley, the previous crop of soybeans for grain corn, the previous crop of barley for soybeans and the previous crop of grain corn for spring wheat. Two of four: a previous crop of soybeans for the yield model of grain corn, and a previous crop of grain corn for the yield model of spring wheat are insignificant statistically. There are several aspects to analyze the rotation effects. Firstly, the data for yield responses has a lower range, mostly ranging from 90% to 110%. In Kubinec’s table, the only factor she considered is rotation effect, which might overrate the actual contributions of crop rotations. In this yield response table (Table 18), other nutritional, environmental, and human management factors other than the rotation effect are extracted. Secondly, all of the data for planting crops continuously is below one, implying negative impacts to yield production from monoculture, parallel to the monoculture agronomic evidence that planting the same crops increases the disease outbreaks and reduces the resistance towards weeds, damaging production. Thirdly, from the data, we can identify soybeans, boost crops in terms of yields, which is consistent with the agronomic theory that nitrogen fixing helps boost crop yields. Finally, rotations with some crops do help improve

the crop yields if other crops help break the outbreak of diseases and the influx of weed, but some may not help increase yield if other crops are susceptible to the same diseases. For example, barley, oats, and spring wheat generate negative yield effects towards each other because all of them are classified as cereal crops and share similar threats from insect diseases, and it is interesting that Kubinec’s analysis shows the same trend as mentioned above.

Table 19: 95% Confidence intervals of coefficients of previous crops in rotations from panel data regression in Manitoba (2006-2018).

| | | Crop planted | | | | | | |
|------------------|----------|--------------|---------|--------|--------|---------|---------|--------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat | |
| Previous Crop | Barley | lower | -10.377 | -0.370 | -5.350 | -8.552 | -1.174 | -3.825 |
| | | upper | -7.811 | 0.028 | 2.734 | -3.463 | -0.045 | -2.375 |
| | Canola | lower | 0 | -3.442 | 0 | 0 | 0 | 0 |
| | | upper | 0 | -3.013 | 0 | 0 | 0 | 0 |
| | G. Corn | lower | -4.397 | 1.310 | -8.420 | -5.136 | 0.232 | -0.189 |
| | | upper | 2.200 | 2.129 | -2.145 | 3.330 | 1.321 | 2.777 |
| | Oats | lower | -8.910 | -1.685 | -8.403 | -15.743 | -0.635 | -4.414 |
| | | upper | -5.597 | -1.166 | 0.922 | -9.695 | 0.340 | -2.967 |
| | Soybeans | lower | -0.674 | -0.482 | -0.295 | 0.586 | -1.941 | 1.705 |
| | | upper | 2.281 | 0.050 | 4.366 | 4.299 | -1.286 | 2.345 |
| | S.Wheat | lower | -3.619 | 0 | -0.207 | -3.489 | -0.054 | -5.519 |
| | | upper | -1.813 | 0 | 5.918 | 0.024 | 0.495 | -4.720 |

“Confidence intervals provide information about a range in which the true value lies with a certain degree of probability, as well as about the direction and strength of the demonstrated effect” (Du Prel et al., 2009). From the regressions of the yield models, a series of 95% confidence intervals are listed in the regression results. From them, 95% confidence intervals of previous crops demonstrate the true value (coefficients of previous crops) lies in confidence intervals with 95% probability. Table 19 illustrates the lower and upper bounds of the coefficients of previous crops, the average values of which are coefficients of previous crops. Table 20 is yield responses and confidence intervals in terms of percentage version, which is converted from table 19 with the same methodology of table 18.

Table 20: Yield response (% change) and confidence intervals of Manitoba crops of previous crops in rotations (2006-2018).

| | | Crop planted | | | | | |
|------------------|-----------------|------------------------------|------------------------------|-----------------------------|------------------------------|------------------------------|------------------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 90.70% (88.9% - 92.5%) | 100.40% (100.0% - 100.9%) | 96.60% (93.3% - 100.0%) | 95.10% (92.6% - 97.5%) | 99.80% (97.2% - 100.4%) | 94.10% (92.8% - 95.5%) |
| | Canola | 103.30% | 92.60% (92.1% - 93.2%) | 97.80% | 100.80% | 100.50% | 100.00% |
| | Grain Corn | 101.80% (97.2% - 106.4%) | 105.20% (104.1% - 106.2%) | 93.30% (90.7% - 95.9%) | 100.00% (95.9% - 104.1%) | 102.70% (101.2% - 104.2%) | 102.40% (100.0% - 105.2%) |
| | Oats | 93.30% (91.0% - 95.6%) | 97.20% (96.6% - 97.9%) | 94.60% (90.7% - 98.4%) | 88.60% (85.7% - 91.5%) | 100.10% (98.7% - 101.5%) | 93.00% (91.7% - 94.4%) |
| | Soybeans | 104.50% (102.4% - 106.5%) | 100.30% (100.0% - 100.9%) | 99.40% (97.4% - 101.3%) | 103.20% (101.4% - 105.0%) | 96.00% (95.1% - 96.9%) | 103.80% (103.2% - 104.4%) |
| | Spring Wheat | 99.60% (98.3% - 100.8%) | 100.80% | 100.00% (97.5% - 102.6%) | 99.20% (97.5% - 100.9%) | 101.10% (100.4% - 101.9%) | 90.30% (89.6% - 91.1%) |

Table 20 shows yield responses and confidence intervals from crop rotations. Firstly, it appears that the ranges of confidence intervals of different previous crops for the same crop are the same, e.g., the confidence intervals of the five previous crops for barley are similar in range. Secondly, the emergence of confidence intervals does not change the directions (positive or negative) of yields responses of crop rotations for most crops, which implies since confidence intervals of yield responses would not influence directions of yield responses, we can generally identify the directions from the yield responses (average yields of lower and upper bound) directly. Thirdly, there is at least a 95% probability that cropping the same crops year by year does yield a negative impact on crop yield potentials. Finally, even with the lower and upper boundaries, the percentage rotation effects still range from 85% to 110%.

The overall results of this study are generally consistent with Kubinec's studies with less extravagant effects. The new yield response table gives us a better understanding of how the previous crop boosts or damages crop yield potentials, identifying that the previous crop generates a less extravagant effect on crop yield of next year compared to Kubinec's table. In addition, the new finding gives farmers' new indications about how to manage their crop choices. The importance of fertilizers and seeding dates could be observed, guiding farmers to seed and grow their crops for higher yields. For example, coefficients show that seeding earlier might help increase crop yield potentials for most crops given soil zones and Risk Areas in general.

Based on panel data crop yield models, different regions (Risk Area) play an important role in crop yield and generate various yield potentials. Yield responses analysed by Risk Area are more precise than those relying on the whole province. Therefore, yield responses in Risk Area by Risk Area are worth examining.

Yield model from Risk Area by Risk Area:

Risk Areas with higher crop yields, lower crop yields, and with crop yields close to the average yields of Manitoba, were selected to show the comparisons and differences between different regions among these data and Kubinec's findings. Data from MASC show the average yields for six crops in each Risk Area (Table 21). There are three procedures to choose representative Risk Areas. First, yields are ranked for each crop based on different Risk Areas and listed. The highest three yields for crops among Risk Areas, lowest three yields for crops in Risk Areas, and two yields for crops in Risk Areas closest to average crop yields for the whole province (Overall in the table) are selected separately. There are higher average yields in Risk Area 12 in terms of grain corn, oats, soybeans, and spring wheat.

Table 21: Average yields in Bushel by crop and ranks by Risk Area in Manitoba (2006-2018).

| | Barley (Bu) | Rank | Canola (Bu) | Rank | G.Corn (Bu) | Rank |
|--------------|-------------|------|-------------|------|-------------|------|
| Risk Area 1 | 56.855 | 14 | 32.442 | 13 | 102.957 | 11 |
| Risk Area 2 | 76.087 | 4 | 39.176 | 7 | 114.076 | 7 |
| Risk Area 3 | 63.882 | 11 | 36.897 | 11 | 98.114 | 12 |
| Risk Area 4 | 70.154 | 8 | 40.064 | 6 | 120.593 | 3 |
| Risk Area 5 | 80.461 | 1 | 43.467 | 1 | 117.433 | 6 |
| Risk Area 6 | 73.418 | 5 | 41.452 | 4 | 123.312 | 2 |
| Risk Area 7 | 72.044 | 6 | 41.860 | 3 | | |
| Risk Area 8 | 70.689 | 7 | 40.482 | 5 | 103.733 | 9 |
| Risk Area 9 | 66.313 | 9 | 38.028 | 9 | 84.031 | 13 |
| Risk Area 10 | 64.922 | 10 | 39.034 | 8 | 120.308 | 4 |
| Risk Area 11 | 77.592 | 2 | 37.201 | 10 | 118.184 | 5 |
| Risk Area 12 | 76.718 | 3 | 43.063 | 2 | 129.593 | 1 |
| Risk Area 14 | 60.423 | 12 | 32.950 | 12 | 113.509 | 8 |
| Risk Area 15 | 59.197 | 13 | 31.010 | 14 | 102.959 | 10 |
| Risk Area 16 | 35.244 | 15 | 25.934 | 15 | | |
| Overall | 72.083 | | 39.477 | | 121.092 | |

| | Oats (Bu) | | Soybean (Bu) | | S.Wheat (Bu) | |
|-------------|-----------|----|--------------|----|--------------|----|
| Risk Area 1 | 91.283 | 13 | 30.957 | 14 | 42.486 | 14 |
| Risk Area 2 | 107.403 | 5 | 35.381 | 8 | 53.026 | 8 |
| Risk Area 3 | 85.421 | 14 | 32.082 | 12 | 49.059 | 12 |
| Risk Area 4 | 91.850 | 12 | 37.419 | 4 | 52.007 | 9 |
| Risk Area 5 | 121.147 | 2 | 37.761 | 2 | 58.880 | 2 |
| Risk Area 6 | 108.606 | 4 | 35.084 | 9 | 54.149 | 6 |
| Risk Area 7 | 110.914 | 3 | 31.408 | 13 | 53.996 | 7 |
| Risk Area 8 | 101.416 | 7 | 37.648 | 3 | 54.654 | 4 |
| Risk Area 9 | 92.005 | 11 | 36.138 | 5 | 49.549 | 11 |
| Risk Area10 | 100.193 | 8 | 35.620 | 7 | 50.758 | 10 |
| Risk Area11 | 103.829 | 6 | 36.028 | 6 | 55.349 | 3 |
| Risk Area12 | 122.560 | 1 | 38.129 | 1 | 60.717 | 1 |
| Risk Area14 | 95.865 | 10 | 33.955 | 10 | 54.298 | 5 |
| Risk Area15 | 96.298 | 9 | 32.735 | 11 | 44.461 | 13 |
| Risk Area16 | | | | | 40.533 | 15 |
| Overall | 103.752 | | 35.687 | | 53.090 | |

Note: no corn is grown in Risk Area 7 and 16; Neither oats nor soybeans are grown in Risk Area 16.

Source: Manitoba Agriculture Service Corporation (2021).

Table 22: Average yields (Bushel) for crops in Bushel after omitted previous crops in Risk Area 10, 12, and 1 (2006-2018).

| | | | | | | |
|-----------------------------------|--------|---------|------------|---------|----------|--------------|
| Risk Area 10 | Barley | Canola | Grain Corn | Oats | Soybeans | Spring Wheat |
| Previous Crop | Canola | S.Wheat | Canola | Canola | Canola | Canola |
| Average Yield after Previous Crop | 64.520 | 39.071 | 121.133 | 96.771 | 36.258 | 49.629 |
| Average Yield | 64.922 | 39.034 | 120.308 | 100.193 | 35.620 | 50.758 |
| Risk Area 12 | Barley | Canola | Grain Corn | Oats | Soybeans | Spring Wheat |
| Previous Crop | Canola | S.Wheat | Canola | Canola | Canola | Canola |
| Average Yield after Previous Crop | 80.299 | 41.418 | 125.744 | 118.733 | 37.787 | 59.993 |
| Average Yield | 76.718 | 43.063 | 129.593 | 122.560 | 38.129 | 60.717 |
| Risk Area 1 | Barley | Canola | Grain Corn | Oats | Soybeans | Spring Wheat |
| Previous Crop | Canola | S.Wheat | Canola | Canola | Canola | Canola |
| Average Yield after Previous Crop | 59.418 | 32.425 | 105.923 | 95.043 | 30.843 | 43.392 |
| Average Yield | 56.855 | 32.442 | 102.957 | 91.283 | 30.957 | 42.486 |

Source: Manitoba Agriculture Service Corporation (2021).

Table 23: Average yields in Bushel for crops after previous crops from MASC data in Risk Area 10 (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 54.534 | 36.355 | 127.700 | 95.773 | 37.991 | 38.913 |
| | Canola | 64.520 | 30.498 | 121.133 | 96.772 | 36.259 | 49.630 |
| | G.Corn | 65.684 | 43.177 | 108.691 | 102.250 | 36.151 | 57.073 |
| | Oats | 53.645 | 36.699 | 117.177 | 80.529 | 35.688 | 45.032 |
| | Soybean | 76.353 | 40.933 | 123.263 | 106.182 | 33.127 | 55.075 |
| | S.Wheat | 59.676 | 39.071 | 126.028 | 102.115 | 37.025 | 46.687 |
| | Overall | 64.923 | 39.035 | 120.309 | 100.193 | 35.620 | 50.759 |

Table 24: Average yields in Bushel for crops after previous crops from MASC data in Risk Area 12 (2006-2018).

| | | Crop planted | | | | | |
|---------------|---------|--------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 61.975 | 38.554 | 102.272 | 72.952 | 35.184 | 47.333 |
| | Canola | 80.299 | 36.128 | 125.744 | 118.733 | 37.788 | 59.993 |
| | G.Corn | 77.672 | 45.880 | 113.817 | 123.835 | 39.033 | 57.730 |
| | Oats | 62.265 | 42.245 | 119.981 | 96.832 | 37.908 | 52.703 |
| | Soybean | 76.723 | 45.499 | 137.925 | 129.791 | 35.488 | 63.357 |
| | S.Wheat | 70.974 | 41.418 | 126.590 | 116.995 | 38.981 | 47.411 |
| | Overall | 76.718 | 43.064 | 129.593 | 122.560 | 38.130 | 60.718 |

Table 25: Average yields in Bushel for crops after previous crops from MASC data in Risk Area 1 (2006-2018).

| | | Crop planted | | | | | |
|---------------|---------|--------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 45.997 | 30.105 | 97.989 | 78.211 | 30.040 | 33.835 |
| | Canola | 59.419 | 27.115 | 105.924 | 95.043 | 30.843 | 43.393 |
| | G.Corn | 68.540 | 40.769 | 100.653 | 67.844 | 37.373 | 49.068 |
| | Oats | 52.831 | 33.605 | 52.508 | 72.928 | 29.322 | 33.666 |
| | Soybean | 73.886 | 36.651 | 116.978 | 87.479 | 31.082 | 49.560 |
| | S.Wheat | 55.297 | 32.425 | 101.765 | 104.250 | 31.367 | 35.483 |
| | Overall | 56.856 | 32.442 | 102.958 | 91.283 | 30.957 | 42.486 |

Average yields for crops in Risk Area 16 are the lowest, however, the dataset for Risk Area 16 is too small to run yield regressions. As a result, Risk Area 1 is selected as a lower yield Risk Area. Risk Area 10 is regarded as the Risk Area with the closest average yields to average yields in Manitoba. Overall, Risk Area 12 has higher yields, Risk Area 1 has lower yields, and Risk Area 10 has yields closest to provincial average yields, so these areas are selected as the relevant Risk Areas. The crop yields for crops after omitted crops are shown in table 22. 23 to 25 tables show the average yield of crops with previous crops from MASC data. Frequencies of previous crops on crops in Risk Area 10, 12, and 1 are given in Appendix D1 to D3.

Least Square Dummy Variable estimator (LSDV) is also adopted in the Risk Area specific regressions because both coefficients of time invariant variables and time variant variables are required which are the same as the yield model for the provincial level. Soil zones are the time invariant variables, while other variables are time variant variables. The coefficients for fertilizers, seeding weeks, previous crops, and yearly dummies will be generated through the LSDV estimator. In this step, the coefficients of previous crops are vital to my research. Before the regressions of panel data yield models, Breusch-Pagan, DFULLER, and Durbin Watson tests are applied to test heteroskedasticity, unit root, and auto-correlation. As a result, barley in Risk Area 10 and 1, grain corn, oats, soybeans, and spring wheat for Risk Area 1 have heteroskedasticity and robust standard error is imposed on these regressions. Among these regressions, climatic variables GS , GDD , GS^2 , GDD^2 , $GS * GDD$ are omitted because of the strong multicollinearity with yearly dummies. Regression results of crops in Risk Area 10, 12, and 1 from Stata are illustrated in Appendix F1 to F6, G1 to G6, and H1 to H6. The calculation of yield responses from coefficients of previous crops and average yields for crops with omitted crops is the same

as that of the provincial level. In addition, Appendix E1 to E3 are Adjusted Average yield of crops based on coefficients Risk Area 10, Risk Area 12, and Risk Area 1.

Table 26: Coefficients (t-statistics) for previous crops in the fixed effect model in Risk Area 10 (2006-2018).

| | | Crop Planted | | | | | |
|------------------|---------------|------------------|------------------|------------------|-------------------|-----------------|------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -9.51 (-2.61) | -1.6 (-2.26) | 18.17 (-3.66) | -3.92 (-0.78) | 0.19 (-0.21) | -5.7 (-2.61) |
| | Canola | 0 | -5.09 (-6.27) | 0 | 0 | 0 | 0 |
| | Grain Corn | 0.43 (-0.12) | 1.74 (-3.13) | -8.13 (-2.61) | -1.11 (-0.31) | 0.98 (-1.61) | 3.19 (-1.9) |
| | Oats | -9.09 (-1.65) | -0.99 (-1.58) | -0.13 (-0.03) | -17.85 (-3.66) | 0.4 (-0.59) | -2.93 (-1.62) |
| | Soybeans | 8.22 (-2.36) | -0.74 (-1.15) | -3 (-1.12) | 2.4 (-1.01) | -3.1 (-5.79) | 1 (-1.13) |
| | S.Wheat | -5.12 (-1.39) | 0 | 6.37 (-1.79) | -0.6 (-0.17) | 0.28 (-0.45) | -2.16 (-0.59) |

Table 27: Yield responses (% change) of crop rotations in Risk Area 10 in fixed effect model (2006-2018).

| | | Crop Planted | | | | | |
|------------------|---------|--------------|---------|---------|--------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 84.70% | 96.00% | 115.80% | 92.70% | 102.30% | 86.50% |
| | Canola | 99.40% | 87.10% | 100.70% | 96.60% | 101.80% | 97.80% |
| | G.Corn | 100.00% | 104.60% | 93.90% | 95.50% | 104.50% | 104.10% |
| | Oats | 85.40% | 97.60% | 100.60% | 78.80% | 102.90% | 92.00% |
| | Soybean | 112.00% | 98.20% | 98.20% | 99.00% | 93.10% | 99.70% |
| | S.Wheat | 91.50% | 100.10% | 106.00% | 96.00% | 102.60% | 93.50% |

Table 28: Coefficients (t-statistics) for previous crops in fixed effect model in Risk Area 12 (2006-2018).

| | | Crop Planted | | | | | |
|------------------|-----------------|------------------|------------------|------------------|-------------------|------------------|------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -9.93 (-2.19) | -1.58 (-2.35) | -7.86 (-2.51) | -28.88 (-3.67) | -2.48 (-2.85) | -8.16 (-3.09) |
| | Canola | 0 | -2.27 (-2.69) | 0 | 0 | 0 | 0 |
| | Grain Corn | -0.11 (-0.03) | 2.44 (-5.97) | 0.15 (-0.06) | -0.85 (-0.30) | 1.06 (-2.3) | -2.54 (-2.02) |
| | Oats | -9.4 (-1.24) | -0.09 (-0.51) | -2.47 (-0.72) | -22.66 (-2.59) | 0.8 (-1.44) | -4.76 (-2.67) |
| | Soybeans | -5.81 (-1.95) | 0.82 (-1.78) | 4.73 (-2.95) | 2.14 (-0.94) | -2.14 (-3.96) | 0.58 (-1.22) |
| | Spring Wheat | -4.85 (-1.38) | 0 | 2.66 (-1.07) | -0.9 (-0.25) | 0.65 (-1.63) | -4.37 (-2.36) |

Table 29: Yield responses (% change) of crop rotations in Risk Area 12 in fixed effect model (2006-2018).

| | | Crop Planted | | | | | |
|------------------|---------|--------------|---------|---------|--------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 91.70% | 92.50% | 91.00% | 73.30% | 92.60% | 85.40% |
| | Canola | 104.70% | 90.90% | 97.00% | 96.90% | 99.10% | 98.80% |
| | G.Corn | 104.50% | 101.80% | 97.10% | 96.20% | 101.90% | 94.60% |
| | Oats | 92.40% | 96.00% | 95.10% | 78.40% | 101.20% | 91.00% |
| | Soybean | 97.10% | 98.10% | 100.70% | 98.60% | 93.50% | 99.80% |
| | S.Wheat | 98.30% | 96.20% | 99.10% | 96.10% | 100.80% | 91.60% |

Table 30: Coefficients (t-statistics) for previous crops in fixed effect model in Risk Area 1 (2006-2018).

| | | Crop Planted | | | | | |
|---------------|--------------|------------------|------------------|-------------------|-------------------|------------------|------------------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | -9.6 (-4.39) | -0.93 (-2.03) | 0.91 (0.13) | -7.31 (-2.03) | -0.09 (-0.06) | -3.9 (-3.73) |
| | Canola | 0 | -4.43 (-4.54) | 0 | 0 | 0 | 0 |
| | Grain Corn | -1.08 (-0.27) | 3.18 (-2.37) | -6.43 (-0.57) | -15.09 (-5.01) | 1.77 (-0.93) | 1.67 (0.37) |
| | Oats | -5.45 (-2.3) | -1.06 (-2.59) | -35.89 (-2.16) | -16.57 (-5.64) | -2.04 (-2.26) | -6.02 (-6.74) |
| | Soybean | 3.01 (1.16) | -1.69 (-2.79) | 4.88 (0.52) | 4.58 (-1.63) | 0.99 (1.31) | -1.27 (-2.00) |
| | Spring Wheat | -6.03 (-3.13) | 0 | -10.01 (-1.15) | -1.56 (-0.64) | 0.76 (1.13) | -2.77 (-4.67) |

Table 31: Yield responses (% change) of crop rotations in Risk Area 1 in fixed effect model (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|---------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 87.60% | 97.10% | 103.80% | 96.10% | 99.30% | 93.00% |
| | Canola | 104.50% | 86.30% | 102.90% | 104.10% | 99.60% | 102.10% |
| | G.Corn | 102.60% | 109.70% | 96.60% | 87.60% | 105.30% | 106.10% |
| | Oats | 94.90% | 96.70% | 68.00% | 86.00% | 93.00% | 88.00% |
| | Soybean | 109.80% | 94.70% | 107.60% | 109.10% | 102.80% | 99.10% |
| | S.Wheat | 93.90% | 99.90% | 93.20% | 102.40% | 102.10% | 95.60% |

Table 32: Adjusted R² of regression results from Risk Area 10, 12, 1 in fixed effect model. (LSDV)

| | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
|--------------|--------|--------|--------|------|---------|---------|
| Risk Area 10 | 0.46 | 0.38 | 0.31 | 0.43 | 0.26 | 0.41 |
| Risk Area 12 | 0.43 | 0.45 | 0.56 | 0.45 | 0.32 | 0.52 |
| Risk Area 1 | 0.49 | 0.35 | 0.73 | 0.44 | 0.38 | 0.43 |

Tables 26, 27, 28, 29, 30, and 31 show coefficients and yield responses of Risk Area 10, 12, and 1. From Adjusted R² in Table 32, the variables applied in yield models explain yield productions for six crops to the similar degree as that in the analysis of provincial level including

all the variables but much stronger degree than that of the simple linear models. Some coefficients are insignificant based on a 95% t-test. It is not surprising that most rotation effects from monoculture are negative, which meets our expectation and expectations of prevailing agronomic theory. However, soybeans generate a negative yield effect for some crops based on the analysis in tables. It is true that data from fixed-effect models including more factors indeed identify less variation in yield responses in Risk Area 5, 12 and 1, mostly ranging from 85% to 110% and reduces overestimation. At least 50% of yield responses are not consistent with Kubinec’s analysis. Oats in Risk Area 10 and oats and spring wheat in Risk Area 12 identify all negative effects to yield of crops, which is deemed abnormal. The main reason for several insignificant coefficients of previous crops is the smaller number of observations for Risk Areas.

Table 33: Yield responses (% change) to canola from other crops as previous crops from Kubinec, linear model, panel data model, Risk Area 10, Risk Area 12, and Risk Area 1 (2006-2018).

| | Canola | | | | | |
|-----------------|------------------------|----------------------------|----------------------------|-----------------|-----------------|----------------|
| | Kubinec (2010-2015) | Linear | Panel (Province) | Risk Area 10 | Risk Area 12 | Risk Area 1 |
| Barley | 104% | 98.00% (97.3%-98.7%) | 100.40% (100.0%-100.9%) | 96.00% | 92.50% | 97.10% |
| Canola | 86% | 90.30% (89.6%-91.0%) | 92.60% (92.1%-93.2%) | 87.10% | 90.90% | 86.30% |
| Grain Corn | 112% | 111.70% (110.5%-113.0%) | 105.20% (104.1%-106.2%) | 104.60% | 101.80% | 109.70% |
| Oats | 95% | 93.70% (92.8%-94.5%) | 97.20% (96.6%-97.9%) | 97.60% | 96.00% | 96.70% |
| Soybean | 104% | 108.90% (108.0%-109.7%) | 100.30% (100.0%-100.9%) | 98.20% | 98.10% | 94.70% |
| Spring Wheat | 102% | 100.80% | 100.80% | 100.10% | 96.20% | 99.90% |

Table 33 illustrates yield responses to canola from other crops in Kubinec's analysis, the linear model, the panel data model for the whole province, as well as the analysis for Risk Area 10, 12, and 1. Canola after canola remains negative in each sector, which abides by the agronomic theory of negative yield effects from monoculture. Soybean as a previous crop to canola generates a positive impact on yields of canola for provincial analysis. In general, the provincial analysis (Kubinec's, Linear, Fixed) tracks the same pattern and is more reasonable than regional analysis does since the data sample for the provincial level analysis is greater than that of the regional analysis.

Chapter 7: Conclusion and Implications

Conclusion:

Yield effects from crop rotations based on 51,433 data points from Manitoba Agriculture Service Corporation are thoroughly explored and analyzed through a variety of yield models for crops in Manitoba. Simple linear yield models (OLS) containing only previous crops as independent variables, and panel data yield models applying a Least Square Dummy Variable estimator (LSDV) including fertilizers, precipitation, temperature, Risk Areas, soil zones, previous crops, seeding dates, yearly shocks in terms of both provincial and regional levels are regressed and analyzed in this research and compared to previous findings. Basic regression results from those regressions are obtained and analyzed, giving new insights of how crop yields are affected by a plethora of factors to farmers and stakeholders in Manitoba.

The exploration of simple linear models of yields for six crops based on MASC data ranging from 2006 to 2018 helps us understand basic trends of yield responses. The results of simple linear regressions show yield responses from crop rotations for MASC data from 2006 to 2018, the methodology of yields estimates similar to Kubinec's (2018) widely used table. But based on previous studies of yields, there is a need to consider multiple natural and human management factors as part of the yield model.

The second main analysis focuses on a panel data yield model taking various factors into considerations. A Least Square Dummy Variable (LSDV) estimator is applied to six yield models in provincial analysis to gain the coefficients of time variant variables – fertilizers, precipitations, temperatures, previous crops, seeding dates, yearly dummies, as well as the

coefficients of time invariant variables – Risk Areas and Soil zones. This panel data yield model explores the various contributions to yield from fertilizers, precipitation, temperature, previous crops, seeding dates, Risk Areas, soil zones, and yearly dummies. The adjusted R^2 from the LSDV regressions suggest a better fit than the simple linear model. The LSDV regression shows that fertilizers, precipitation, and temperature influence yields. Both seeding dates and soil zones contribute to yield growth. The earlier the seeding dates are, the higher the yield potentials are, and additionally, the better the soil zone is, the higher the generated yield. Dummies for Risk Areas, 5, 10, and 12, suggest higher yields in mid-southern Manitoba as appropriate warmth and humidity enrich the crop growth environment and benefit yields for crops. In the LSDV, yield response results effects are generally in the same direction to those of Kubinec's but the effects from previous crops are smaller as yield responses from the provincial level range from 85% to 105%.

Least Square Dummy Variable (LSDV) estimator is applied to yield models in Risk Area 12, 1, and 10 separately to examine yield responses as representative areas with higher yields, lower yields, and average yield areas respectively. The yield responses are again less variable compared to Kubinec's results. Although adjusted R^2 for those models are reasonably robust, some coefficients in regional regressions are insignificant due to fewer observations and perhaps less variation.

Overall, the LSDV analysis of yield models from provincial level is more robust in this research for two reasons. First, it includes many influential factors into the model. Secondly, the coefficients for more variables pass t-tests for significance, ensuring more coefficients are significant as compared to that of regional models. The provincial LSDV examines yield responses from crop rotations in a panel data yield model including the contributions from

fertilizers, precipitation and temperature, seeding dates, soil zones, Risk Areas, yearly dummies, identifying more significant influences on yield responses compared to Kubinec. The results here are consistent with previous findings that monoculture leads to negative yield potential and rotating crops with soybeans is likely to help boost crop yields. The yield impacts from the previous crops in this study indicate a more precise estimate of previous crop impacts on current year crops to farmers than Kubinec's since it contains more influential factors, which in return helps farmers better estimate their profits. Also, coefficients of seeding dates, regional levels, fertilizers, precipitation and temperature help understand how much these factors affect crop yields. These new results provide farmers with a more thorough understanding of crop rotations so they can make better choices about crop selections for production in Manitoba.

Crop rotation effects on crop yields that consider other natural and human factors in Manitoba have not been explored before this. This research was conducted to help farmers and policy makers understand the contributions to crop yields from crop rotations as well as other factors more thoroughly. Soil zones, seeding dates, and Risk Areas are found to affect yields for crops based on significance tests on the coefficients of these variables. Fertilizers and climates also have some influence on crop yields. Most of the coefficients in the yields model for regional dummies are insignificant.

Application of rotation effects from previous study – Sakulanda:

Sakulanda (2018) analyzed optimal crop rotations with considerations for corn in southern Manitoba. In her research, the author simulated five-year crop rotations and obtained the 10 most profitable crop rotations in southern Manitoba using Kubinec’s yield response table (Kubinec, 2014) shown on Table 34 based on data from 2008 to 2012. Profits could be calculated by operating costs subtracted by revenues (prices times average yield times yield response) like below:

$$\text{Profit} = \text{Price} * \text{Yield} * \text{Yield Response} - \text{Operating Costs} \quad (11)$$

Table 34: Impact of Previous Crops on Yield of Various Crops Planted from Kubinec (2008-2012).

| | | Crop planted | | | | |
|---------------|----------|--------------|--------|------|----------|---------|
| | | Canola | G.Corn | Oats | Soybeans | S.Wheat |
| Previous Crop | Canola | 85% | 95% | 104% | 101% | 102% |
| | G.Corn | 104% | 87% | 106% | 107% | 100% |
| | Oats | 92% | 93% | 82% | 99% | 90% |
| | Soybeans | 98% | 103% | 105% | 95% | 106% |
| | S.Wheat | 104% | 100% | 101% | 103% | 85% |

Source: Kubinec, 2014.

Table 35 shows Sakulanda’s top 10 crop rotations measured in mean revenue in southern Manitoba. Since a new yield response table (Table 18) is established based on the research, it could be implemented in Sakulanda’s crop rotation results. Consequently, new results could be compared to Sakulanda’s results and analyzed. Here the same operating costs (MAFRD, 2016) and crop prices (Manitoba Agriculture, ndb) in Table 36 are applied in the top 10 crop rotations except yield responses.

Table 35: Sakulanda’s Top 10 Crop Rotations measured in Mean Revenue (\$) in Southern Manitoba.

| Rank | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Mean Revenue |
|---------|----------|----------|----------|----------|----------|--------------|
| 1 | Soybeans | G.Corn | Soybeans | G.Corn | | |
| Revenue | \$195.82 | \$258.60 | \$195.82 | \$258.60 | | \$227.21 |
| 2 | Canola | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | \$196.04 | \$173.81 | \$258.60 | \$195.82 | \$258.60 | \$216.57 |
| 3 | Canola | G.Corn | Soybeans | G.Corn | | |
| Revenue | \$196.04 | \$213.98 | \$195.82 | \$258.60 | | \$216.11 |
| 4 | G.Corn | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | \$169.36 | \$195.82 | \$258.60 | \$195.82 | \$258.60 | \$215.64 |
| 5 | S.Wheat | G.Corn | Soybeans | G.Corn | Soybeans | |
| Revenue | \$171.76 | \$241.87 | \$195.82 | \$258.60 | \$195.82 | \$212.77 |
| 6 | Soybeans | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | \$195.82 | \$151.80 | \$258.69 | \$195.82 | \$258.60 | \$212.13 |
| 7 | S.Wheat | G.Corn | Soybeans | G.Corn | | |
| Revenue | \$150.64 | \$241.87 | \$195.04 | \$258.60 | | \$211.73 |
| 8 | Soybeans | G.Corn | Canola | S.Wheat | G.Corn | |
| Revenue | \$195.82 | \$258.60 | \$196.04 | \$157.68 | 241.87 | \$210.00 |
| 9 | Canola | Soybeans | G.Corn | | | |
| Revenue | \$196.04 | \$173.81 | \$258.60 | | | \$209.48 |
| 10 | G.Corn | S.Wheat | Soybeans | G.Corn | Soybeans | |
| Revenue | \$258.60 | \$150.64 | \$181.14 | \$258.60 | \$195.82 | \$208.96 |

Source: Sakulanda, Hazel, K. (2018).

Table 36: Top 5 Crops by Seeded Area in Southern Manitoba.

| Crop | Operating Costs \$ Per Acre | Price \$ Per Bushel | Average Yield Per Acre (Bu) |
|--------------|-----------------------------|---------------------|-----------------------------|
| Canola | 256.98 | 10.89 | 40 |
| Soybeans | 196.66 | 10.48 | 35 |
| Spring Wheat | 201.36 | 6.4 | 55 |
| Corn | 315.88 | 4.85 | 115 |
| Oats | 161.53 | 2.98 | 100 |

Source: Manitoba Agriculture, Food and Rural Development (MAFRD), 2016; Manitoba Agriculture (ndb).

Table 35 and 36 show the top 10 most profitable crop rotations with operating costs, crop prices, and average yields for crops. In my analysis, the same operating costs, price, and yield for five crops will be used in my calculation for the convenience of comparison between results from

this research and Sakulanda’s results. Yield responses from Table 18 which are from the provincial yield model including other factors in my research is applied in the profit calculation.

Table 37: Top 10 crop rotations based on mean revenue (\$) using yield responses of provincial level regression (Table 18) in this research.

| Rank | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Mean Revenue |
|---------|----------|----------|----------|----------|----------|--------------|
| 2 | Soybeans | G.Corn | Soybeans | G.Corn | | |
| Revenue | 180.04 | 238.52 | 180.04 | 238.52 | | 209.28 |
| 4 | Canola | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | 201.27 | 171.97 | 238.52 | 180.04 | 238.52 | 206.07 |
| 1 | Canola | G.Corn | Soybeans | G.Corn | | |
| Revenue | 201.27 | 229.04 | 180.04 | 238.52 | | 212.22 |
| 3 | G.Corn | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | 204.5 | 180.04 | 238.52 | 180.04 | 238.52 | 208.33 |
| 8 | S.Wheat | G.Corn | Soybeans | G.Corn | Soybeans | |
| Revenue | 164.02 | 241.87 | 180.04 | 238.52 | 180.04 | 200.9 |
| 9 | Soybeans | Soybeans | G.Corn | Soybeans | G.Corn | |
| Revenue | 180.04 | 155.47 | 238.52 | 180.04 | 238.52 | 198.52 |
| 5 | S.Wheat | G.Corn | Soybeans | G.Corn | | |
| Revenue | 159.09 | 241.87 | 180.04 | 238.52 | | 204.88 |
| 7 | Soybeans | G.Corn | Canola | S.Wheat | G.Corn | |
| Revenue | 180.04 | 238.52 | 201.27 | 150.64 | 241.87 | 202.47 |
| 6 | Canola | Soybeans | G.Corn | | | |
| Revenue | 201.27 | 171.97 | 238.52 | | | 203.92 |
| 10 | G.Corn | S.Wheat | Soybeans | G.Corn | Soybeans | |
| Revenue | 238.52 | 159.09 | 174.17 | 238.52 | 180.04 | 198.07 |

The same top 10 rotations, operating costs and prices from Sakulanda were applied to this analysis with updated yield responses from crop rotations using the provincial LSDV coefficients. Yield responses from provincial level regression (Table 18) were used in the new calculation. Revenues from every crop and average yields from crop rotations are calculated in Table 37. According to Table 37, some changes occur to both average yields of crop rotations and ranks of crop rotations. Firstly, the average yields from crop rotations are lower than those of Sakulanda’s in general. The smaller effects of yield responses generated from this study result in less variable yield impacts compared to Sakulanda’s yield estimations, which relied on Kubinec’s yield

responses. Secondly, different yield responses applied to the calculation lead to different ranks of crop rotations. For example, soybean yields after grain corn increased by 2.7% based on this research, less than Kubinec's 7% increase, which makes rotation 1 and 2 in Sakulanda's research move to 2 and 4, respectively, in Table 37. Thirdly, grain corn, canola, and soybeans with higher yields among five crops result in higher ranks in crop rotations of grain corn, canola, and soybeans, which is one of the reasons why the ranks for crop rotations switch.

Analysis on top 4 common crops planted by Risk Area:

In practice, farmers do not always pursue the highest profits of crop rotations as other crops need to be grown for offsetting potential crop diseases and risks. In table 4 of Chapter 3, the most common crops are displayed as spring wheat, canola, and soybeans in all Risk Areas. Spring wheat is popular with farmers for its strong resistance towards extreme weather and low risk although the returns of spring wheat can be lower compared to that of soybeans and grain corn.

Limitations:

Although the proposed research offers a yield model considering natural factors, yield responses, and risks from crop rotations in each Risk Area, there are still some drawbacks and limitations. Firstly, the research only focuses on selected fields and the 6 main crops in different regions, so the results from the study might be biased and restrictive. Potatoes should be considered in future studies although this crop needs special equipment. Fields suited for other minor crops are ignored in the research too, and they are worth further exploration. Secondly, in empirical work, other related elements such as weeds and pests, frost, flooding, and drought significantly influence yield potential. These factors are excluded from this research because it

was not possible to track the extent of damage from them. Thirdly, unmeasured differences may come from differences in chemical inputs, which were not addressed here as the changes in chemical inputs by crop rotation are often unmeasured. Fourthly, yield response from this research is exclusive to Manitoba, not for other agricultural areas. Yield response from crop rotations targeted to other areas might vary due to different factors. Fifthly, this study solely tracks the effect from the previous crop, not long-term rotations, which is quite limited. Finally, there are always econometric errors from yield models. 13 years of crops data for the crop yield models generates less significant regression results than econometric models with data of longer period do. Moreover, some other influential variables to crop yields are omitted for the lack of data and appropriate methods. Also, a series of insignificant coefficients result from some crop yield models, especially regional models due to a smaller number of observations.

New research could be conducted to further this research on crop rotations. Other factors which are likely to influence yields could be selected into crop yield models for further yield exploration, e.g., diseases, insects, and weeds. Similar yield models including all the factors in this research could be applied for data in other agricultural provinces and areas. New yield models can be built based on other econometric methodologies, such as distributing precipitation and temperature into different stages of crop growth. Economic impacts from long-term rotations could be explored based on current research on the previous crop in Manitoba. New yield responses from this research could be applied in research of a term of crop rotations in Manitoba, figuring out new simulated profits and risks for crop rotations.

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Appendix

Appendix A: Frequencies of previous crops on current crops in crop rotations in Manitoba (2006-2018).

| | | Crop Planted | | | | | |
|----------------|---------|--------------|--------|--------|------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crops | Barley | 938 | 9737 | 234 | 546 | 921 | 1000 |
| | Canola | 7006 | 8516 | 1206 | 4821 | 8298 | 70700 |
| | G.Corn | 130 | 2322 | 511 | 188 | 1104 | 245 |
| | Oats | 527 | 5402 | 165 | 344 | 1370 | 1010 |
| | Soybean | 796 | 5779 | 1415 | 1477 | 4018 | 6749 |
| | S.Wheat | 2240 | 67314 | 488 | 1238 | 6378 | 3565 |
| | Total | 11637 | 99070 | 4019 | 8614 | 22089 | 83269 |

Appendix B1: Linear model (OLS) of barley yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 11,63 |
|----------|------------|--------|------------|---------------|---|-------|
| > 7 | | | | | | |
| | | | | F(5, 11631) | = | 110.9 |
| > 8 | | | | | | |
| Model | 309174.083 | 5 | 61834.8166 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 6480408.73 | 11,631 | 557.166945 | R-squared | = | 0.045 |
| > 5 | | | | | | |
| | | | | Adj R-squared | = | 0.045 |
| > 1 | | | | | | |
| Total | 6789582.82 | 11,636 | 583.498008 | Root MSE | = | 23.60 |
| > 4 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|----------|-----------|-----------|--------|-------|---------------------|----------|
| > - | | | | | | |
| >] | | | | | | |
| > - | | | | | | |
| Barley | -15.11975 | .8206837 | -18.42 | 0.000 | -16.72843 | -13.5110 |
| > 7 | | | | | | |
| Corn | -1.152459 | 2.08936 | -0.55 | 0.581 | -5.247956 | 2.94303 |
| > 8 | | | | | | |
| Oats | -12.36975 | 1.066194 | -11.60 | 0.000 | -14.45967 | -10.2798 |
| > 3 | | | | | | |
| Soybeans | 5.383609 | .8828848 | 6.10 | 0.000 | 3.653006 | 7.11421 |
| > 1 | | | | | | |
| SWheat | -5.093377 | .5729418 | -8.89 | 0.000 | -6.216439 | -3.97031 |
| > 5 | | | | | | |
| _cons | 74.21985 | .2820055 | 263.19 | 0.000 | 73.66707 | 74.7726 |
| > 3 | | | | | | |

Appendix B2: Linear model (OLS) of canola yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 99,07 |
|----------|------------|--------|------------|---------------|---|-------|
| > 0 | | | | | | |
| | | | | F(5, 99064) | = | 402.3 |
| > 6 | | | | | | |
| Model | 291759.331 | 5 | 58351.8662 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 14366739.8 | 99,064 | 145.024831 | R-squared | = | 0.019 |
| > 9 | | | | | | |
| | | | | Adj R-squared | = | 0.019 |
| > 9 | | | | | | |
| Total | 14658499.2 | 99,069 | 147.962523 | Root MSE | = | 12.04 |
| > 3 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval |
|---------|-----------|-----------|--------|-------|---------------------|
| > - | | | | | |
| >] | | | | | |
| > - | | | | | |
| Barley | -1.110741 | .1305705 | -8.51 | 0.000 | -1.366658 - .854824 |
| > 4 | | | | | |
| Canola | -4.146043 | .1385068 | -29.93 | 0.000 | -4.417515 -3.87457 |
| > 2 | | | | | |
| Corn | 4.312917 | .2541876 | 16.97 | 0.000 | 3.814712 4.81112 |
| > 2 | | | | | |
| Oats | -2.814632 | .1702967 | -16.53 | 0.000 | -3.148411 -2.48085 |
| > 2 | | | | | |
| Soybean | 3.177079 | .1650745 | 19.25 | 0.000 | 2.853535 3.50062 |
| > 3 | | | | | |
| _cons | 39.77811 | .0464161 | 856.99 | 0.000 | 39.68714 39.8690 |
| > 9 | | | | | |

Appendix B3: Linear model (OLS) of grain corn yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 4,01 |
|----------|------------|-------|------------|---------------|---|-------|
| > 9 | | | | | | |
| | | | | F(5, 4013) | = | 29.5 |
| > 0 | | | | | | |
| Model | 179939.983 | 5 | 35987.9965 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 4896245.87 | 4,013 | 1220.09615 | R-squared | = | 0.035 |
| > 4 | | | | | | |
| | | | | Adj R-squared | = | 0.034 |
| > 2 | | | | | | |
| Total | 5076185.85 | 4,018 | 1263.36134 | Root MSE | = | 34.9 |
| > 3 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|----------|-----------|-----------|--------|-------|---------------------|----------|
| > - | | | | | | |
| > 1 | | | | | | |
| > - | | | | | | |
| Barley | -9.443396 | 2.49515 | -3.78 | 0.000 | -14.33528 | -4.55151 |
| > 6 | | | | | | |
| Corn | -6.312599 | 1.843733 | -3.42 | 0.001 | -9.92734 | -2.69785 |
| > 8 | | | | | | |
| Oats | -4.039751 | 2.899347 | -1.39 | 0.164 | -9.72408 | 1.64457 |
| > 8 | | | | | | |
| Soybeans | 10.5668 | 1.368922 | 7.72 | 0.000 | 7.88295 | 13.2506 |
| > 4 | | | | | | |
| SWheat | 3.194728 | 1.874003 | 1.70 | 0.088 | -.4793576 | 6.86881 |
| > 4 | | | | | | |
| _cons | 118.3723 | 1.005827 | 117.69 | 0.000 | 116.4003 | 120.344 |
| > 2 | | | | | | |

Appendix B4: Linear model (OLS) of oats yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 8,61 |
|----------|------------|-------|------------|---------------|---|-------|
| > 4 | | | | | | |
| | | | | F(5, 8608) | = | 76.5 |
| > 7 | | | | | | |
| Model | 445072.028 | 5 | 89014.4056 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 10006510.6 | 8,608 | 1162.46638 | R-squared | = | 0.042 |
| > 6 | | | | | | |
| | | | | Adj R-squared | = | 0.042 |
| > 0 | | | | | | |
| Total | 10451582.6 | 8,613 | 1213.46599 | Root MSE | = | 34.09 |
| > 5 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|----------|-----------|-----------|--------|-------|---------------------|----------|
| > 1 | | | | | | |
| > - | | | | | | |
| Barley | -10.33335 | 1.53954 | -6.71 | 0.000 | -13.35122 | -7.31547 |
| > 9 | | | | | | |
| Corn | 9.021894 | 2.534651 | 3.56 | 0.000 | 4.05337 | 13.9904 |
| > 2 | | | | | | |
| Oats | -25.61902 | 1.902732 | -13.46 | 0.000 | -29.34883 | -21.8892 |
| > 1 | | | | | | |
| Soybeans | 8.266171 | 1.013988 | 8.15 | 0.000 | 6.278512 | 10.2538 |
| > 3 | | | | | | |
| SWheat | -6.575981 | 1.08633 | -6.05 | 0.000 | -8.705448 | -4.44651 |
| > 4 | | | | | | |
| _cons | 104.3834 | .4910454 | 212.57 | 0.000 | 103.4208 | 105.345 |
| > 9 | | | | | | |

Appendix B5: Linear model (OLS) of soybeans yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 22,08 |
|----------|------------|--------|------------|---------------|---|-------|
| > 9 | | | | | | |
| | | | | F(5, 22083) | = | 43.9 |
| > 7 | | | | | | |
| Model | 19644.2027 | 5 | 3928.84055 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 1973073.12 | 22,083 | 89.3480561 | R-squared | = | 0.009 |
| > 9 | | | | | | |
| | | | | Adj R-squared | = | 0.009 |
| > 6 | | | | | | |
| Total | 1992717.32 | 22,088 | 90.2171915 | Root MSE | = | 9.452 |
| > 4 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|----------|-----------|-----------|--------|-------|---------------------|----------|
| > - | | | | | | |
| > 1 | | | | | | |
| > - | | | | | | |
| Barley | -.5314709 | .3282978 | -1.62 | 0.105 | -1.174958 | .112016 |
| > 1 | | | | | | |
| Corn | .9248515 | .3028178 | 3.05 | 0.002 | .331307 | 1.51839 |
| > 6 | | | | | | |
| Oats | -1.046285 | .2756537 | -3.80 | 0.000 | -1.586586 | -.505983 |
| > 8 | | | | | | |
| Soybeans | -1.879562 | .181671 | -10.35 | 0.000 | -2.235651 | -1.52347 |
| > 4 | | | | | | |
| SWheat | .7299634 | .1574046 | 4.64 | 0.000 | .4214391 | 1.03848 |
| > 8 | | | | | | |
| _cons | 35.79816 | .1037662 | 344.99 | 0.000 | 35.59478 | 36.0015 |
| > 5 | | | | | | |

Appendix B6: Linear model (OLS) of spring wheat yield only with previous crops as exogenous variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 83,26 |
|----------|------------|--------|------------|---------------|---|--------|
| > 9 | | | | | | |
| | | | | F(5, 83263) | = | 1021.1 |
| > 1 | | | | | | |
| Model | 1228841.21 | 5 | 245768.242 | Prob > F | = | 0.000 |
| > 0 | | | | | | |
| Residual | 20040280.1 | 83,263 | 240.6865 | R-squared | = | 0.057 |
| > 8 | | | | | | |
| | | | | Adj R-squared | = | 0.057 |
| > 7 | | | | | | |
| Total | 21269121.3 | 83,268 | 255.429712 | Root MSE | = | 15.51 |
| > 4 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval |
|----------|-----------|-----------|--------|-------|---------------------|
| > - | | | | | |
| > 1 | | | | | |
| > - | | | | | |
| Barley | -8.376202 | .4940555 | -16.95 | 0.000 | -9.344547 -7.40785 |
| > 7 | | | | | |
| Corn | 1.099458 | .9928737 | 1.11 | 0.268 | -.8465672 3.04548 |
| > 3 | | | | | |
| Oats | -9.231602 | .4916379 | -18.78 | 0.000 | -10.19521 -8.26799 |
| > 5 | | | | | |
| Soybeans | 8.957255 | .1976534 | 45.32 | 0.000 | 8.569855 9.34465 |
| > 4 | | | | | |
| SWheat | -12.2024 | .2663045 | -45.82 | 0.000 | -12.72436 -11.6804 |
| > 5 | | | | | |
| _cons | 52.97399 | .0583467 | 907.92 | 0.000 | 52.85963 53.0883 |
| > 5 | | | | | |

Appendix C1: Fixed effect model (LSDV) of barley yield including all variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 11,63 |
|--------|----------|------------|-----------|---------------|---------------|---------------------|
| > 7 | | | | | | |
| | | | | F(57, 11579) | = | 156.1 |
| > 1 | Model | 2950348.13 | 57 | 51760.4934 | Prob > F | = 0.000 |
| > 0 | Residual | 3839234.69 | 11,579 | 331.568762 | R-squared | = 0.434 |
| > 5 | | | | | Adj R-squared | = 0.431 |
| > 8 | Total | 6789582.82 | 11,636 | 583.498008 | Root MSE | = 18.20 |
| > 9 | | | | | | |
| <hr/> | | | | | | |
| > - | YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval |
| >] | <hr/> | | | | | |
| > - | N | .1248619 | .008688 | 14.37 | 0.000 | .107832 .141891 |
| > 9 | P | -.0316541 | .0161893 | -1.96 | 0.051 | -.0633877 .000079 |
| > 6 | K | .1371806 | .0179527 | 7.64 | 0.000 | .1019903 .172370 |
| > 9 | S | .1033888 | .0292268 | 3.54 | 0.000 | .0460993 .160678 |
| > 3 | GS | -.0015509 | .0381067 | -0.04 | 0.968 | -.0762466 .073144 |
| > 7 | GS2 | -.0001515 | .0000366 | -4.14 | 0.000 | -.0002233 -.000079 |
| > 7 | GDD | .0896642 | .0230154 | 3.90 | 0.000 | .0445502 .134778 |
| > 2 | GDD2 | -.0000419 | 7.98e-06 | -5.26 | 0.000 | -.0000576 -.000026 |
| > 3 | GSGDD | .0000167 | .0000199 | 0.84 | 0.402 | -.0000223 .000055 |
| > 6 | SB | -3.000566 | 2.210658 | -1.36 | 0.175 | -7.333828 1.33269 |
| > 7 | SC | -3.553383 | 2.169652 | -1.64 | 0.101 | -7.806268 .699501 |
| > 6 | SD | -6.092623 | 2.157122 | -2.82 | 0.005 | -10.32095 -1.864 |
| > 3 | SE | -10.1171 | 2.152857 | -4.70 | 0.000 | -14.33706 -5.89713 |
| > 8 | SF | -12.17842 | 2.156672 | -5.65 | 0.000 | -16.40586 -7.95097 |
| > 9 | SG | -13.5814 | 2.183841 | -6.22 | 0.000 | -17.8621 -9.30070 |
| > 7 | SH | -17.99843 | 2.274158 | -7.91 | 0.000 | -22.45617 -13.540 |
| > 7 | SI | -19.53318 | 2.610917 | -7.48 | 0.000 | -24.65102 -14.4153 |
| > 5 | SJ | -23.15355 | 3.249161 | -7.13 | 0.000 | -29.52245 -16.7846 |

| | | | | | | | | |
|-----|----------|--|-----------|----------|--------|-------|-----------|----------|
| > 1 | Barley | | -9.093691 | .6545256 | -13.89 | 0.000 | -10.37667 | -7.8107 |
| > 3 | Corn | | -1.098443 | 1.682858 | -0.65 | 0.514 | -4.397129 | 2.20024 |
| > 8 | Oats | | -7.253548 | .8452744 | -8.58 | 0.000 | -8.910429 | -5.59666 |
| > 1 | Soybeans | | .8034911 | .7537872 | 1.07 | 0.286 | -.6740591 | 2.28104 |
| > 4 | SWheat | | -2.715907 | .4608392 | -5.89 | 0.000 | -3.619229 | -1.81258 |
| > 6 | D2 | | -2.745077 | 1.081993 | -2.54 | 0.011 | -4.865966 | -.624188 |
| > 7 | D3 | | -7.589807 | 1.094273 | -6.94 | 0.000 | -9.734766 | -5.44484 |
| > 5 | D4 | | -11.99066 | 1.084462 | -11.06 | 0.000 | -14.11639 | -9.86493 |
| > 5 | D5 | | -15.78944 | 1.131427 | -13.96 | 0.000 | -18.00723 | -13.5716 |
| > 9 | D6 | | -17.30493 | 1.239863 | -13.96 | 0.000 | -19.73527 | -14.8745 |
| > 8 | D7 | | -22.69608 | 1.308193 | -17.35 | 0.000 | -25.26036 | -20.131 |
| > 1 | D8 | | -29.25233 | 1.47794 | -19.79 | 0.000 | -32.14934 | -26.3553 |
| > 9 | D9 | | -33.19486 | 1.815746 | -18.28 | 0.000 | -36.75402 | -29.6356 |
| > 7 | BL | | -4.083686 | .9821681 | -4.16 | 0.000 | -6.008901 | -2.1584 |
| > 3 | BM | | -19.77839 | 1.189115 | -16.63 | 0.000 | -22.10926 | -17.4475 |
| > 1 | BN | | -7.605379 | 1.445823 | -5.26 | 0.000 | -10.43944 | -4.77132 |
| > 6 | BO | | -2.189752 | 1.664264 | -1.32 | 0.188 | -5.451991 | 1.07248 |
| > 8 | BP | | -19.54249 | 1.361162 | -14.36 | 0.000 | -22.2106 | -16.8743 |
| > 7 | BQ | | -35.89114 | 1.322217 | -27.14 | 0.000 | -38.4829 | -33.2993 |
| > 5 | BR | | -28.09769 | 1.108346 | -25.35 | 0.000 | -30.27024 | -25.9251 |
| > 5 | BS | | 12.19534 | 1.233929 | 9.88 | 0.000 | 9.776628 | 14.6140 |
| > 6 | BT | | -4.945502 | 1.384598 | -3.57 | 0.000 | -7.659548 | -2.23145 |
| > 4 | BU | | -11.1707 | 1.179839 | -9.47 | 0.000 | -13.48338 | -8.85801 |
| > 6 | BV | | -5.031627 | 1.192443 | -4.22 | 0.000 | -7.369017 | -2.69423 |
| | BW | | 2.488614 | 1.367714 | 1.82 | 0.069 | -.1923368 | 5.16956 |

| | | | | | | | | |
|-----|-------|--|----------|----------|-------|-------|-----------|----------|
| > 6 | 2 | | 13.52286 | 1.022412 | 13.23 | 0.000 | 11.51876 | 15.5269 |
| > 3 | 3 | | 4.589354 | 1.108179 | 4.14 | 0.000 | 2.417135 | 6.76157 |
| > 2 | 4 | | 6.730523 | 1.091707 | 6.17 | 0.000 | 4.590593 | 8.87045 |
| > 5 | 5 | | 15.11233 | 1.027624 | 14.71 | 0.000 | 13.09801 | 17.1266 |
| > 8 | 6 | | 3.469684 | 1.350727 | 2.57 | 0.010 | .8220309 | 6.11733 |
| > 2 | 7 | | 3.616486 | 1.316497 | 2.75 | 0.006 | 1.03593 | 6.19704 |
| > 8 | 8 | | 12.03993 | 2.100403 | 5.73 | 0.000 | 7.922789 | 16.1570 |
| > 5 | 9 | | 4.78927 | 1.205822 | 3.97 | 0.000 | 2.425655 | 7.15288 |
| > 4 | 10 | | 5.16626 | 1.445785 | 3.57 | 0.000 | 2.332276 | 8.00024 |
| > 2 | 11 | | 16.71822 | 1.047716 | 15.96 | 0.000 | 14.66452 | 18.7719 |
| > 3 | 12 | | 15.5306 | 1.441374 | 10.77 | 0.000 | 12.70526 | 18.3559 |
| > 5 | 14 | | 3.444889 | 1.485477 | 2.32 | 0.020 | .5331033 | 6.35667 |
| > 6 | 15 | | 3.673181 | 1.486553 | 2.47 | 0.013 | .7592862 | 6.58707 |
| > 4 | 16 | | -16.3633 | 4.756044 | -3.44 | 0.001 | -25.68595 | -7.04065 |
| | _cons | | 46.15172 | 17.73662 | 2.60 | 0.009 | 11.38495 | 80.9184 |

Appendix C2: Fixed effect model (LSDV) of canola yield including all variables in Manitoban (2006-2018).

| Source | SS | df | MS | Number of obs | = | 99,07 |
|--------|----------|------------|--------|---------------|-----------|---------|
| > 0 | | | | F(57, 99012) | = | 1358.7 |
| > 1 | Model | 6433507.87 | 57 | 112868.559 | Prob > F | = 0.000 |
| > 0 | Residual | 8224991.3 | 99,012 | 83.070651 | R-squared | = 0.438 |
| > 9 | | | | Adj R-squared | = | 0.438 |
| > 6 | Total | 14658499.2 | 99,069 | 147.962523 | Root MSE | = 9.114 |
| > 3 | | | | | | |

| | YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval |
|-----|-------|-----------|-----------|--------|-------|---------------------|
| > - | | | | | | |
| > 4 | N | .0542427 | .0013657 | 39.72 | 0.000 | .0515659 .056919 |
| > 4 | P | -.0000137 | .0028649 | -0.00 | 0.996 | -.0056288 .005601 |
| > 4 | K | .0048926 | .0026631 | 1.84 | 0.066 | -.000327 .010112 |
| > 2 | S | .1125254 | .0036896 | 30.50 | 0.000 | .1052939 .119756 |
| > 9 | GS | -.0530131 | .0058146 | -9.12 | 0.000 | -.0644097 -.041616 |
| > 6 | GS2 | -.0001239 | 5.07e-06 | -24.45 | 0.000 | -.0001338 -.00011 |
| > 4 | GDD | -.0367776 | .0040431 | -9.10 | 0.000 | -.044702 -.028853 |
| > 3 | GDD2 | 3.94e-06 | 1.44e-06 | 2.74 | 0.006 | 1.12e-06 6.75e-0 |
| > 6 | GSGDD | .000061 | 3.33e-06 | 18.33 | 0.000 | .0000545 .000067 |
| > 5 | SB | -3.13085 | .4008507 | -7.81 | 0.000 | -3.916513 -2.34518 |
| > 8 | SC | -4.084252 | .3917474 | -10.43 | 0.000 | -4.852072 -3.31643 |
| > 1 | SD | -5.614589 | .3917148 | -14.33 | 0.000 | -6.382345 -4.84683 |
| > 3 | SE | -7.72584 | .3913314 | -19.74 | 0.000 | -8.492845 -6.95883 |
| > 6 | SF | -8.117206 | .3941975 | -20.59 | 0.000 | -8.889829 -7.34458 |
| > 4 | SG | -8.343149 | .4041677 | -20.64 | 0.000 | -9.135313 -7.55098 |
| > 6 | SH | -9.961413 | .4300605 | -23.16 | 0.000 | -10.80433 -9.118 |
| > 5 | SI | -11.13614 | .5041568 | -22.09 | 0.000 | -12.12428 -10.14 |
| > 8 | SJ | -10.93818 | .6867065 | -15.93 | 0.000 | -12.28412 -9.59224 |

| | | | | | | | | |
|-----|---------|--|-----------|----------|---------|-------|-----------|----------|
| > 4 | Barley | | -.1712682 | .1015117 | -1.69 | 0.092 | -.3702299 | .027693 |
| > 1 | Canola | | -3.227615 | .1093036 | -29.53 | 0.000 | -3.441849 | -3.01338 |
| > 9 | Corn | | 1.719561 | .2087917 | 8.24 | 0.000 | 1.310331 | 2.1287 |
| > 7 | Oats | | -1.425556 | .1325209 | -10.76 | 0.000 | -1.685296 | -1.16581 |
| > 8 | Soybean | | -.2159152 | .135706 | -1.59 | 0.112 | -.4818973 | .050066 |
| > 9 | D1 | | -.6801465 | .7099627 | -0.96 | 0.338 | -2.071665 | .711371 |
| > 5 | D3 | | -.4348108 | .2636079 | -1.65 | 0.099 | -.9514792 | .081857 |
| > 6 | D4 | | .2184533 | .2492609 | 0.88 | 0.381 | -.270095 | .707001 |
| > 9 | D5 | | -.4286481 | .251847 | -1.70 | 0.089 | -.9222652 | .06496 |
| > 6 | D6 | | -1.604039 | .2607889 | -6.15 | 0.000 | -2.115182 | -1.09289 |
| > 2 | D7 | | -2.850807 | .2661619 | -10.71 | 0.000 | -3.372481 | -2.32913 |
| > 4 | D8 | | -6.363662 | .2896841 | -21.97 | 0.000 | -6.931439 | -5.79588 |
| > 4 | D9 | | -5.971116 | .5064477 | -11.79 | 0.000 | -6.963747 | -4.97848 |
| > 4 | AY | | -7.829795 | .1676699 | -46.70 | 0.000 | -8.158426 | -7.50116 |
| > 8 | AZ | | -16.42725 | .2044264 | -80.36 | 0.000 | -16.82793 | -16.0265 |
| > 5 | BA | | -4.703173 | .2572657 | -18.28 | 0.000 | -5.207411 | -4.19893 |
| > 5 | BB | | -4.01697 | .3096375 | -12.97 | 0.000 | -4.623856 | -3.41008 |
| > 5 | BC | | -6.21646 | .2035241 | -30.54 | 0.000 | -6.615365 | -5.81755 |
| > 3 | BD | | -14.17088 | .1885462 | -75.16 | 0.000 | -14.54043 | -13.8013 |
| > 8 | BE | | -18.3861 | .1694516 | -108.50 | 0.000 | -18.71823 | -18.0539 |
| > 6 | BF | | -.841307 | .1917549 | -4.39 | 0.000 | -1.217144 | -.465469 |
| > 9 | BG | | -5.813913 | .2075637 | -28.01 | 0.000 | -6.220735 | -5.4070 |
| > 2 | BH | | -1.555811 | .1721587 | -9.04 | 0.000 | -1.89324 | -1.21838 |
| > 6 | BI | | -2.670607 | .1699503 | -15.71 | 0.000 | -3.003707 | -2.33750 |
| | BJ | | -2.821299 | .205181 | -13.75 | 0.000 | -3.223452 | -2.41914 |

| | | | | | | | | |
|-----|-------|--|-----------|----------|--------|-------|-----------|----------|
| > 6 | 2 | | 6.596375 | .1957468 | 33.70 | 0.000 | 6.212713 | 6.98003 |
| > 2 | 3 | | 2.431717 | .2312235 | 10.52 | 0.000 | 1.978521 | 2.88491 |
| > 4 | 4 | | 4.160188 | .2175196 | 19.13 | 0.000 | 3.733852 | 4.58652 |
| > 9 | 5 | | 7.520197 | .1970121 | 38.17 | 0.000 | 7.134056 | 7.90633 |
| > 1 | 6 | | 1.353745 | .2806935 | 4.82 | 0.000 | .8035893 | 1.90390 |
| > 2 | 7 | | 2.559824 | .2579241 | 9.92 | 0.000 | 2.054296 | 3.06535 |
| > 8 | 8 | | 5.723706 | .2355386 | 24.30 | 0.000 | 5.262053 | 6.18535 |
| > 8 | 9 | | 4.226424 | .2188095 | 19.32 | 0.000 | 3.79756 | 4.65528 |
| > 2 | 10 | | 5.047712 | .2739915 | 18.42 | 0.000 | 4.510692 | 5.58473 |
| > 3 | 11 | | 4.027386 | .2099338 | 19.18 | 0.000 | 3.615918 | 4.43885 |
| > 2 | 12 | | 8.605045 | .2611636 | 32.95 | 0.000 | 8.093167 | 9.11692 |
| > 2 | 14 | | 1.434702 | .2922466 | 4.91 | 0.000 | .8619026 | 2.00750 |
| > 6 | 15 | | -1.034217 | .2798422 | -3.70 | 0.000 | -1.582704 | -.485729 |
| > 2 | 16 | | -12.90826 | .6650754 | -19.41 | 0.000 | -14.2118 | -11.6047 |
| | _cons | | 85.0519 | 3.087275 | 27.55 | 0.000 | 79.00088 | 91.1029 |

Appendix C3: Fixed effect model (LSDV) of grain corn yield including all variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 4,01 |
|--------|----------|------------|-------|---------------|-----------|---------|
| > 9 | | | | F(54, 3964) | = | 46.4 |
| > 0 | Model | 1965866.95 | 54 | 36404.9435 | Prob > F | = 0.000 |
| > 0 | Residual | 3110318.9 | 3,964 | 784.641499 | R-squared | = 0.387 |
| > 3 | | | | Adj R-squared | = | 0.378 |
| > 9 | Total | 5076185.85 | 4,018 | 1263.36134 | Root MSE | = 28.01 |
| > 1 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|-------|-------|-----------|----------|-------|---------------------|--------------------|
| > - | | | | | | |
| >] | | | | | | |
| > - | N | .0505071 | .0139021 | 3.63 | 0.000 | .0232512 .07776 |
| > 3 | P | -.0625321 | .0354406 | -1.76 | 0.078 | -.1320156 .006951 |
| > 3 | K | .0757769 | .026176 | 2.89 | 0.004 | .0244571 .127096 |
| > 6 | S | .0604861 | .0571558 | 1.06 | 0.290 | -.0515714 .172543 |
| > 7 | GS | -.3953788 | .1017828 | -3.88 | 0.000 | -.5949303 -.195827 |
| > 3 | GS2 | .0001653 | .0000688 | 2.40 | 0.016 | .0000303 .000300 |
| > 3 | GDD | -.2619576 | .1296553 | -2.02 | 0.043 | -.5161549 -.007760 |
| > 3 | GDD2 | .0000955 | .0000719 | 1.33 | 0.184 | -.0000454 .000236 |
| > 5 | GSGDD | .0003325 | .000087 | 3.82 | 0.000 | .0001618 .000503 |
| > 2 | SB | -7.82923 | 5.744723 | -1.36 | 0.173 | -19.09212 3.43365 |
| > 9 | SC | -10.43257 | 5.486261 | -1.90 | 0.057 | -21.18873 .323589 |
| > 5 | SD | -12.20814 | 5.500509 | -2.22 | 0.027 | -22.99223 -1.42404 |
| > 2 | SE | -9.573426 | 5.498387 | -1.74 | 0.082 | -20.35336 1.20650 |
| > 7 | SF | -9.381812 | 5.584437 | -1.68 | 0.093 | -20.33045 1.56682 |
| > 6 | SG | -10.28173 | 5.655862 | -1.82 | 0.069 | -21.3704 .806940 |
| > 9 | SH | -17.61131 | 5.765357 | -3.05 | 0.002 | -28.91465 -6.30796 |
| > 4 | SI | -16.85408 | 6.278235 | -2.68 | 0.007 | -29.16295 -4.54520 |
| > 4 | SJ | -25.8404 | 9.144394 | -2.83 | 0.005 | -43.76855 -7.91223 |

| | | | | | | | |
|-----|----------|-----------|----------|--------|-------|-----------|----------|
| > 7 | Barley | -1.307832 | 2.061602 | -0.63 | 0.526 | -5.349731 | 2.73406 |
| > 5 | Corn | -5.282492 | 1.600442 | -3.30 | 0.001 | -8.420259 | -2.14472 |
| > 2 | Oats | -3.740594 | 2.377989 | -1.57 | 0.116 | -8.40279 | .92160 |
| > 2 | Soybeans | 2.035743 | 1.18874 | 1.71 | 0.087 | -.2948556 | 4.36634 |
| > 8 | SWheat | 2.85519 | 1.56201 | 1.83 | 0.068 | -.2072274 | 5.91760 |
| > 5 | D1 | -9.001821 | 5.439539 | -1.65 | 0.098 | -19.66638 | 1.66273 |
| > 5 | D3 | -1.858822 | 1.884897 | -0.99 | 0.324 | -5.55428 | 1.83663 |
| > 8 | D4 | -5.830979 | 1.977525 | -2.95 | 0.003 | -9.70804 | -1.95391 |
| > 9 | D5 | -13.46922 | 2.3283 | -5.78 | 0.000 | -18.034 | -8.90443 |
| > 4 | D6 | -22.88367 | 2.972069 | -7.70 | 0.000 | -28.7106 | -17.0567 |
| > 6 | D7 | -37.7094 | 7.391651 | -5.10 | 0.000 | -52.20119 | -23.217 |
| > 5 | D8 | -31.98601 | 28.2534 | -1.13 | 0.258 | -87.37856 | 23.4065 |
| > 2 | BI | -6.493194 | 3.948548 | -1.64 | 0.100 | -14.23457 | 1.24818 |
| > 1 | BJ | -3.121878 | 2.814304 | -1.11 | 0.267 | -8.639498 | 2.39574 |
| > 5 | BK | -3.914849 | 3.209545 | -1.22 | 0.223 | -10.20736 | 2.37766 |
| > 8 | BL | -60.91038 | 3.534393 | -17.23 | 0.000 | -67.83978 | -53.9809 |
| > 1 | BM | -7.191109 | 3.683394 | -1.95 | 0.051 | -14.41263 | .030416 |
| > 8 | BN | -10.67425 | 3.112189 | -3.43 | 0.001 | -16.77589 | -4.57260 |
| > 6 | BO | 3.230421 | 2.798934 | 1.15 | 0.249 | -2.257064 | 8.71790 |
| > 9 | BP | 19.27565 | 2.120636 | 9.09 | 0.000 | 15.11801 | 23.4332 |
| > 6 | BQ | .1843345 | 2.8374 | 0.06 | 0.948 | -5.378567 | 5.74723 |
| > 3 | BR | 13.74079 | 2.667266 | 5.15 | 0.000 | 8.511447 | 18.9701 |
| > 1 | BS | 24.37224 | 2.520431 | 9.67 | 0.000 | 19.43078 | 29.3137 |
| | BT | 15.85665 | 1.932457 | 8.21 | 0.000 | 12.06795 | 19.6453 |

| | | | | | | | |
|-----|-------|-----------|----------|-------|-------|-----------|----------|
| | RA | | | | | | |
| | 2 | 8.571443 | 3.917795 | 2.19 | 0.029 | .8903607 | 16.2525 |
| > 3 | | | | | | | |
| | 3 | -8.897514 | 5.41373 | -1.64 | 0.100 | -19.51147 | 1.71644 |
| > 3 | | | | | | | |
| | 4 | 20.78057 | 4.077153 | 5.10 | 0.000 | 12.78705 | 28.7740 |
| > 8 | | | | | | | |
| | 5 | 21.80191 | 3.869066 | 5.63 | 0.000 | 14.21636 | 29.3874 |
| > 5 | | | | | | | |
| | 6 | 10.35426 | 8.013379 | 1.29 | 0.196 | -5.356468 | 26.06 |
| > 5 | | | | | | | |
| | 8 | 6.400331 | 20.63558 | 0.31 | 0.756 | -34.05702 | 46.8576 |
| > 9 | | | | | | | |
| | 9 | -19.55016 | 8.089111 | -2.42 | 0.016 | -35.40937 | -3.69094 |
| > 9 | | | | | | | |
| | 10 | 21.26012 | 3.488515 | 6.09 | 0.000 | 14.42066 | 28.0995 |
| > 7 | | | | | | | |
| | 11 | 15.50835 | 3.856053 | 4.02 | 0.000 | 7.94832 | 23.0683 |
| > 9 | | | | | | | |
| | 12 | 30.93032 | 3.694452 | 8.37 | 0.000 | 23.68712 | 38.1735 |
| > 3 | | | | | | | |
| | 14 | 22.38062 | 3.818502 | 5.86 | 0.000 | 14.89421 | 29.8670 |
| > 4 | | | | | | | |
| | 15 | -.6443826 | 8.044761 | -0.08 | 0.936 | -16.41664 | 15.1278 |
| > 7 | | | | | | | |
| | _cons | 275.832 | 62.68529 | 4.40 | 0.000 | 152.9335 | 398.730 |

Appendix C4: Fixed effect model (LSDV) of oats yield including all variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 8,61 |
|--------|----------|------------|-------|---------------|-----------|---------|
| > 4 | ----- | | | F(56, 8557) | = | 101.3 |
| > 6 | Model | 4168020.52 | 56 | 74428.9379 | Prob > F | = 0.000 |
| > 0 | Residual | 6283562.09 | 8,557 | 734.318346 | R-squared | = 0.398 |
| > 8 | ----- | | | Adj R-squared | = | 0.394 |
| > 9 | Total | 10451582.6 | 8,613 | 1213.46599 | Root MSE | = 27.09 |
| > 8 | ----- | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | | |
|-------|-------|-----------|----------|-------|---------------------|-----------|----------|
| > - | ----- | | | | | | |
| >] | ----- | | | | | | |
| > - | N | .2235631 | .0167249 | 13.37 | 0.000 | .1907783 | .25634 |
| > 8 | P | .1651521 | .0302451 | 5.46 | 0.000 | .1058645 | .224439 |
| > 8 | K | .108374 | .0265218 | 4.09 | 0.000 | .0563849 | .160363 |
| > 2 | S | .0564004 | .0535524 | 1.05 | 0.292 | -.0485752 | .161376 |
| > 1 | GS | .1643671 | .0652113 | 2.52 | 0.012 | .0365371 | .29219 |
| > 7 | GS2 | -.0005193 | .0000601 | -8.65 | 0.000 | -.000637 | -.000401 |
| > 6 | GDD | .0497089 | .0437235 | 1.14 | 0.256 | -.0359998 | .135417 |
| > 5 | GDD2 | -.0000312 | .0000153 | -2.03 | 0.042 | -.0000612 | -1.13e-0 |
| > 6 | GSGDD | .0000434 | .0000347 | 1.25 | 0.211 | -.0000246 | .000111 |
| > 4 | SB | -.1852802 | 4.510462 | -0.04 | 0.967 | -9.026874 | 8.65631 |
| > 4 | SC | -1.006417 | 4.417825 | -0.23 | 0.820 | -9.66642 | 7.65358 |
| > 7 | SD | -9.19355 | 4.379253 | -2.10 | 0.036 | -17.77794 | -.609157 |
| > 1 | SE | -12.45644 | 4.373437 | -2.85 | 0.004 | -21.02943 | -3.88345 |
| > 1 | SF | -19.00626 | 4.387442 | -4.33 | 0.000 | -27.6067 | -10.4058 |
| > 1 | SG | -19.02497 | 4.417207 | -4.31 | 0.000 | -27.68376 | -10.3661 |
| > 8 | SH | -25.9971 | 4.472337 | -5.81 | 0.000 | -34.76396 | -17.2302 |
| > 4 | SI | -28.08893 | 4.733236 | -5.93 | 0.000 | -37.36721 | -18.8106 |
| > 5 | SJ | -41.05023 | 5.962596 | -6.88 | 0.000 | -52.73836 | -29.3621 |

| | | | | | | | | |
|-----|----------|--|-----------|----------|--------|-------|-----------|----------|
| > 1 | Barley | | -6.007389 | 1.298135 | -4.63 | 0.000 | -8.552046 | -3.46273 |
| > 5 | Corn | | -.9029687 | 2.159236 | -0.42 | 0.676 | -5.135593 | 3.32965 |
| > 1 | Oats | | -12.71898 | 1.542579 | -8.25 | 0.000 | -15.74281 | -9.69515 |
| > 2 | Soybeans | | 2.442692 | .9469649 | 2.58 | 0.010 | .5864125 | 4.29897 |
| > 6 | SWheat | | -1.73243 | .8962354 | -1.93 | 0.053 | -3.489268 | .024407 |
| > 8 | D2 | | -1.689497 | 2.030227 | -0.83 | 0.405 | -5.669233 | 2.29023 |
| > 9 | D3 | | -3.997122 | 2.039383 | -1.96 | 0.050 | -7.994804 | .000559 |
| > 9 | D4 | | -8.78131 | 2.037775 | -4.31 | 0.000 | -12.77584 | -4.78677 |
| > 5 | D5 | | -13.85286 | 2.117089 | -6.54 | 0.000 | -18.00287 | -9.70285 |
| > 5 | D6 | | -20.45601 | 2.247916 | -9.10 | 0.000 | -24.86247 | -16.0495 |
| > 2 | D7 | | -27.07256 | 2.389675 | -11.33 | 0.000 | -31.7569 | -22.3882 |
| > 7 | D8 | | -35.63017 | 2.565708 | -13.89 | 0.000 | -40.65958 | -30.6007 |
| > 9 | D9 | | -46.78771 | 3.091057 | -15.14 | 0.000 | -52.84693 | -40.7284 |
| > 4 | BK | | -8.317464 | 1.55642 | -5.34 | 0.000 | -11.36842 | -5.26650 |
| > 7 | BL | | -17.27336 | 1.995869 | -8.65 | 0.000 | -21.18574 | -13.3609 |
| > 6 | BM | | -5.796313 | 2.468207 | -2.35 | 0.019 | -10.63459 | -.958031 |
| > 6 | BN | | 7.975159 | 2.964124 | 2.69 | 0.007 | 2.164761 | 13.7855 |
| > 3 | BO | | -13.66238 | 2.321333 | -5.89 | 0.000 | -18.21276 | -9.11201 |
| > 5 | BP | | -20.63661 | 2.049367 | -10.07 | 0.000 | -24.65386 | -16.6193 |
| > 2 | BQ | | -24.83207 | 2.005441 | -12.38 | 0.000 | -28.76322 | -20.9009 |
| > 3 | BR | | 21.85043 | 2.196719 | 9.95 | 0.000 | 17.54433 | 26.1565 |
| > 2 | BS | | -2.365717 | 2.379176 | -0.99 | 0.320 | -7.029476 | 2.29804 |
| > 6 | BT | | -5.842699 | 1.976095 | -2.96 | 0.003 | -9.716322 | -1.96907 |
| > 9 | BU | | 9.757415 | 2.04198 | 4.78 | 0.000 | 5.754642 | 13.7601 |
| | BV | | 15.12509 | 2.112447 | 7.16 | 0.000 | 10.98418 | 19.26 |

| | | | | | | | |
|-----|-------|-----------|----------|-------|-------|-----------|----------|
| | RA | | | | | | |
| > 6 | 2 | 7.409798 | 1.508772 | 4.91 | 0.000 | 4.45224 | 10.3673 |
| > 9 | 3 | -5.033772 | 2.120436 | -2.37 | 0.018 | -9.190339 | -.877204 |
| > 9 | 4 | -4.679859 | 2.08923 | -2.24 | 0.025 | -8.775253 | -.584464 |
| > 8 | 5 | 14.98052 | 1.649983 | 9.08 | 0.000 | 11.74615 | 18.2148 |
| > 9 | 6 | -4.936197 | 2.371385 | -2.08 | 0.037 | -9.584684 | -.287709 |
| > 7 | 7 | -4.043687 | 2.320567 | -1.74 | 0.081 | -8.592557 | .505183 |
| > 1 | 8 | 3.007758 | 2.828276 | 1.06 | 0.288 | -2.536345 | 8.55186 |
| > 9 | 9 | -4.006787 | 1.880345 | -2.13 | 0.033 | -7.692716 | -.320856 |
| > 1 | 10 | 2.946783 | 1.681573 | 1.75 | 0.080 | -.3495044 | 6.24307 |
| > 6 | 11 | 6.718216 | 1.490817 | 4.51 | 0.000 | 3.795856 | 9.64057 |
| > 3 | 12 | 8.942437 | 1.899047 | 4.71 | 0.000 | 5.219848 | 12.6650 |
| > 7 | 14 | -2.023185 | 1.732675 | -1.17 | 0.243 | -5.419647 | 1.37327 |
| > 4 | 15 | -2.033131 | 1.794017 | -1.13 | 0.257 | -5.549836 | 1.48357 |
| | _cons | 80.06681 | 32.78972 | 2.44 | 0.015 | 15.79104 | 144.342 |

Appendix C5: Fixed effect model (LSDV) of soybeans yield including all variables in Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 22,08 |
|--------|----------|------------|--------|---------------|-----------|---------|
| > 9 | | | | | | |
| <hr/> | | | | | | |
| > 9 | | | | F(56, 22032) | = | 142.7 |
| > 0 | Model | 530652.8 | 56 | 9475.94286 | Prob > F | = 0.000 |
| > 3 | Residual | 1462064.52 | 22,032 | 66.3609534 | R-squared | = 0.266 |
| <hr/> | | | | | | |
| > 4 | | | | Adj R-squared | = | 0.264 |
| > 2 | Total | 1992717.32 | 22,088 | 90.2171915 | Root MSE | = 8.146 |

| | YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interval | |
|-------|-------|-----------|-----------|--------|-------|---------------------|----------|
| > - | | | | | | | |
| >] | | | | | | | |
| <hr/> | | | | | | | |
| > - | N | .0153471 | .0072361 | 2.12 | 0.034 | .0011638 | .029530 |
| > 4 | P | .0388212 | .0034789 | 11.16 | 0.000 | .0320023 | .045640 |
| > 2 | K | .0067038 | .0039071 | 1.72 | 0.086 | -.0009544 | .014361 |
| > 9 | S | -.0001786 | .0093572 | -0.02 | 0.985 | -.0185194 | .018162 |
| > 2 | GS | -.0227145 | .0116648 | -1.95 | 0.052 | -.0455783 | .000149 |
| > 3 | GS2 | -.0000521 | 8.76e-06 | -5.95 | 0.000 | -.0000693 | -.000003 |
| > 5 | GDD | .0899971 | .0143653 | 6.26 | 0.000 | .0618401 | .118154 |
| > 1 | GDD2 | -.000071 | 7.94e-06 | -8.94 | 0.000 | -.0000865 | -.000055 |
| > 4 | GSGDD | .0000915 | 9.94e-06 | 9.20 | 0.000 | .000072 | .00011 |
| > 1 | SB | -3.733866 | .6960785 | -5.36 | 0.000 | -5.09823 | -2.36950 |
| > 2 | SC | -3.735659 | .6708819 | -5.57 | 0.000 | -5.050635 | -2.42068 |
| > 2 | SD | -5.537114 | .6670207 | -8.30 | 0.000 | -6.844522 | -4.22970 |
| > 5 | SE | -6.337206 | .6660839 | -9.51 | 0.000 | -7.642778 | -5.03163 |
| > 4 | SF | -7.381637 | .6726373 | -10.97 | 0.000 | -8.700054 | -6.06321 |
| > 9 | SG | -8.154834 | .6874257 | -11.86 | 0.000 | -9.502237 | -6.8074 |
| > 3 | SH | -11.06731 | .7079628 | -15.63 | 0.000 | -12.45497 | -9.67965 |
| > 3 | SI | -11.28584 | .8174862 | -13.81 | 0.000 | -12.88817 | -9.68350 |
| > 4 | SJ | -11.0042 | 1.117794 | -9.84 | 0.000 | -13.19516 | -8.81324 |

| | | | | | | | | |
|-----|----------|--|-----------|----------|--------|-------|-----------|----------|
| > 4 | Barley | | -.6090544 | .2879777 | -2.11 | 0.034 | -1.173511 | -.044597 |
| > 6 | Corn | | .776361 | .2779058 | 2.79 | 0.005 | .2316458 | 1.32107 |
| > 2 | Oats | | -.147181 | .2486523 | -0.59 | 0.554 | -.6345573 | .340195 |
| > 7 | Soybeans | | -1.613475 | .1672022 | -9.65 | 0.000 | -1.941204 | -1.28574 |
| > 7 | SWheat | | .2206466 | .1401633 | 1.57 | 0.115 | -.0540835 | .495376 |
| > 1 | D1 | | -3.132438 | 2.888205 | -1.08 | 0.278 | -8.793526 | 2.52865 |
| > 6 | D2 | | -1.734986 | 1.888866 | -0.92 | 0.358 | -5.437299 | 1.96732 |
| > 3 | D3 | | -.7117926 | .2991341 | -2.38 | 0.017 | -1.298117 | -.125468 |
| > 5 | D5 | | -1.230133 | .1488505 | -8.26 | 0.000 | -1.52189 | -.93837 |
| > 8 | D6 | | -3.566771 | .1869337 | -19.08 | 0.000 | -3.933175 | -3.20036 |
| > 1 | D7 | | -5.107684 | .4286237 | -11.92 | 0.000 | -5.947817 | -4.26755 |
| > 5 | D8 | | -12.91357 | 2.124005 | -6.08 | 0.000 | -17.07677 | -8.75036 |
| > 8 | BK | | 2.772015 | .6447589 | 4.30 | 0.000 | 1.508241 | 4.03578 |
| > 4 | BL | | 2.559261 | .6794713 | 3.77 | 0.000 | 1.227449 | 3.89107 |
| > 7 | BM | | -1.24041 | .6038954 | -2.05 | 0.040 | -2.424088 | -.056731 |
| > 2 | BN | | -.4614751 | .5323872 | -0.87 | 0.386 | -1.504992 | .58204 |
| > 5 | BO | | -2.69374 | .5304681 | -5.08 | 0.000 | -3.733496 | -1.65398 |
| > 2 | BP | | 1.246189 | .4382663 | 2.84 | 0.004 | .3871555 | 2.10522 |
| > 5 | BQ | | 8.567347 | .3926937 | 21.82 | 0.000 | 7.797639 | 9.33705 |
| > 4 | BR | | 6.154903 | .2702764 | 22.77 | 0.000 | 5.625142 | 6.68466 |
| > 9 | BS | | 1.021047 | .2882249 | 3.54 | 0.000 | .4561056 | 1.58598 |
| > 3 | BT | | 5.544143 | .2964126 | 18.70 | 0.000 | 4.963153 | 6.12513 |
| > 7 | BU | | 8.460171 | .2371377 | 35.68 | 0.000 | 7.995364 | 8.92497 |
| | BV | | 5.191679 | .2179656 | 23.82 | 0.000 | 4.764451 | 5.61890 |

| | | | | | | | | |
|-----|-------|--|-----------|----------|-------|-------|-----------|----------|
| | RA | | | | | | | |
| | 2 | | .2350039 | .4031385 | 0.58 | 0.560 | -.5551765 | 1.02518 |
| > 4 | | | | | | | | |
| | 3 | | -2.422818 | .542941 | -4.46 | 0.000 | -3.487021 | -1.35861 |
| > 4 | | | | | | | | |
| | 4 | | 2.126187 | .4425382 | 4.80 | 0.000 | 1.258781 | 2.99359 |
| > 4 | | | | | | | | |
| | 5 | | 1.963702 | .3970206 | 4.95 | 0.000 | 1.185514 | 2.74189 |
| > 1 | | | | | | | | |
| | 6 | | 1.259571 | .8853361 | 1.42 | 0.155 | -.475751 | 2.99489 |
| > 3 | | | | | | | | |
| | 7 | | -3.822853 | .9452848 | -4.04 | 0.000 | -5.675679 | -1.97002 |
| > 7 | | | | | | | | |
| | 8 | | 3.142429 | .6387589 | 4.92 | 0.000 | 1.890416 | 4.39444 |
| > 2 | | | | | | | | |
| | 9 | | 1.54226 | .5406557 | 2.85 | 0.004 | .4825363 | 2.60198 |
| > 4 | | | | | | | | |
| | 10 | | 6.047391 | .3996475 | 15.13 | 0.000 | 5.264053 | 6.83072 |
| > 9 | | | | | | | | |
| | 11 | | 1.191331 | .3838059 | 3.10 | 0.002 | .4390436 | 1.94361 |
| > 8 | | | | | | | | |
| | 12 | | 3.40446 | .4246419 | 8.02 | 0.000 | 2.572132 | 4.23678 |
| > 9 | | | | | | | | |
| | 14 | | -.1791614 | .3988714 | -0.45 | 0.653 | -.9609779 | .602655 |
| > 1 | | | | | | | | |
| | 15 | | -.5405885 | .4338236 | -1.25 | 0.213 | -1.390914 | .309736 |
| > 9 | | | | | | | | |
| | 16 | | -15.26138 | 5.23301 | -2.92 | 0.004 | -25.51845 | -5.00430 |
| > 3 | | | | | | | | |
| | _cons | | 1.036744 | 7.203655 | 0.14 | 0.886 | -13.08294 | 15.1564 |

Appendix C6: Fixed effect model (LSDV) of spring wheat yield including all variables in Manitoba (2006-2018).

```

Linear regression
> 69      Number of obs   =    83,2
          F(57, 83211)    =    1380.
          Prob > F        =    0.00
          R-squared       =    0.48
          Root MSE       =    11.5
> 09

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva | |
|------|-------|-----------|------------------|--------|-------|--------------------|---------|
| > 1] | | | | | | | |
| > 31 | N | .111123 | .0025577 | 43.49 | 0.000 | .1062169 | .11624 |
| > 53 | P | .0124206 | .0041492 | 2.99 | 0.003 | .0042882 | .0205 |
| > 03 | K | .0679544 | .004054 | 16.76 | 0.000 | .0600085 | .07590 |
| > 45 | S | .0695174 | .0063404 | 10.96 | 0.000 | .0570903 | .08194 |
| > 57 | GS | -.0198012 | .0094977 | -2.08 | 0.037 | -.0384167 | -.00118 |
| > 32 | GS2 | -.0001691 | 8.11e-06 | -20.85 | 0.000 | -.000185 | -.00015 |
| > 05 | GDD | .0074968 | .0062111 | 1.21 | 0.227 | -.004677 | .01967 |
| > 43 | GDD2 | -.0000184 | 2.12e-06 | -8.71 | 0.000 | -.0000226 | -.00001 |
| > 16 | GSGDD | .0000615 | 5.14e-06 | 11.98 | 0.000 | .0000514 | .00007 |
| > 87 | SB | -1.430621 | .485845 | -2.94 | 0.003 | -2.382874 | -.47836 |
| > 86 | SC | -2.340834 | .4762002 | -4.92 | 0.000 | -3.274183 | -1.4074 |
| > 72 | SD | -4.132143 | .4755485 | -8.69 | 0.000 | -5.064215 | -3.2000 |
| > 68 | SE | -6.594312 | .4752795 | -13.87 | 0.000 | -7.525857 | -5.6627 |
| > 74 | SF | -7.991524 | .4808951 | -16.62 | 0.000 | -8.934075 | -7.0489 |
| > 94 | SG | -8.643844 | .5028844 | -17.19 | 0.000 | -9.629493 | -7.6581 |
| > 15 | SH | -11.65226 | .5602601 | -20.80 | 0.000 | -12.75037 | -10.554 |
| > 76 | SI | -13.94962 | .6693997 | -20.84 | 0.000 | -15.26164 | -12.63 |
| | SJ | -14.7737 | 1.212999 | -12.18 | 0.000 | -17.15117 | -12.396 |

| | | | | | | | |
|------|----------|-----------|----------|--------|-------|-----------|---------|
| > 16 | Barley | -3.099893 | .3701428 | -8.37 | 0.000 | -3.82537 | -2.3744 |
| > 26 | Corn | 1.2938 | .7893528 | 1.64 | 0.101 | -.2533252 | 2.8409 |
| > 88 | Oats | -3.690423 | .3732784 | -9.89 | 0.000 | -4.422046 | -2.95 |
| > 71 | Soybeans | 2.025298 | .1705989 | 11.87 | 0.000 | 1.690925 | 2.3596 |
| > 57 | SWheat | -5.119156 | .1907654 | -26.83 | 0.000 | -5.493054 | -4.7452 |
| > 24 | D2 | -2.563521 | .2463769 | -10.40 | 0.000 | -3.046418 | -2.0806 |
| > 03 | D3 | -4.913737 | .2467527 | -19.91 | 0.000 | -5.39737 | -4.4301 |
| > 44 | D4 | -7.486345 | .2492361 | -30.04 | 0.000 | -7.974846 | -6.9978 |
| > 93 | D5 | -9.789852 | .2661024 | -36.79 | 0.000 | -10.31141 | -9.2682 |
| > 48 | D6 | -13.31543 | .300487 | -44.31 | 0.000 | -13.90439 | -12.726 |
| > 97 | D7 | -17.35561 | .3448536 | -50.33 | 0.000 | -18.03152 | -16.67 |
| > 25 | D8 | -21.76465 | .4466384 | -48.73 | 0.000 | -22.64006 | -20.889 |
| > 53 | D9 | -22.8452 | .9013637 | -25.35 | 0.000 | -24.61186 | -21.078 |
| > 37 | AY | -15.14445 | .2158568 | -70.16 | 0.000 | -15.56752 | -14.721 |
| > 77 | AZ | -26.6573 | .3074164 | -86.71 | 0.000 | -27.25983 | -26.054 |
| > 23 | BA | -17.98695 | .3554702 | -50.60 | 0.000 | -18.68367 | -17.290 |
| > 35 | BB | -15.74529 | .4239522 | -37.14 | 0.000 | -16.57624 | -14.914 |
| > 35 | BC | -21.55831 | .318014 | -67.79 | 0.000 | -22.18161 | -20.9 |
| > 74 | BD | -21.52696 | .29807 | -72.22 | 0.000 | -22.11117 | -20.942 |
| > 35 | BE | -18.95837 | .2648066 | -71.59 | 0.000 | -19.47739 | -18.439 |
| > 36 | BF | .052057 | .2878463 | 0.18 | 0.856 | -.5121196 | .61623 |
| > 54 | BG | -10.72516 | .319192 | -33.60 | 0.000 | -11.35077 | -10.099 |
| > 56 | BH | -16.94847 | .2479145 | -68.36 | 0.000 | -17.43438 | -16.462 |
| > 53 | BI | -13.65064 | .2607681 | -52.35 | 0.000 | -14.16174 | -13.139 |
| | BJ | -2.512168 | .2979735 | -8.43 | 0.000 | -3.096194 | -1.9281 |

| | | | | | | | |
|------|-------|-----------|----------|-------|-------|-----------|---------|
| | RA | | | | | | |
| > 43 | 2 | 6.041645 | .2718878 | 22.22 | 0.000 | 5.508747 | 6.5745 |
| > 82 | 3 | .4330662 | .3109786 | 1.39 | 0.164 | -.1764495 | 1.0425 |
| > 77 | 4 | 2.395321 | .2904891 | 8.25 | 0.000 | 1.825965 | 2.9646 |
| > 52 | 5 | 8.531531 | .2781749 | 30.67 | 0.000 | 7.98631 | 9.0767 |
| > 83 | 6 | -3.548305 | .3713391 | -9.56 | 0.000 | -4.276127 | -2.8204 |
| > 57 | 7 | -2.083054 | .3422954 | -6.09 | 0.000 | -2.75395 | -1.4121 |
| > 39 | 8 | 2.861847 | .33663 | 8.50 | 0.000 | 2.202054 | 3.5216 |
| > 35 | 9 | -.0407487 | .3058594 | -0.13 | 0.894 | -.6402309 | .55873 |
| > 09 | 10 | 3.519473 | .4503165 | 7.82 | 0.000 | 2.636856 | 4.402 |
| > 41 | 11 | 8.577393 | .3060972 | 28.02 | 0.000 | 7.977444 | 9.1773 |
| > 03 | 12 | 10.36648 | .356404 | 29.09 | 0.000 | 9.667936 | 11.065 |
| > 26 | 14 | 3.40798 | .4705527 | 7.24 | 0.000 | 2.485701 | 4.330 |
| > 14 | 15 | -1.368213 | .4534567 | -3.02 | 0.003 | -2.256985 | -.47944 |
| > 32 | 16 | -10.19903 | 1.20975 | -8.43 | 0.000 | -12.57013 | -7.8279 |
| | _cons | 84.27545 | 4.897782 | 17.21 | 0.000 | 74.67583 | 93.875 |

Appendix D1: Frequencies of previous crops on current crops in crop rotations in Risk Area 10 of Manitoba (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|--------|------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 34 | 223 | 36 | 21 | 85 | 31 |
| | Canola | 126 | 157 | 187 | 264 | 448 | 766 |
| | G.Corn | 47 | 468 | 154 | 46 | 254 | 50 |
| | Oats | 18 | 300 | 57 | 23 | 188 | 43 |
| | Soybean | 68 | 327 | 309 | 205 | 383 | 275 |
| | S.Wheat | 39 | 730 | 107 | 56 | 225 | 10 |
| Total | | 332 | 2205 | 850 | 615 | 1583 | 1175 |

Appendix D2: Frequencies of previous crops on current crops in crop rotations in Risk Area 12 of Manitoba (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|--------|------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 21 | 196 | 70 | 10 | 74 | 14 |
| | Canola | 165 | 136 | 345 | 206 | 499 | 1265 |
| | G.Corn | 31 | 776 | 142 | 105 | 448 | 66 |
| | Oats | 7 | 235 | 53 | 7 | 250 | 31 |
| | Soybean | 63 | 576 | 598 | 219 | 255 | 722 |
| | S.Wheat | 41 | 969 | 130 | 52 | 851 | 29 |
| Total | | 328 | 2888 | 1338 | 599 | 2377 | 2127 |

Appendix D3: Frequencies of previous crops on current crops in crop rotations in Risk Area 1 of Manitoba (2006-2018).

| | | Crop Planted | | | | | |
|----------------|---------|--------------|--------|--------|------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crops | Barley | 72 | 362 | 12 | 55 | 31 | 69 |
| | Canola | 311 | 70 | 39 | 366 | 289 | 2273 |
| | G.Corn | 3 | 36 | 6 | 2 | 13 | 3 |
| | Oats | 52 | 487 | 4 | 59 | 80 | 126 |
| | Soybean | 15 | 221 | 13 | 81 | 102 | 224 |
| | S.Wheat | 74 | 2135 | 11 | 159 | 238 | 280 |
| Total | | 527 | 3311 | 85 | 722 | 753 | 2975 |

Appendix E1: Adjusted average yield of crops after previous crops based on coefficients of previous crops in Risk Area 10 (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 55.013 | 37.501 | 139.301 | 92.850 | 36.445 | 43.933 |
| | Canola | 64.520 | 33.980 | 121.133 | 96.772 | 36.259 | 49.630 |
| | G.Corn | 64.952 | 40.811 | 113.004 | 95.666 | 37.237 | 52.823 |
| | Oats | 55.426 | 38.080 | 121.001 | 78.921 | 36.656 | 46.703 |
| | Soybean | 72.738 | 38.327 | 118.134 | 99.172 | 33.189 | 50.633 |
| | S.Wheat | 59.397 | 39.071 | 127.499 | 96.173 | 36.540 | 47.469 |
| Overall | | 64.923 | 39.035 | 120.309 | 100.193 | 35.620 | 50.759 |

Appendix E2: Adjusted average yield of crops after previous crops based on coefficients of previous crops in Risk Area 12 (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|---------|---------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 70.365 | 39.841 | 117.882 | 89.853 | 35.303 | 51.834 |
| | Canola | 80.299 | 39.152 | 125.744 | 118.733 | 37.788 | 59.993 |
| | G.Corn | 80.188 | 43.862 | 125.899 | 117.883 | 38.848 | 57.450 |
| | Oats | 70.899 | 41.330 | 123.271 | 96.070 | 38.584 | 55.234 |
| | Soybean | 74.493 | 42.234 | 130.471 | 120.872 | 35.649 | 60.576 |
| | S.Wheat | 75.448 | 41.418 | 128.405 | 117.829 | 38.436 | 55.619 |
| Overall | | 76.718 | 43.064 | 129.593 | 122.560 | 38.130 | 60.718 |

Appendix E3: Adjusted average yield of crops after previous crops based on coefficients of previous crops in Risk Area 1 (2006-2018).

| | | Crop Planted | | | | | |
|---------------|---------|--------------|--------|---------|--------|---------|---------|
| | | Barley | Canola | G.Corn | Oats | Soybean | S.Wheat |
| Previous Crop | Barley | 49.819 | 31.497 | 106.834 | 87.729 | 30.751 | 39.493 |
| | Canola | 59.419 | 27.997 | 105.924 | 95.043 | 30.843 | 43.393 |
| | G.Corn | 58.343 | 35.607 | 99.495 | 79.950 | 32.609 | 45.066 |
| | Oats | 53.973 | 31.360 | 70.030 | 78.472 | 28.802 | 37.369 |
| | Soybean | 62.425 | 30.731 | 110.803 | 99.625 | 31.830 | 42.118 |
| | S.Wheat | 53.388 | 32.425 | 95.912 | 93.486 | 31.603 | 40.625 |
| Overall | | 56.856 | 32.442 | 102.958 | 91.283 | 30.957 | 42.486 |

Appendix F1: Fixed effect model (LSDV) of barley yield in Risk Area 10 of Manitoba (2006-2018).

```

Linear regression      Number of obs   =      3
> 31
                        F(31, 296)      =
> .
                        Prob > F        =
> .
                        R-squared       =      0.46
> 58
                        Root MSE     =      17.7
> 74

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva | |
|------|----------|-----------|------------------|-------|-------|--------------------|---------|
| > 1] | | | | | | | |
| > 56 | N | -.0013709 | .0648353 | -0.02 | 0.983 | -.1289674 | .12622 |
| > 07 | P | -.1444296 | .1136124 | -1.27 | 0.205 | -.36802 | .07916 |
| > 53 | K | .3393337 | .1106811 | 3.07 | 0.002 | .1215121 | .55715 |
| > 58 | S | -.1174266 | .257007 | -0.46 | 0.648 | -.6232191 | .38836 |
| > 18 | Barley | -9.507625 | 3.636061 | -2.61 | 0.009 | -16.66343 | -2.3518 |
| > 09 | Corn | .4314403 | 3.490717 | 0.12 | 0.902 | -6.438328 | 7.3012 |
| > 65 | Oats | -9.094616 | 5.519777 | -1.65 | 0.100 | -19.9576 | 1.7683 |
| > 63 | Soybeans | 8.217557 | 3.485284 | 2.36 | 0.019 | 1.358481 | 15.076 |
| > 77 | SWheat | -5.122851 | 3.686173 | -1.39 | 0.166 | -12.37728 | 2.1315 |
| > 18 | D1 | -5.806303 | 6.17645 | -0.94 | 0.348 | -17.96162 | 6.3490 |
| > 87 | D3 | -6.742289 | 3.410043 | -1.98 | 0.049 | -13.45329 | -.0312 |
| > 34 | D4 | -13.57959 | 3.649754 | -3.72 | 0.000 | -20.76234 | -6.3968 |
| > 12 | D5 | -16.589 | 4.36857 | -3.80 | 0.000 | -25.1864 | -7.9916 |
| > 42 | D6 | -27.10661 | 5.282589 | -5.13 | 0.000 | -37.5028 | -16.710 |
| > 25 | D7 | -31.766 | 6.089146 | -5.22 | 0.000 | -43.7495 | -19.78 |
| > 09 | D8 | -30.77558 | 6.510376 | -4.73 | 0.000 | -43.58807 | -17.963 |
| | D9 | -37.41399 | 6.585851 | -5.68 | 0.000 | -50.37502 | -24.452 |

| | | | | | | | |
|------|-------|-----------|----------|-------|-------|-----------|---------|
| > 67 | AV | 5.227699 | 5.715403 | 0.91 | 0.361 | -6.020276 | 16.475 |
| > 21 | AW | -5.048615 | 5.091708 | -0.99 | 0.322 | -15.06915 | 4.9719 |
| > 24 | AX | 3.921901 | 5.984389 | 0.66 | 0.513 | -7.855441 | 15.699 |
| > 36 | AY | 15.73168 | 7.492177 | 2.10 | 0.037 | .9869912 | 30.476 |
| > 15 | AZ | -18.92397 | 6.389171 | -2.96 | 0.003 | -31.49793 | -6.3500 |
| > 94 | BA | -7.047976 | 8.078673 | -0.87 | 0.384 | -22.94689 | 8.850 |
| > 01 | BB | -18.20122 | 6.850075 | -2.66 | 0.008 | -31.68224 | -4.7202 |
| > 02 | BC | 11.30613 | 5.619326 | 2.01 | 0.045 | .2472357 | 22.365 |
| > 86 | BD | -4.71076 | 6.455171 | -0.73 | 0.466 | -17.41461 | 7.9930 |
| > 69 | BE | -6.241826 | 5.04433 | -1.24 | 0.217 | -16.16912 | 3.6854 |
| > 55 | BF | 2.886983 | 5.66794 | 0.51 | 0.611 | -8.267583 | 14.041 |
| > 42 | BG | 18.16091 | 4.853381 | 3.74 | 0.000 | 8.609408 | 27.712 |
| | SZ | | | | | | |
| > 32 | 5 | 16.91115 | 6.957366 | 2.43 | 0.016 | 3.218984 | 30.603 |
| > 74 | 6 | -10.32836 | 7.726295 | -1.34 | 0.182 | -25.53379 | 4.8770 |
| > 36 | 7 | 17.95028 | 4.97715 | 3.61 | 0.000 | 8.155194 | 27.745 |
| > 26 | 8 | 15.21643 | 5.628106 | 2.70 | 0.007 | 4.140255 | 26.29 |
| > 78 | 9 | 13.94874 | 6.466957 | 2.16 | 0.032 | 1.221698 | 26.675 |
| | _cons | 60.42902 | 8.844141 | 6.83 | 0.000 | 43.02366 | 77.834 |

Appendix F2: Fixed effect model (LSDV) of canola yield in Risk Area 10 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 2,2 |
|----------|------------|-------|------------|---------------|---|------|
| > 05 | | | | | | |
| | | | | F(36, 2168) | = | 39. |
| > 48 | | | | | | |
| Model | 112580.723 | 36 | 3127.2423 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 171717.037 | 2,168 | 79.2052753 | R-squared | = | 0.39 |
| > 60 | | | | | | |
| | | | | Adj R-squared | = | 0.38 |
| > 60 | | | | | | |
| Total | 284297.76 | 2,204 | 128.991724 | Root MSE | = | 8.89 |
| > 97 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva | |
|---------|-----------|-----------|-------|-------|--------------------|---------|
| > 1] | | | | | | |
| > — | | | | | | |
| N | .0442451 | .0091297 | 4.85 | 0.000 | .0263413 | .06214 |
| > 89 | | | | | | |
| P | -.0811491 | .0207886 | -3.90 | 0.000 | -.1219167 | -.04038 |
| > 14 | | | | | | |
| K | .0246267 | .0114658 | 2.15 | 0.032 | .0021416 | .04711 |
| > 17 | | | | | | |
| S | .0366374 | .029133 | 1.26 | 0.209 | -.0204942 | .09376 |
| > 89 | | | | | | |
| Barley | -1.56975 | .6937153 | -2.26 | 0.024 | -2.930166 | -.2093 |
| > 33 | | | | | | |
| Canola | -5.09119 | .8120155 | -6.27 | 0.000 | -6.6836 | -3.498 |
| > 78 | | | | | | |
| Corn | 1.739928 | .5564408 | 3.13 | 0.002 | .6487153 | 2.8311 |
| > 41 | | | | | | |
| Oats | -.991511 | .6285626 | -1.58 | 0.115 | -2.224159 | .24113 |
| > 72 | | | | | | |
| Soybean | -.7441636 | .6467076 | -1.15 | 0.250 | -2.012395 | .52406 |
| > 81 | | | | | | |
| D2 | -5.098626 | 3.521043 | -1.45 | 0.148 | -12.0036 | 1.8063 |
| > 46 | | | | | | |
| D3 | -6.737511 | 3.470375 | -1.94 | 0.052 | -13.54312 | .06809 |
| > 89 | | | | | | |
| D4 | -7.076092 | 3.4607 | -2.04 | 0.041 | -13.86273 | -.28945 |
| > 52 | | | | | | |
| D5 | -7.853716 | 3.486381 | -2.25 | 0.024 | -14.69071 | -1.0167 |
| > 17 | | | | | | |
| D6 | -7.953459 | 3.51921 | -2.26 | 0.024 | -14.85484 | -1.0520 |
| > 82 | | | | | | |
| D7 | -11.45379 | 3.558915 | -3.22 | 0.001 | -18.43303 | -4.4745 |
| > 48 | | | | | | |
| D8 | -13.18146 | 3.572471 | -3.69 | 0.000 | -20.18729 | -6.1756 |
| > 38 | | | | | | |
| D9 | -12.77957 | 3.77079 | -3.39 | 0.001 | -20.17431 | -5.3848 |

| | | | | | | | | |
|------|-------|--|-----------|----------|--------|-------|-----------|---------|
| > 86 | AV | | -.2796401 | 1.161376 | -0.24 | 0.810 | -2.557166 | 1.9978 |
| > 62 | AW | | -12.34715 | 1.001258 | -12.33 | 0.000 | -14.31067 | -10.383 |
| > 31 | AX | | -7.174184 | .9964786 | -7.20 | 0.000 | -9.128337 | -5.2200 |
| > 94 | AY | | 5.320314 | 1.008629 | 5.27 | 0.000 | 3.342334 | 7.2982 |
| > 31 | AZ | | -14.89144 | .991873 | -15.01 | 0.000 | -16.83656 | -12.946 |
| > 87 | BA | | -3.418461 | 1.068746 | -3.20 | 0.001 | -5.514336 | -1.3225 |
| > 56 | BB | | -16.812 | 1.092491 | -15.39 | 0.000 | -18.95444 | -14.669 |
| > 84 | BC | | 1.142319 | .9454917 | 1.21 | 0.227 | -.711846 | 2.9964 |
| > 67 | BD | | -1.349574 | .9696707 | -1.39 | 0.164 | -3.251156 | .55200 |
| > 92 | BE | | -2.531473 | .9235219 | -2.74 | 0.006 | -4.342553 | -.7203 |
| > 51 | BF | | -6.209199 | .8828636 | -7.03 | 0.000 | -7.940546 | -4.4778 |
| > 69 | BG | | 3.46003 | .8657257 | 4.00 | 0.000 | 1.762291 | 5.1577 |
| | SZ | | | | | | | |
| > 39 | 4 | | -3.423241 | 5.648877 | -0.61 | 0.545 | -14.50102 | 7.6545 |
| > 77 | 5 | | 4.924141 | 4.566731 | 1.08 | 0.281 | -4.031487 | 13.879 |
| > 56 | 6 | | -.682204 | 3.565502 | -0.19 | 0.848 | -7.674364 | 6.3099 |
| > 46 | 7 | | -4.145404 | 3.426083 | -1.21 | 0.226 | -10.86415 | 2.5733 |
| > 25 | 8 | | -6.92377 | 3.438315 | -2.01 | 0.044 | -13.66651 | -.18103 |
| > 37 | 9 | | -10.0604 | 3.721539 | -2.70 | 0.007 | -17.35855 | -2.7622 |
| > 05 | 10 | | -9.935139 | 7.212198 | -1.38 | 0.168 | -24.07868 | 4.2084 |
| | _cons | | 52.95814 | 4.614784 | 11.48 | 0.000 | 43.90827 | 62.0 |

Appendix F3: Fixed effect model (LSDV) of grain corn yield in Risk Area 10 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 8 |
|----------|------------|-----|------------|---------------|---|------|
| > 50 | | | | | | |
| | | | | F(33, 816) | = | 12. |
| > 95 | | | | | | |
| Model | 299197.753 | 33 | 9066.59857 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 571096.062 | 816 | 699.872625 | R-squared | = | 0.34 |
| > 38 | | | | | | |
| | | | | Adj R-squared | = | 0.31 |
| > 73 | | | | | | |
| Total | 870293.815 | 849 | 1025.08105 | Root MSE | = | 26.4 |
| > 55 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|-------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | .0719314 | .0355697 | 2.02 | 0.043 | .0021124 .14175 |
| > 03 | | | | | |
| P | -.1738315 | .0710079 | -2.45 | 0.015 | -.3132112 -.03445 |
| > 18 | | | | | |
| K | -.0120521 | .0430079 | -0.28 | 0.779 | -.0964713 .07236 |
| > 71 | | | | | |
| S | .334977 | .1408853 | 2.38 | 0.018 | .0584367 .61151 |
| > 73 | | | | | |
| Barley | 18.16815 | 4.963533 | 3.66 | 0.000 | 8.42535 27.910 |
| > 95 | | | | | |
| Corn | -8.129331 | 3.113852 | -2.61 | 0.009 | -14.24144 -2.0172 |
| > 26 | | | | | |
| Oats | -.1318849 | 4.198065 | -0.03 | 0.975 | -8.372163 8.1083 |
| > 94 | | | | | |
| Soybeans | -2.998739 | 2.685125 | -1.12 | 0.264 | -8.269304 2.2718 |
| > 26 | | | | | |
| SWheat | 6.365638 | 3.564376 | 1.79 | 0.074 | -.6307868 13.362 |
| > 06 | | | | | |
| D2 | -5.429442 | 16.81227 | -0.32 | 0.747 | -38.42984 27.570 |
| > 95 | | | | | |
| D3 | -10.00845 | 16.42538 | -0.61 | 0.542 | -42.24942 22.232 |
| > 51 | | | | | |
| D4 | -15.5817 | 16.33671 | -0.95 | 0.340 | -47.64863 16.485 |
| > 23 | | | | | |
| D5 | -20.93167 | 16.44462 | -1.27 | 0.203 | -53.21042 11.347 |
| > 07 | | | | | |
| D6 | -31.64867 | 16.92933 | -1.87 | 0.062 | -64.87884 1.5814 |
| > 92 | | | | | |
| D7 | -12.48839 | 22.60531 | -0.55 | 0.581 | -56.85979 31.883 |
| > 02 | | | | | |
| D8 | 0 | (omitted) | | | |

| | | | | | | | |
|------|---------|-----------|----------|-------|-------|-----------|---------|
| > 11 | AU | -20.15312 | 5.799304 | -3.48 | 0.001 | -31.53643 | -8.7698 |
| > 83 | AV | -15.06775 | 5.188848 | -2.90 | 0.004 | -25.25281 | -4.8826 |
| > 64 | AW | -21.23213 | 5.06323 | -4.19 | 0.000 | -31.17062 | -11.293 |
| > 64 | AX | -45.16601 | 6.437682 | -7.02 | 0.000 | -57.80237 | -32.529 |
| > 07 | AY | -18.23002 | 5.861917 | -3.11 | 0.002 | -29.73623 | -6.7238 |
| > 87 | AZ | -20.26945 | 6.062111 | -3.34 | 0.001 | -32.16862 | -8.3702 |
| > 65 | BA | -14.39024 | 4.420033 | -3.26 | 0.001 | -23.06621 | -5.7142 |
| > 27 | BB | 11.26213 | 4.073689 | 2.76 | 0.006 | 3.265982 | 19.258 |
| > 66 | BC | -19.26104 | 4.633702 | -4.16 | 0.000 | -28.35642 | -10.165 |
| > 29 | BD | 4.409294 | 4.141372 | 1.06 | 0.287 | -3.719703 | 12.538 |
| > 89 | BE | .2732602 | 3.511547 | 0.08 | 0.938 | -6.619469 | 7.1659 |
| > 48 | BF | 13.43233 | 3.372172 | 3.98 | 0.000 | 6.813177 | 20.051 |
| > 41 | SZ 4 | -20.16471 | 37.95 | -0.53 | 0.595 | -94.65582 | 54.326 |
| > 31 | 5 | -88.90899 | 38.37364 | -2.32 | 0.021 | -164.2317 | -13.586 |
| > 19 | 6 | 2.920624 | 27.28934 | 0.11 | 0.915 | -50.64494 | 56.486 |
| > 75 | 7 | -.0579445 | 26.79472 | -0.00 | 0.998 | -52.65264 | 52.536 |
| > 94 | 8 | -9.377712 | 26.85685 | -0.35 | 0.727 | -62.09436 | 43.338 |
| > 91 | 9 | -9.726204 | 27.72164 | -0.35 | 0.726 | -64.14032 | 44.687 |
| | _cons | 137.7178 | 31.65205 | 4.35 | 0.000 | 75.58878 | 199.84 |

Appendix F4: Fixed effect model (LSDV) of oats yield in Risk Area 10 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 6 |
|--------|----------|------------|-----|---------------|-----------|--------|
| > 15 | | | | F(34, 580) | = | 15. |
| > 00 | | | | Prob > F | = | 0.00 |
| > 00 | Model | 232159.084 | 34 | 6828.20834 | | |
| > 78 | Residual | 264090.548 | 580 | 455.328531 | R-squared | = 0.46 |
| > 66 | | | | Adj R-squared | = | 0.43 |
| > 38 | Total | 496249.632 | 614 | 808.224156 | Root MSE | = 21.3 |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva | |
|-------|----------|-----------|-----------|-------|--------------------|-------------------|
| > 1] | | | | | | |
| > — | | | | | | |
| > 49 | N | .3911968 | .0506135 | 7.73 | 0.000 | .2917886 .49060 |
| > 38 | P | -.1898319 | .0957089 | -1.98 | 0.048 | -.3778101 -.00185 |
| > 61 | K | -.0483187 | .0595576 | -0.81 | 0.418 | -.1652935 .06865 |
| > 38 | S | .2070405 | .1787384 | 1.16 | 0.247 | -.1440128 .55809 |
| > 89 | Barley | -3.919666 | 5.016721 | -0.78 | 0.435 | -13.77282 5.9334 |
| > 36 | Corn | -1.108613 | 3.571194 | -0.31 | 0.756 | -8.122661 5.9054 |
| > 73 | Oats | -17.85031 | 4.869161 | -3.67 | 0.000 | -27.41365 -8.2869 |
| > 65 | Soybeans | 2.398415 | 2.377903 | 1.01 | 0.314 | -2.271934 7.0687 |
| > 27 | SWheat | -.5998574 | 3.455737 | -0.17 | 0.862 | -7.387141 6.1874 |
| | D1 | 0 | (omitted) | | | |
| > 68 | D3 | -1.185127 | 3.052904 | -0.39 | 0.698 | -7.181222 4.8109 |
| > 46 | D4 | -11.40955 | 3.284622 | -3.47 | 0.001 | -17.86075 -4.9583 |
| > 37 | D5 | -19.40557 | 3.959243 | -4.90 | 0.000 | -27.18177 -11.629 |
| > 36 | D6 | -21.79937 | 5.019197 | -4.34 | 0.000 | -31.65739 -11.941 |
| > 89 | D7 | -36.26603 | 7.980982 | -4.54 | 0.000 | -51.94118 -20.590 |
| > 15 | D8 | -36.86758 | 5.950637 | -6.20 | 0.000 | -48.555 -25.180 |
| | D9 | -51.14271 | 9.006478 | -5.68 | 0.000 | -68.832 -33.453 |

| | | | | | | | |
|------|-------|-----------|----------|-------|-------|-----------|---------|
| > 91 | AV | 5.658248 | 4.653955 | 1.22 | 0.225 | -3.482411 | 14.798 |
| > 44 | AW | -9.448999 | 4.140935 | -2.28 | 0.023 | -17.58205 | -1.3159 |
| > 33 | AX | .8079165 | 4.256441 | 0.19 | 0.850 | -7.552 | 9.1678 |
| > 22 | AY | 33.98665 | 5.00675 | 6.79 | 0.000 | 24.15308 | 43.820 |
| > 46 | AZ | -24.26633 | 4.962102 | -4.89 | 0.000 | -34.01221 | -14.520 |
| > 58 | BA | 6.641489 | 6.270724 | 1.06 | 0.290 | -5.674606 | 18.957 |
| > 24 | BB | -35.61044 | 5.96478 | -5.97 | 0.000 | -47.32564 | -23.895 |
| > 54 | BC | 20.96112 | 5.477637 | 3.83 | 0.000 | 10.2027 | 31.719 |
| > 05 | BD | 1.62298 | 5.024033 | 0.32 | 0.747 | -8.244535 | 11.49 |
| > 63 | BE | -6.416242 | 4.081288 | -1.57 | 0.116 | -14.43215 | 1.5996 |
| > 19 | BF | -2.240469 | 4.771176 | -0.47 | 0.639 | -11.61136 | 7.1304 |
| > 77 | BG | 24.62907 | 4.144832 | 5.94 | 0.000 | 16.48836 | 32.769 |
| | SZ | | | | | | |
| > 24 | 4 | .9435918 | 26.93888 | 0.04 | 0.972 | -51.96606 | 53.853 |
| > 46 | 5 | -25.53297 | 26.80487 | -0.95 | 0.341 | -78.17941 | 27.113 |
| > 77 | 6 | -10.09476 | 16.49258 | -0.61 | 0.541 | -42.48722 | 22.29 |
| > 25 | 7 | -20.02137 | 15.6597 | -1.28 | 0.202 | -50.77799 | 10.735 |
| > 49 | 8 | -26.57394 | 15.69461 | -1.69 | 0.091 | -57.39913 | 4.2512 |
| > 94 | 9 | -30.4773 | 16.95389 | -1.80 | 0.073 | -63.77579 | 2.8211 |
| | _cons | 110.6916 | 16.11531 | 6.87 | 0.000 | 79.04014 | 142.34 |

Appendix F5: Fixed effect model (LSDV) of soybeans yield in Risk Area 10 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 1,5 |
|----------|------------|-------|------------|---------------|---|------|
| > 83 | | | | | | |
| | | | | F(33, 1549) | = | 18. |
| > 07 | | | | | | |
| Model | 32826.931 | 33 | 994.755484 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 85255.2656 | 1,549 | 55.0389061 | R-squared | = | 0.27 |
| > 80 | | | | | | |
| | | | | Adj R-squared | = | 0.26 |
| > 26 | | | | | | |
| Total | 118082.197 | 1,582 | 74.6410851 | Root MSE | = | 7.41 |
| > 88 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|-------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | -.0241984 | .0207254 | -1.17 | 0.243 | -.0648511 .01645 |
| > 44 | | | | | |
| P | -.0015448 | .0169108 | -0.09 | 0.927 | -.0347152 .03162 |
| > 57 | | | | | |
| K | .0345852 | .0140839 | 2.46 | 0.014 | .0069596 .06221 |
| > 08 | | | | | |
| S | .0327325 | .0347005 | 0.94 | 0.346 | -.0353324 .10079 |
| > 75 | | | | | |
| Barley | .1867022 | .9018653 | 0.21 | 0.836 | -1.582303 1.9557 |
| > 08 | | | | | |
| Corn | .9788678 | .6079063 | 1.61 | 0.108 | -.2135385 2.1712 |
| > 74 | | | | | |
| Oats | .3977386 | .6708802 | 0.59 | 0.553 | -.9181906 1.7136 |
| > 68 | | | | | |
| Soybeans | -3.06975 | .5305101 | -5.79 | 0.000 | -4.110344 -2.0291 |
| > 56 | | | | | |
| SWheat | .2815193 | .6193021 | 0.45 | 0.649 | -.9332397 1.4962 |
| > 78 | | | | | |
| D1 | -5.01453 | 7.538619 | -0.67 | 0.506 | -19.80151 9.7724 |
| > 45 | | | | | |
| D2 | 0 | (omitted) | | | |
| D4 | -2.300182 | 1.051654 | -2.19 | 0.029 | -4.362998 -.23736 |
| > 58 | | | | | |
| D5 | -3.420601 | 1.038366 | -3.29 | 0.001 | -5.457353 -1.383 |
| > 85 | | | | | |
| D6 | -4.667864 | 1.107594 | -4.21 | 0.000 | -6.840405 -2.4953 |
| > 23 | | | | | |
| D7 | -3.690423 | 1.627126 | -2.27 | 0.023 | -6.882025 -.49881 |
| > 99 | | | | | |
| D8 | 0 | (omitted) | | | |

| | | | | | | | |
|------|---------|-----------|----------|-------|-------|-----------|---------|
| > 25 | AU | -4.555987 | 1.393406 | -3.27 | 0.001 | -7.289148 | -1.8228 |
| > 33 | AV | 3.528321 | 2.133989 | 1.65 | 0.098 | -.657492 | 7.7141 |
| > 51 | AW | -2.063573 | 1.698256 | -1.22 | 0.225 | -5.394696 | 1.2675 |
| > 67 | AX | 2.878643 | 1.451914 | 1.98 | 0.048 | .0307188 | 5.7265 |
| > 96 | AY | 1.319416 | 1.26173 | 1.05 | 0.296 | -1.155464 | 3.7942 |
| > 47 | AZ | -3.600766 | 1.652014 | -2.18 | 0.029 | -6.841186 | -.3603 |
| > 19 | BA | 2.852144 | .967667 | 2.95 | 0.003 | .9540681 | 4.7502 |
| > 42 | BB | 6.952778 | .8619258 | 8.07 | 0.000 | 5.262113 | 8.6434 |
| > 73 | BC | 1.029582 | .8079498 | 1.27 | 0.203 | -.5552088 | 2.6143 |
| > 84 | BD | 6.445379 | .7254183 | 8.89 | 0.000 | 5.022473 | 7.8682 |
| > 41 | BE | 9.083106 | .6581693 | 13.80 | 0.000 | 7.792109 | 10.37 |
| > 63 | BF | 5.040745 | .5908843 | 8.53 | 0.000 | 3.881728 | 6.1997 |
| > 29 | SZ 4 | -7.199436 | 6.856839 | -1.05 | 0.294 | -20.6491 | 6.2502 |
| > 01 | 5 | 4.863875 | 5.72529 | 0.85 | 0.396 | -6.366263 | 16.094 |
| > 73 | 6 | -.1908467 | 4.536036 | -0.04 | 0.966 | -9.088267 | 8.7065 |
| > 74 | 7 | -3.391353 | 4.323294 | -0.78 | 0.433 | -11.87148 | 5.0887 |
| > 92 | 8 | -6.880375 | 4.332593 | -1.59 | 0.112 | -15.37874 | 1.6179 |
| > 01 | 9 | -6.873013 | 4.679189 | -1.47 | 0.142 | -16.05123 | 2.3052 |
| > 02 | 10 | -13.19077 | 5.106237 | -2.58 | 0.010 | -23.20663 | -3.1749 |
| | _cons | 39.36372 | 4.459335 | 8.83 | 0.000 | 30.61675 | 48.110 |

Appendix F6: Fixed effect model (LSDV) of spring wheat yield in Risk Area 10 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 1,1 |
|----------|------------|-------|------------|---------------|---|------|
| > 75 | | | | | | |
| | | | | F(35, 1139) | = | 25. |
| > 27 | | | | | | |
| Model | 111638.784 | 35 | 3189.67956 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 143758.962 | 1,139 | 126.215068 | R-squared | = | 0.43 |
| > 71 | | | | | | |
| | | | | Adj R-squared | = | 0.41 |
| > 98 | | | | | | |
| Total | 255397.747 | 1,174 | 217.544929 | Root MSE | = | 11.2 |
| > 35 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva | |
|----------|-----------|-----------|-------|-------|--------------------|---------|
| > 1] | | | | | | |
| > — | | | | | | |
| N | .0704813 | .0178119 | 3.96 | 0.000 | .0355336 | .10542 |
| > 91 | | | | | | |
| P | -.0811064 | .0423333 | -1.92 | 0.056 | -.1641663 | .00195 |
| > 36 | | | | | | |
| K | -.0327383 | .0246457 | -1.33 | 0.184 | -.0810943 | .01561 |
| > 78 | | | | | | |
| S | .1914782 | .062803 | 3.05 | 0.002 | .0682557 | .31470 |
| > 07 | | | | | | |
| Barley | -5.696612 | 2.183753 | -2.61 | 0.009 | -9.981242 | -1.4119 |
| > 81 | | | | | | |
| Corn | 3.193647 | 1.680221 | 1.90 | 0.058 | -.1030281 | 6.4903 |
| > 23 | | | | | | |
| Oats | -2.926424 | 1.809654 | -1.62 | 0.106 | -6.477054 | .62420 |
| > 58 | | | | | | |
| Soybeans | 1.002864 | .8888083 | 1.13 | 0.259 | -.7410211 | 2.746 |
| > 75 | | | | | | |
| SWheat | -2.160906 | 3.676375 | -0.59 | 0.557 | -9.374134 | 5.0523 |
| > 22 | | | | | | |
| D2 | -5.705721 | 1.524356 | -3.74 | 0.000 | -8.696583 | -2.714 |
| > 86 | | | | | | |
| D3 | -8.246692 | 1.670672 | -4.94 | 0.000 | -11.52463 | -4.9687 |
| > 51 | | | | | | |
| D4 | -9.038158 | 1.847194 | -4.89 | 0.000 | -12.66244 | -5.4138 |
| > 73 | | | | | | |
| D5 | -10.21815 | 2.096629 | -4.87 | 0.000 | -14.33184 | -6.1044 |
| > 62 | | | | | | |
| D6 | -17.36047 | 2.383741 | -7.28 | 0.000 | -22.03748 | -12.683 |
| > 45 | | | | | | |
| D7 | -20.71662 | 3.11967 | -6.64 | 0.000 | -26.83757 | -14.595 |
| > 68 | | | | | | |
| D8 | -24.8994 | 3.139282 | -7.93 | 0.000 | -31.05883 | -18.739 |
| > 98 | | | | | | |
| D9 | -26.77978 | 4.188806 | -6.39 | 0.000 | -34.99842 | -18.561 |

| | | | | | | | |
|------|---------|-----------|----------|--------|-------|-----------|---------|
| > 35 | AU | -4.917233 | 1.614689 | -3.05 | 0.002 | -8.085331 | -1.7491 |
| > 16 | AV | -9.317171 | 1.902223 | -4.90 | 0.000 | -13.04943 | -5.5849 |
| > 73 | AW | -5.094109 | 1.614606 | -3.16 | 0.002 | -8.262044 | -1.9261 |
| > 92 | AX | 4.505534 | 1.755337 | 2.57 | 0.010 | 1.061476 | 7.9495 |
| > 74 | AY | -20.52434 | 1.742366 | -11.78 | 0.000 | -23.94295 | -17.105 |
| > 35 | AZ | -14.62048 | 2.444459 | -5.98 | 0.000 | -19.41663 | -9.8243 |
| > 23 | BA | -16.13754 | 1.844149 | -8.75 | 0.000 | -19.75585 | -12.519 |
| > 37 | BB | 2.653913 | 1.728154 | 1.54 | 0.125 | -.7368097 | 6.0446 |
| > 17 | BC | -1.231047 | 1.825879 | -0.67 | 0.500 | -4.81351 | 2.3514 |
| > 42 | BD | -5.047951 | 1.447471 | -3.49 | 0.001 | -7.88796 | -2.2079 |
| > 51 | BE | -4.613112 | 1.447396 | -3.19 | 0.001 | -7.452973 | -1.7732 |
| > 59 | BF | 13.59691 | 1.496234 | 9.09 | 0.000 | 10.66123 | 16.532 |
| > 77 | SZ 4 | 11.98625 | 7.858886 | 1.53 | 0.127 | -3.433269 | 27.405 |
| > 97 | 5 | 7.914896 | 5.947393 | 1.33 | 0.184 | -3.75418 | 19.583 |
| > 39 | 6 | 2.703894 | 4.566656 | 0.59 | 0.554 | -6.256108 | 11.66 |
| > 51 | 7 | -2.844283 | 4.326056 | -0.66 | 0.511 | -11.33222 | 5.6436 |
| > 22 | 8 | -8.297115 | 4.367912 | -1.90 | 0.058 | -16.86717 | .27294 |
| > 96 | 9 | -7.74165 | 5.222319 | -1.48 | 0.139 | -17.9881 | 2.5047 |
| | _cons | 62.73878 | 4.957661 | 12.65 | 0.000 | 53.01161 | 72.465 |

Appendix G1: Fixed effect model (LSDV) of barley yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 3 |
|----------|------------|-----|------------|---------------|---|------|
| > 28 | | | | | | |
| | | | | F(37, 290) | = | 7. |
| > 90 | | | | | | |
| Model | 94953.709 | 37 | 2566.31646 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 94259.8888 | 290 | 325.034099 | R-squared | = | 0.50 |
| > 18 | | | | | | |
| | | | | Adj R-squared | = | 0.43 |
| > 83 | | | | | | |
| Total | 189213.598 | 327 | 578.634856 | Root MSE | = | 18.0 |
| > 29 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva | |
|----------|-----------|-----------|-------|-------|--------------------|---------|
| > 1] | | | | | | |
| > — | | | | | | |
| N | .2183714 | .0533198 | 4.10 | 0.000 | .1134286 | .32331 |
| > 42 | | | | | | |
| P | .1324728 | .1044109 | 1.27 | 0.206 | -.0730264 | .33797 |
| > 21 | | | | | | |
| K | -.1791016 | .1424196 | -1.26 | 0.210 | -.4594087 | .10120 |
| > 55 | | | | | | |
| S | -.0034847 | .2451508 | -0.01 | 0.989 | -.4859852 | .47901 |
| > 58 | | | | | | |
| Barley | -9.934477 | 4.534981 | -2.19 | 0.029 | -18.86013 | -1.0088 |
| > 28 | | | | | | |
| Corn | -.1109362 | 3.922188 | -0.03 | 0.977 | -7.8305 | 7.6086 |
| > 27 | | | | | | |
| Oats | -9.400458 | 7.569295 | -1.24 | 0.215 | -24.29818 | 5.4972 |
| > 61 | | | | | | |
| Soybeans | -5.806278 | 2.971488 | -1.95 | 0.052 | -11.65469 | .04213 |
| > 89 | | | | | | |
| SWheat | -4.851076 | 3.51018 | -1.38 | 0.168 | -11.75973 | 2.0575 |
| > 82 | | | | | | |
| D2 | -5.629967 | 3.886637 | -1.45 | 0.149 | -13.27956 | 2.0196 |
| > 26 | | | | | | |
| D3 | -8.342456 | 4.662982 | -1.79 | 0.075 | -17.52003 | .83512 |
| > 15 | | | | | | |
| D4 | -7.339438 | 5.735972 | -1.28 | 0.202 | -18.62885 | 3.9499 |
| > 75 | | | | | | |
| D5 | -11.03647 | 6.49796 | -1.70 | 0.090 | -23.82561 | 1.7526 |
| > 74 | | | | | | |
| D6 | -20.80484 | 7.33563 | -2.84 | 0.005 | -35.24267 | -6.3670 |
| > 18 | | | | | | |
| D7 | -19.28229 | 7.628812 | -2.53 | 0.012 | -34.29715 | -4.2674 |
| > 27 | | | | | | |
| D8 | -25.42393 | 7.304128 | -3.48 | 0.001 | -39.79975 | -11.04 |
| > 81 | | | | | | |
| D9 | -38.93462 | 8.532635 | -4.56 | 0.000 | -55.72837 | -22.140 |

| | | | | | | | |
|------|---------|-----------|----------|-------|-------|-----------|---------|
| > 78 | AU | -9.545786 | 7.263299 | -1.31 | 0.190 | -23.84125 | 4.7496 |
| > 53 | AV | -23.32009 | 6.597248 | -3.53 | 0.000 | -36.30465 | -10.335 |
| > 26 | AW | 2.01374 | 6.425496 | 0.31 | 0.754 | -10.63278 | 14.660 |
| > 89 | AX | 4.299261 | 7.473223 | 0.58 | 0.566 | -10.40937 | 19.007 |
| > 47 | AY | -40.05328 | 7.446897 | -5.38 | 0.000 | -54.7101 | -25.396 |
| > 76 | AZ | -34.50733 | 7.653055 | -4.51 | 0.000 | -49.5699 | -19.444 |
| > 99 | BA | -19.05707 | 6.7227 | -2.83 | 0.005 | -32.28854 | -5.8255 |
| > 31 | BB | 10.61314 | 7.407445 | 1.43 | 0.153 | -3.96603 | 25.192 |
| > 96 | BC | .6993904 | 7.855778 | 0.09 | 0.929 | -14.76218 | 16.160 |
| > 39 | BD | -21.0269 | 6.827004 | -3.08 | 0.002 | -34.46365 | -7.5901 |
| > 57 | BE | -15.13006 | 6.6526 | -2.27 | 0.024 | -28.22356 | -2.0365 |
| > 26 | BF | 4.916472 | 7.208592 | 0.68 | 0.496 | -9.271319 | 19.104 |
| > 72 | SZ 3 | -14.59946 | 9.480458 | -1.54 | 0.125 | -33.25868 | 4.0597 |
| > 76 | 4 | -13.91732 | 9.148156 | -1.52 | 0.129 | -31.92252 | 4.0878 |
| > 37 | 5 | -13.75042 | 9.146812 | -1.50 | 0.134 | -31.75297 | 4.2521 |
| > 13 | 6 | -15.39724 | 11.18946 | -1.38 | 0.170 | -37.4201 | 6.6256 |
| > 09 | 7 | -19.26082 | 11.21811 | -1.72 | 0.087 | -41.34006 | 2.8184 |
| > 98 | 8 | -19.53275 | 10.85585 | -1.80 | 0.073 | -40.89901 | 1.8334 |
| > 57 | 9 | -26.35881 | 9.981436 | -2.64 | 0.009 | -46.00405 | -6.713 |
| > 71 | 10 | -26.4344 | 10.84309 | -2.44 | 0.015 | -47.77552 | -5.0932 |
| | _cons | 95.1488 | 10.94689 | 8.69 | 0.000 | 73.60338 | 116.69 |

Appendix G2: Fixed effect model (LSDV) of canola yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 2,8 |
|----------|------------|-------|------------|---------------|---|------|
| > 88 | | | | | | |
| | | | | F(37, 2850) | = | 65. |
| > 35 | | | | | | |
| Model | 161969.109 | 37 | 4377.5435 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 190896.011 | 2,850 | 66.9810564 | R-squared | = | 0.45 |
| > 90 | | | | | | |
| | | | | Adj R-squared | = | 0.45 |
| > 20 | | | | | | |
| Total | 352865.12 | 2,887 | 122.225535 | Root MSE | = | 8.18 |
| > 42 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|---------|-----------|-----------|-------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | .0227277 | .007157 | 3.18 | 0.002 | .0086943 .03676 |
| > 11 | | | | | |
| P | .0327247 | .014466 | 2.26 | 0.024 | .0043598 .06108 |
| > 96 | | | | | |
| K | .0613005 | .0171691 | 3.57 | 0.000 | .0276353 .09496 |
| > 57 | | | | | |
| S | .0186854 | .0225516 | 0.83 | 0.407 | -.0255337 .06290 |
| > 44 | | | | | |
| Barley | -1.577218 | .6711552 | -2.35 | 0.019 | -2.893217 -.26121 |
| > 92 | | | | | |
| Canola | -2.265796 | .8432874 | -2.69 | 0.007 | -3.919312 -.61228 |
| > 11 | | | | | |
| Corn | 2.44423 | .4095067 | 5.97 | 0.000 | 1.64127 3.2471 |
| > 89 | | | | | |
| Oats | -.0877929 | .603561 | -0.15 | 0.884 | -1.271253 1.0956 |
| > 67 | | | | | |
| Soybean | .8157206 | .4581144 | 1.78 | 0.075 | -.0825485 1.713 |
| > 99 | | | | | |
| D1 | -1.683711 | 1.088751 | -1.55 | 0.122 | -3.818531 .45110 |
| > 84 | | | | | |
| D3 | -1.877447 | .6003043 | -3.13 | 0.002 | -3.054522 -.70037 |
| > 21 | | | | | |
| D4 | -2.170313 | .6443836 | -3.37 | 0.001 | -3.433818 -.90680 |
| > 81 | | | | | |
| D5 | -1.449975 | .6983962 | -2.08 | 0.038 | -2.819388 -.08056 |
| > 19 | | | | | |
| D6 | -5.10135 | .890172 | -5.73 | 0.000 | -6.846796 -3.3559 |
| > 03 | | | | | |
| D7 | -6.011782 | .8427143 | -7.13 | 0.000 | -7.664174 -4.3593 |
| > 91 | | | | | |
| D8 | -8.29203 | .9427376 | -8.80 | 0.000 | -10.14055 -6.4435 |
| > 13 | | | | | |
| D9 | -10.56482 | 1.906022 | -5.54 | 0.000 | -14.30214 -6.8274 |

| | | | | | | | |
|------|---------|-----------|----------|--------|-------|-----------|---------|
| > 76 | AU | -10.16248 | 1.022901 | -9.93 | 0.000 | -12.16818 | -8.1567 |
| > 15 | AV | -13.54355 | .8600626 | -15.75 | 0.000 | -15.22996 | -11.857 |
| > 69 | AW | -3.77196 | .8007417 | -4.71 | 0.000 | -5.342052 | -2.2018 |
| > 16 | AX | -3.921883 | .8533094 | -4.60 | 0.000 | -5.595049 | -2.2487 |
| > 62 | AY | -10.08139 | .8152438 | -12.37 | 0.000 | -11.67992 | -8.4828 |
| > 16 | AZ | -13.89292 | .7776244 | -17.87 | 0.000 | -15.41769 | -12.368 |
| > 03 | BA | -19.64005 | .7899935 | -24.86 | 0.000 | -21.18906 | -18.091 |
| > 75 | BB | -.5934863 | .763819 | -0.78 | 0.437 | -2.09118 | .90420 |
| > 99 | BC | -1.292821 | .7869355 | -1.64 | 0.101 | -2.835841 | .25019 |
| > 32 | BD | -6.82223 | .7299062 | -9.35 | 0.000 | -8.253427 | -5.3910 |
| > 43 | BE | -10.45597 | .7317595 | -14.29 | 0.000 | -11.89081 | -9.0211 |
| > 88 | BF | 1.860925 | .7308065 | 2.55 | 0.011 | .4279625 | 3.2938 |
| > 07 | SZ 3 | -2.035935 | .6296648 | -3.23 | 0.001 | -3.27058 | -.80129 |
| > 75 | 4 | -1.873863 | .6417469 | -2.92 | 0.004 | -3.132198 | -.61552 |
| > 67 | 5 | -3.317225 | .7015304 | -4.73 | 0.000 | -4.692784 | -1.9416 |
| > 26 | 6 | -1.228156 | .8642094 | -1.42 | 0.155 | -2.922695 | .46638 |
| > 83 | 7 | -3.96944 | 1.804119 | -2.20 | 0.028 | -7.506951 | -.43192 |
| > 59 | 8 | -12.3314 | 2.00237 | -6.16 | 0.000 | -16.25764 | -8.4051 |
| > 17 | 9 | -8.50722 | 1.193955 | -7.13 | 0.000 | -10.84832 | -6.1661 |
| > 46 | 10 | -6.184125 | 1.349033 | -4.58 | 0.000 | -8.829304 | -3.5389 |
| | _cons | 50.09272 | 1.245653 | 40.21 | 0.000 | 47.65025 | 52.535 |

Appendix G3: Fixed effect model (LSDV) of grain corn yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 1,3 |
|----------|------------|-------|------------|---------------|---|------|
| > 38 | | | | | | |
| | | | | F(33, 1304) | = | 54. |
| > 64 | | | | | | |
| Model | 923015.764 | 33 | 27970.1747 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 667490.666 | 1,304 | 511.879345 | R-squared | = | 0.58 |
| > 03 | | | | | | |
| | | | | Adj R-squared | = | 0.56 |
| > 97 | | | | | | |
| Total | 1590506.43 | 1,337 | 1189.6084 | Root MSE | = | 22.6 |
| > 25 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|-------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | -.0120498 | .0251648 | -0.48 | 0.632 | -.0614176 .03731 |
| > 81 | | | | | |
| P | .1118956 | .0504919 | 2.22 | 0.027 | .0128412 .21094 |
| > 99 | | | | | |
| K | .1097921 | .0528223 | 2.08 | 0.038 | .0061661 .21341 |
| > 81 | | | | | |
| S | -.1062683 | .1033258 | -1.03 | 0.304 | -.3089714 .09643 |
| > 47 | | | | | |
| Barley | -7.861971 | 3.135992 | -2.51 | 0.012 | -14.01411 -1.7098 |
| > 29 | | | | | |
| Corn | .1541858 | 2.446537 | 0.06 | 0.950 | -4.645394 4.9537 |
| > 66 | | | | | |
| Oats | -2.473888 | 3.425932 | -0.72 | 0.470 | -9.194829 4.2470 |
| > 53 | | | | | |
| Soybeans | 4.726985 | 1.602565 | 2.95 | 0.003 | 1.583098 7.8708 |
| > 72 | | | | | |
| SWheat | 2.66029 | 2.487078 | 1.07 | 0.285 | -2.218823 7.5394 |
| > 02 | | | | | |
| D1 | -13.46099 | 5.194712 | -2.59 | 0.010 | -23.6519 -3.2700 |
| > 82 | | | | | |
| D3 | -4.567474 | 2.199885 | -2.08 | 0.038 | -8.883176 -.25177 |
| > 26 | | | | | |
| D4 | -6.22288 | 2.721575 | -2.29 | 0.022 | -11.56203 -.88373 |
| > 56 | | | | | |
| D5 | -6.703058 | 3.302554 | -2.03 | 0.043 | -13.18196 -.22415 |
| > 77 | | | | | |
| D6 | -10.53195 | 4.874393 | -2.16 | 0.031 | -20.09446 -.96944 |
| > 22 | | | | | |
| D7 | -32.84237 | 8.387444 | -3.92 | 0.000 | -49.29673 -16.388 |
| > 01 | | | | | |
| D8 | -24.68996 | 23.16306 | -1.07 | 0.287 | -70.13089 20.750 |

| | | | | | | | | |
|------|-------|--|-----------|----------|--------|-------|-----------|---------|
| > 65 | AT | | -5.260377 | 4.434095 | -1.19 | 0.236 | -13.95912 | 3.4383 |
| > 03 | AU | | 5.021417 | 3.684204 | 1.36 | 0.173 | -2.206198 | 12.249 |
| > 73 | AV | | 4.149143 | 3.444902 | 1.20 | 0.229 | -2.609014 | 10.90 |
| > 82 | AW | | -82.31844 | 3.972213 | -20.72 | 0.000 | -90.11107 | -74.525 |
| > 71 | AX | | 2.39756 | 3.539028 | 0.68 | 0.498 | -4.54525 | 9.3403 |
| > 05 | AY | | -11.48656 | 3.923242 | -2.93 | 0.003 | -19.18312 | -3.7900 |
| > 71 | AZ | | 10.19785 | 2.758133 | 3.70 | 0.000 | 4.786986 | 15.608 |
| > 39 | BA | | 24.72933 | 3.188202 | 7.76 | 0.000 | 18.47476 | 30.98 |
| > 76 | BB | | 8.058519 | 3.138589 | 2.57 | 0.010 | 1.901283 | 14.215 |
| > 23 | BC | | 15.6657 | 3.195321 | 4.90 | 0.000 | 9.397165 | 21.934 |
| > 76 | BD | | 33.1145 | 2.652816 | 12.48 | 0.000 | 27.91025 | 38.318 |
| > 34 | BE | | 20.57731 | 2.674109 | 7.70 | 0.000 | 15.33129 | 25.823 |
| > 39 | SZ | | | | | | | |
| > 03 | 3 | | -4.550801 | 2.306291 | -1.97 | 0.049 | -9.075248 | -.02635 |
| > 95 | 4 | | -5.611921 | 2.441226 | -2.30 | 0.022 | -10.40108 | -.82276 |
| > 41 | 5 | | -5.900684 | 2.645012 | -2.23 | 0.026 | -11.08963 | -.71173 |
| > 07 | 6 | | -.8821376 | 2.846631 | -0.31 | 0.757 | -6.466616 | 4.7023 |
| | 7 | | -4.867545 | 7.620923 | -0.64 | 0.523 | -19.81816 | 10.083 |
| | _cons | | 126.9609 | 4.685073 | 27.10 | 0.000 | 117.7698 | 136.1 |

Appendix G4: Fixed effect model (LSDV) of oats yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 5 |
|----------|------------|-----|------------|---------------|---|------|
| <hr/> | | | | | | |
| | | | | F(37, 561) | = | 14. |
| Model | 253870.288 | 37 | 6861.35914 | Prob > F | = | 0.00 |
| Residual | 265645.223 | 561 | 473.520897 | R-squared | = | 0.48 |
| <hr/> | | | | | | |
| | | | | Adj R-squared | = | 0.45 |
| Total | 519515.511 | 598 | 868.755036 | Root MSE | = | 21.7 |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|-------|-------|--------------------|
| N | -.0205452 | .0483488 | -0.42 | 0.671 | -.1155119 .07442 |
| P | .118747 | .0981882 | 1.21 | 0.227 | -.0741144 .31160 |
| K | .2564616 | .093269 | 2.75 | 0.006 | .0732624 .43966 |
| S | -.3453676 | .1967648 | -1.76 | 0.080 | -.7318534 .04111 |
| Barley | -28.88071 | 7.872708 | -3.67 | 0.000 | -44.3443 -13.417 |
| Corn | -.8503538 | 2.867237 | -0.30 | 0.767 | -6.482185 4.7814 |
| Oats | -22.66349 | 8.734998 | -2.59 | 0.010 | -39.82079 -5.5061 |
| Soybeans | 2.138699 | 2.27159 | 0.94 | 0.347 | -2.323162 6.6005 |
| SWheat | -.904755 | 3.578253 | -0.25 | 0.800 | -7.933165 6.1236 |
| D2 | -3.55108 | 3.66622 | -0.97 | 0.333 | -10.75228 3.6501 |
| D3 | -9.936353 | 3.947559 | -2.52 | 0.012 | -17.69016 -2.1825 |
| D4 | -14.42903 | 4.774934 | -3.02 | 0.003 | -23.80796 -5.0500 |
| D5 | -13.91501 | 5.620841 | -2.48 | 0.014 | -24.95547 -2.8745 |
| D6 | -8.371837 | 7.198967 | -1.16 | 0.245 | -22.51206 5.7683 |
| D7 | -31.76447 | 8.062482 | -3.94 | 0.000 | -47.60082 -15.928 |
| D8 | -28.98587 | 9.569142 | -3.03 | 0.003 | -47.78159 -10.190 |
| D9 | -49.51114 | 22.76562 | -2.17 | 0.030 | -94.2274 -4.7948 |

| | | | | | | | |
|------|-------|-----------|----------|-------|-------|-----------|---------|
| > 76 | AU | -3.354657 | 4.89584 | -0.69 | 0.493 | -12.97107 | 6.261 |
| > 24 | AV | -2.531966 | 4.109706 | -0.62 | 0.538 | -10.60426 | 5.5403 |
| > 42 | AW | 13.5646 | 4.401698 | 3.08 | 0.002 | 4.918778 | 22.210 |
| > 04 | AX | 24.06299 | 5.626739 | 4.28 | 0.000 | 13.01094 | 35.115 |
| > 22 | AY | -10.81057 | 4.838429 | -2.23 | 0.026 | -20.31422 | -1.3069 |
| > 73 | AZ | -8.515412 | 5.897656 | -1.44 | 0.149 | -20.0996 | 3.0687 |
| > 14 | BA | -4.237525 | 5.258587 | -0.81 | 0.421 | -14.56645 | 6.09 |
| > 43 | BB | 20.82965 | 5.948805 | 3.50 | 0.000 | 9.144999 | 32.51 |
| > 96 | BC | 27.20865 | 4.959243 | 5.49 | 0.000 | 17.4677 | 36.94 |
| > 75 | BD | 15.97889 | 4.516773 | 3.54 | 0.000 | 7.107038 | 24.850 |
| > 73 | BE | 18.51525 | 4.435416 | 4.17 | 0.000 | 9.803195 | 27.22 |
| > 31 | BF | 41.12959 | 4.135382 | 9.95 | 0.000 | 33.00686 | 49.252 |
| | SZ | | | | | | |
| > 56 | 3 | -4.376509 | 2.807892 | -1.56 | 0.120 | -9.891775 | 1.1387 |
| > 13 | 4 | -2.908603 | 2.956222 | -0.98 | 0.326 | -8.715219 | 2.8980 |
| > 44 | 5 | -9.142836 | 4.150522 | -2.20 | 0.028 | -17.2953 | -.99037 |
| > 46 | 6 | -9.508873 | 5.016164 | -1.90 | 0.059 | -19.36163 | .34388 |
| > 64 | 7 | -22.07356 | 15.86142 | -1.39 | 0.165 | -53.22858 | 9.0814 |
| > 68 | 8 | -42.26357 | 22.5279 | -1.88 | 0.061 | -86.51291 | 1.9857 |
| > 81 | 9 | -50.16676 | 6.999615 | -7.17 | 0.000 | -63.91541 | -36.41 |
| > 43 | 10 | -70.33455 | 16.92093 | -4.16 | 0.000 | -103.5707 | -37.098 |
| | _cons | 122.9607 | 7.069692 | 17.39 | 0.000 | 109.0744 | 136.8 |

Appendix G5: Fixed effect model (LSDV) of soybeans yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 2,3 |
|----------|------------|-------|------------|---------------|---|------|
| > 77 | | | | | | |
| | | | | F(36, 2340) | = | 33. |
| > 08 | | | | | | |
| Model | 56797.8044 | 36 | 1577.71679 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 111617.817 | 2,340 | 47.6999219 | R-squared | = | 0.33 |
| > 72 | | | | | | |
| | | | | Adj R-squared | = | 0.32 |
| > 71 | | | | | | |
| Total | 168415.622 | 2,376 | 70.8819957 | Root MSE | = | 6.90 |
| > 65 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|-------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | .0189073 | .0178482 | 1.06 | 0.290 | -.0160926 .05390 |
| > 71 | | | | | |
| P | .0116848 | .0092463 | 1.26 | 0.206 | -.0064469 .02981 |
| > 65 | | | | | |
| K | .0509903 | .0213086 | 2.39 | 0.017 | .0092046 .0927 |
| > 76 | | | | | |
| S | .0735305 | .0588156 | 1.25 | 0.211 | -.0418057 .18886 |
| > 67 | | | | | |
| Barley | -2.484193 | .8708776 | -2.85 | 0.004 | -4.191965 -.7764 |
| > 21 | | | | | |
| Corn | 1.060289 | .461866 | 2.30 | 0.022 | .1545799 1.9659 |
| > 98 | | | | | |
| Oats | .796105 | .5511708 | 1.44 | 0.149 | -.284729 1.8769 |
| > 39 | | | | | |
| Soybeans | -2.139021 | .5399451 | -3.96 | 0.000 | -3.197842 -1.0802 |
| > 01 | | | | | |
| SWheat | .6482704 | .3973465 | 1.63 | 0.103 | -.1309173 1.4274 |
| > 58 | | | | | |
| D1 | -8.184239 | 8.499896 | -0.96 | 0.336 | -24.85235 8.4838 |
| > 72 | | | | | |
| D3 | -4.180417 | 4.928307 | -0.85 | 0.396 | -13.84472 5.4838 |
| > 87 | | | | | |
| D4 | -4.508779 | 4.916262 | -0.92 | 0.359 | -14.14946 5.1319 |
| > 03 | | | | | |
| D5 | -5.622637 | 4.92344 | -1.14 | 0.254 | -15.2774 4.0321 |
| > 22 | | | | | |
| D6 | -6.223288 | 4.936824 | -1.26 | 0.208 | -15.90429 3.4577 |
| > 16 | | | | | |
| D7 | -9.607057 | 4.980322 | -1.93 | 0.054 | -19.37336 .15924 |
| > 67 | | | | | |
| D8 | -17.63166 | 5.241236 | -3.36 | 0.001 | -27.90961 -7.3537 |

| | | | | | | | | |
|------|-------|--|-----------|----------|-------|-------|-----------|---------|
| > 38 | AU | | 1.085652 | .8926086 | 1.22 | 0.224 | -.6647341 | 2.8360 |
| > 92 | AV | | 11.26264 | 1.042988 | 10.80 | 0.000 | 9.217365 | 13.307 |
| > 88 | AW | | 2.502472 | .9324003 | 2.68 | 0.007 | .6740551 | 4.3308 |
| > 07 | AX | | 9.73585 | .9379069 | 10.38 | 0.000 | 7.896635 | 11.575 |
| > 63 | AY | | 8.403661 | .8674106 | 9.69 | 0.000 | 6.702688 | 10.104 |
| > 05 | AZ | | 5.47502 | .8299352 | 6.60 | 0.000 | 3.847535 | 7.1025 |
| > 11 | BA | | 8.042816 | .64952 | 12.38 | 0.000 | 6.769122 | 9.3165 |
| > 37 | BB | | 11.79826 | .6956267 | 16.96 | 0.000 | 10.43415 | 13.162 |
| > 45 | BC | | 7.261598 | .6671399 | 10.88 | 0.000 | 5.953351 | 8.5698 |
| > 44 | BD | | 7.596578 | .6656196 | 11.41 | 0.000 | 6.291313 | 8.9018 |
| > 59 | BE | | 16.40286 | .6306721 | 26.01 | 0.000 | 15.16612 | 17.639 |
| > 07 | BF | | 6.330634 | .5623073 | 11.26 | 0.000 | 5.227962 | 7.4333 |
| | SZ | | | | | | | |
| > 82 | 3 | | -.5259871 | .460783 | -1.14 | 0.254 | -1.429573 | .37759 |
| > 05 | 4 | | -1.514719 | .472039 | -3.21 | 0.001 | -2.440377 | -.58906 |
| > 33 | 5 | | -3.045724 | .6158612 | -4.95 | 0.000 | -4.253414 | -1.8380 |
| > 67 | 6 | | .702263 | .6992958 | 1.00 | 0.315 | -.6690409 | 2.0735 |
| > 08 | 7 | | -.6870394 | 2.656402 | -0.26 | 0.796 | -5.896187 | 4.5221 |
| > 29 | 8 | | -6.266661 | 2.233952 | -2.81 | 0.005 | -10.64739 | -1.8859 |
| > 29 | 9 | | -9.737484 | 1.606012 | -6.06 | 0.000 | -12.88684 | -6.5881 |
| > 95 | 10 | | -5.284477 | 2.675194 | -1.98 | 0.048 | -10.53047 | -.03847 |
| | _cons | | 36.48857 | 4.966102 | 7.35 | 0.000 | 26.75015 | 46.226 |

Appendix G6: Fixed effect model (LSDV) of spring wheat yield in Risk Area 12 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 2,1 |
|----------|------------|-------|------------|---------------|---|------|
| > 27 | | | | | | |
| | | | | F(37, 2089) | = | 63. |
| > 89 | | | | | | |
| Model | 219444.821 | 37 | 5930.94111 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 193930.135 | 2,089 | 92.8339564 | R-squared | = | 0.53 |
| > 09 | | | | | | |
| | | | | Adj R-squared | = | 0.52 |
| > 26 | | | | | | |
| Total | 413374.956 | 2,126 | 194.437891 | Root MSE | = | 9.6 |
| > 35 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva |
|----------|-----------|-----------|--------|-------|--------------------|
| > 1] | | | | | |
| > — | | | | | |
| N | .0876407 | .0108021 | 8.11 | 0.000 | .0664567 .10882 |
| > 47 | | | | | |
| P | .0468857 | .0186372 | 2.52 | 0.012 | .0103362 .08343 |
| > 52 | | | | | |
| K | .0543282 | .0202996 | 2.68 | 0.008 | .0145186 .09413 |
| > 78 | | | | | |
| S | .004534 | .0428949 | 0.11 | 0.916 | -.0795873 .08865 |
| > 52 | | | | | |
| Barley | -8.159343 | 2.64279 | -3.09 | 0.002 | -13.34212 -2.9765 |
| > 66 | | | | | |
| Corn | -2.543644 | 1.261818 | -2.02 | 0.044 | -5.018196 -.06909 |
| > 16 | | | | | |
| Oats | -4.758949 | 1.781031 | -2.67 | 0.008 | -8.251729 -1.2661 |
| > 69 | | | | | |
| Soybeans | .5830229 | .4787426 | 1.22 | 0.223 | -.3558393 1.5218 |
| > 85 | | | | | |
| SWheat | -4.374552 | 1.850365 | -2.36 | 0.018 | -8.003304 -.74579 |
| > 98 | | | | | |
| D2 | -2.627394 | .7811576 | -3.36 | 0.001 | -4.159322 -1.0954 |
| > 65 | | | | | |
| D3 | -4.753846 | .9256176 | -5.14 | 0.000 | -6.569075 -2.9386 |
| > 17 | | | | | |
| D4 | -6.795273 | 1.172918 | -5.79 | 0.000 | -9.095483 -4.4950 |
| > 64 | | | | | |
| D5 | -8.170442 | 1.229888 | -6.64 | 0.000 | -10.58237 -5.7585 |
| > 09 | | | | | |
| D6 | -11.59374 | 1.946868 | -5.96 | 0.000 | -15.41174 -7.7757 |
| > 37 | | | | | |
| D7 | -15.39385 | 1.749192 | -8.80 | 0.000 | -18.82419 -11.963 |
| > 51 | | | | | |
| D8 | -22.64188 | 2.08547 | -10.86 | 0.000 | -26.73169 -18.552 |
| > 06 | | | | | |
| D9 | -30.05752 | 4.105921 | -7.32 | 0.000 | -38.10964 -22.00 |

| | | | | | | | |
|------|---------|-----------|----------|--------|-------|-----------|---------|
| > 29 | AU | -6.414403 | 1.121194 | -5.72 | 0.000 | -8.613177 | -4.2156 |
| > 62 | AV | -16.20408 | 1.176612 | -13.77 | 0.000 | -18.51153 | -13.896 |
| > 45 | AW | -3.04945 | 1.072564 | -2.84 | 0.005 | -5.152855 | -.9460 |
| > 23 | AX | 1.366039 | 1.253217 | 1.09 | 0.276 | -1.091646 | 3.8237 |
| > 03 | AY | -17.3722 | 1.187685 | -14.63 | 0.000 | -19.70137 | -15.043 |
| > 11 | AZ | -14.32467 | 1.252137 | -11.44 | 0.000 | -16.78024 | -11.869 |
| > 45 | BA | -6.077482 | 1.155442 | -5.26 | 0.000 | -8.343419 | -3.8115 |
| > 27 | BB | 4.899446 | 1.226342 | 4.00 | 0.000 | 2.494466 | 7.3044 |
| > 38 | BC | 3.43246 | 1.107205 | 3.10 | 0.002 | 1.261121 | 5.60 |
| > 54 | BD | -8.580514 | 1.03767 | -8.27 | 0.000 | -10.61549 | -6.545 |
| > 33 | BE | -10.91053 | .952117 | -11.46 | 0.000 | -12.77773 | -9.0433 |
| > 77 | BF | 11.61031 | .9976361 | 11.64 | 0.000 | 9.653846 | 13.566 |
| > 07 | SZ 3 | -2.826654 | .7665836 | -3.69 | 0.000 | -4.330002 | -1.3233 |
| > 84 | 4 | -3.900457 | .7885743 | -4.95 | 0.000 | -5.446931 | -2.3539 |
| > 34 | 5 | -7.293158 | .8994055 | -8.11 | 0.000 | -9.056983 | -5.5293 |
| > 93 | 6 | -4.158326 | 1.166862 | -3.56 | 0.000 | -6.446659 | -1.8699 |
| > 64 | 7 | -8.298056 | 2.686459 | -3.09 | 0.002 | -13.56647 | -3.029 |
| > 08 | 8 | -8.398991 | 2.487218 | -3.38 | 0.001 | -13.27667 | -3.5213 |
| > 94 | 9 | -16.45501 | 1.476246 | -11.15 | 0.000 | -19.35007 | -13.559 |
| > 35 | 10 | -14.35705 | 2.484787 | -5.78 | 0.000 | -19.22997 | -9.4841 |
| | _cons | 63.06996 | 1.772074 | 35.59 | 0.000 | 59.59474 | 66.545 |

Appendix H1: Fixed effect model (LSDV) of barley yield in Risk Area 1 of Manitoba (2006-2018).

```

Linear regression                               Number of obs   =       5
> 27                                           F(34, 491)     =
> .                                           Prob > F       =
> .                                           R-squared      =    0.49
> 67                                           Root MSE      =    14.
> 31

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva | |
|------|----------|-----------|------------------|-------|-------|--------------------|---------|
| > 88 | N | .1780576 | .0472012 | 3.77 | 0.000 | .0853165 | .27079 |
| > 74 | P | .1303713 | .0838773 | 1.55 | 0.121 | -.0344314 | .2951 |
| > 55 | K | .4992542 | .1029319 | 4.85 | 0.000 | .2970128 | .70149 |
| > 92 | s | .353501 | .1559395 | 2.27 | 0.024 | .04711 | .6598 |
| > 25 | Barley | -9.599472 | 2.187617 | -4.39 | 0.000 | -13.89772 | -5.3012 |
| > 52 | Corn | -1.07583 | 4.012344 | -0.27 | 0.789 | -8.959312 | 6.8076 |
| > 57 | Oats | -5.446004 | 2.369346 | -2.30 | 0.022 | -10.10131 | -.79069 |
| > 59 | Soybeans | 3.005898 | 2.582575 | 1.16 | 0.245 | -2.068364 | 8.0801 |
| > 45 | SWheat | -6.030941 | 1.926876 | -3.13 | 0.002 | -9.816882 | -2.2 |
| > 15 | D2 | -9.13837 | 5.705947 | -1.60 | 0.110 | -20.34946 | 2.0727 |
| > 82 | D3 | -10.89399 | 5.579009 | -1.95 | 0.051 | -21.85567 | .0676 |
| > 61 | D4 | -14.0936 | 5.520052 | -2.55 | 0.011 | -24.93944 | -3.2477 |
| > 57 | D5 | -15.20649 | 5.583647 | -2.72 | 0.007 | -26.17728 | -4.23 |
| > 47 | D6 | -19.98771 | 6.436798 | -3.11 | 0.002 | -32.63478 | -7.3406 |
| > 71 | D7 | -19.06379 | 6.486343 | -2.94 | 0.003 | -31.8082 | -6.3193 |
| > 78 | D8 | -25.28453 | 7.53089 | -3.36 | 0.001 | -40.08128 | -10.487 |
| | D9 | -24.30476 | 7.904821 | -3.07 | 0.002 | -39.83621 | -8.7733 |

| | | | | | | | |
|------|-------|-----------|----------|--------|-------|-----------|---------|
| > 74 | AV | 3.862352 | 3.591389 | 1.08 | 0.283 | -3.194035 | 10.918 |
| > 68 | AW | -2.967834 | 3.348675 | -0.89 | 0.376 | -9.547335 | 3.6116 |
| > 15 | AX | -1.685016 | 3.411106 | -0.49 | 0.622 | -8.387183 | 5.017 |
| > 21 | AY | 12.26048 | 3.465343 | 3.54 | 0.000 | 5.451747 | 19.069 |
| > 57 | AZ | -20.67175 | 3.267082 | -6.33 | 0.000 | -27.09094 | -14.252 |
| > 66 | BA | -49.38086 | 4.007109 | -12.32 | 0.000 | -57.25406 | -41.507 |
| > 39 | BB | -17.99325 | 3.225691 | -5.58 | 0.000 | -24.33111 | -11.655 |
| > 28 | BC | .0312614 | 3.807736 | 0.01 | 0.993 | -7.450205 | 7.5127 |
| > 98 | BD | 6.142384 | 5.445623 | 1.13 | 0.260 | -4.557216 | 16.841 |
| > 09 | BE | -13.9844 | 4.139791 | -3.38 | 0.001 | -22.11829 | -5.8505 |
| > 73 | BF | 2.515419 | 4.018874 | 0.63 | 0.532 | -5.380893 | 10.411 |
| > 47 | BG | 8.624021 | 3.557319 | 2.42 | 0.016 | 1.634576 | 15.613 |
| > 21 | SZ | | | | | | |
| > 78 | 5 | -17.85059 | 12.29582 | -1.45 | 0.147 | -42.00949 | 6.3083 |
| > 89 | 6 | -3.384964 | 10.56834 | -0.32 | 0.749 | -24.14971 | 17.379 |
| > 69 | 7 | -5.878425 | 10.6638 | -0.55 | 0.582 | -26.83074 | 15.073 |
| > 34 | 8 | -8.382311 | 10.75526 | -0.78 | 0.436 | -29.51431 | 12.749 |
| > 72 | 9 | -7.863385 | 10.81008 | -0.73 | 0.467 | -29.10311 | 13.376 |
| | 10 | -9.847507 | 11.70355 | -0.84 | 0.401 | -32.84273 | 13.147 |
| | _cons | 62.93491 | 13.16674 | 4.78 | 0.000 | 37.06481 | 88.805 |

Appendix H2: Fixed effect model (LSDV) of canola yield in Risk Area 1 of Manitoba (2006-2018).

| Source | SS | df | MS | Number of obs | = | 3,3 |
|----------|-----------|-------|------------|---------------|---|------|
| > 11 | | | | | | |
| | | | | F(35, 3275) | = | 51. |
| > 95 | | | | | | |
| Model | 111378.53 | 35 | 3182.24371 | Prob > F | = | 0.00 |
| > 00 | | | | | | |
| Residual | 200612.16 | 3,275 | 61.2556213 | R-squared | = | 0.35 |
| > 70 | | | | | | |
| | | | | Adj R-squared | = | 0.35 |
| > 01 | | | | | | |
| Total | 311990.69 | 3,310 | 94.2570059 | Root MSE | = | 7.82 |
| > 66 | | | | | | |

| YLDbu | Coef. | Std. Err. | t | P> t | [95% Conf. Interva | |
|---------|-----------|-----------|-------|-------|--------------------|---------|
| > 1] | | | | | | |
| > — | | | | | | |
| N | .0949091 | .0085367 | 11.12 | 0.000 | .0781713 | .1116 |
| > 47 | | | | | | |
| P | -.0266835 | .0158802 | -1.68 | 0.093 | -.0578197 | .00445 |
| > 28 | | | | | | |
| K | .0282796 | .0198688 | 1.42 | 0.155 | -.0106769 | .06723 |
| > 61 | | | | | | |
| R | .1017174 | .0242346 | 4.20 | 0.000 | .0542009 | .14923 |
| > 38 | | | | | | |
| Barley | -.9286792 | .4574833 | -2.03 | 0.042 | -1.825661 | -.03169 |
| > 69 | | | | | | |
| Canola | -4.427769 | .9742323 | -4.54 | 0.000 | -6.337935 | -2.5176 |
| > 03 | | | | | | |
| Corn | 3.181562 | 1.342533 | 2.37 | 0.018 | .5492719 | 5.8138 |
| > 51 | | | | | | |
| Oats | -1.064965 | .4110263 | -2.59 | 0.010 | -1.870859 | -.259 |
| > 07 | | | | | | |
| Soybean | -1.694203 | .6078545 | -2.79 | 0.005 | -2.886016 | -.50238 |
| > 92 | | | | | | |
| D1 | -19.72461 | 3.638813 | -5.42 | 0.000 | -26.85919 | -12.590 |
| > 03 | | | | | | |
| D3 | -.7135824 | .946913 | -0.75 | 0.451 | -2.570184 | 1.1430 |
| > 19 | | | | | | |
| D4 | -.6154006 | .9373196 | -0.66 | 0.512 | -2.453192 | 1.2223 |
| > 91 | | | | | | |
| D5 | -1.343807 | .9490797 | -1.42 | 0.157 | -3.204657 | .51704 |
| > 27 | | | | | | |
| D6 | -1.071962 | .9889054 | -1.08 | 0.278 | -3.010897 | .86697 |
| > 38 | | | | | | |
| D7 | -.9226265 | 1.117278 | -0.83 | 0.409 | -3.11326 | 1.2680 |
| > 07 | | | | | | |
| D8 | -2.427082 | 1.198845 | -2.02 | 0.043 | -4.777645 | -.07651 |
| > 95 | | | | | | |
| D9 | -8.992548 | 2.308937 | -3.89 | 0.000 | -13.51965 | -4.4654 |

| | | | | | | | |
|------|-------|-----------|----------|--------|-------|-----------|---------|
| > 45 | AU | -8.111565 | .8008515 | -10.13 | 0.000 | -9.681786 | -6.5413 |
| > 54 | AV | -9.562335 | .6845462 | -13.97 | 0.000 | -10.90452 | -8.2201 |
| > 26 | AW | -3.77311 | .6630756 | -5.69 | 0.000 | -5.073195 | -2.4730 |
| > 94 | AX | 2.941096 | .6036641 | 4.87 | 0.000 | 1.757499 | 4.1246 |
| > 11 | AY | -11.17106 | .6033338 | -18.52 | 0.000 | -12.35401 | -9.988 |
| > 07 | AZ | -23.13673 | 1.297328 | -17.83 | 0.000 | -25.68039 | -20.593 |
| > 88 | BA | -7.783043 | 1.549433 | -5.02 | 0.000 | -10.821 | -4.7450 |
| > 17 | BB | -6.911178 | .5957128 | -11.60 | 0.000 | -8.079185 | -5.743 |
| > 09 | BC | -7.596758 | .9093994 | -8.35 | 0.000 | -9.379807 | -5.8137 |
| > 36 | BD | -4.005512 | .9425643 | -4.25 | 0.000 | -5.853587 | -2.1574 |
| > 35 | BE | -3.439238 | .5884171 | -5.84 | 0.000 | -4.592941 | -2.2855 |
| > 46 | BF | -.3542609 | .5381913 | -0.66 | 0.510 | -1.409486 | .70096 |
| | S | | | | | | |
| > 34 | 5 | 1.024013 | 2.433085 | 0.42 | 0.674 | -3.746509 | 5.7945 |
| > 66 | 6 | -1.629375 | 1.989625 | -0.82 | 0.413 | -5.530409 | 2.271 |
| > 53 | 7 | .1088451 | 2.002617 | 0.05 | 0.957 | -3.817663 | 4.0353 |
| > 17 | 8 | -1.223747 | 2.013458 | -0.61 | 0.543 | -5.17151 | 2.7240 |
| > 26 | 9 | -1.379749 | 2.035446 | -0.68 | 0.498 | -5.370624 | 2.6111 |
| > 19 | 10 | -10.26299 | 2.535012 | -4.05 | 0.000 | -15.23336 | -5.2926 |
| | _cons | 31.76803 | 2.237695 | 14.20 | 0.000 | 27.3806 | 36.155 |

Appendix H3: Fixed effect model (LSDV) of grain corn yield in Risk Area 1 of Manitoba (2006-2018).

```

Linear regression
> 85
                                     Number of obs   =
                                     F(23, 56)       =
> .
                                     Prob > F        =
> .
                                     R-squared       =    0.73
> 59
                                     Root MSE     =    17.2
> 76

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva |
|------|----------|-----------|------------------|-------|-------|--------------------|
| > 1] | | | | | | |
| > — | N | .279927 | .106927 | 2.62 | 0.011 | .0657265 .49412 |
| > 76 | P | -.0225379 | .3287734 | -0.07 | 0.946 | -.6811501 .63607 |
| > 43 | K | -.2196262 | .1858681 | -1.18 | 0.242 | -.5919649 .15271 |
| > 24 | S | -.0414613 | .2543404 | -0.16 | 0.871 | -.5509663 .46804 |
| > 37 | Barley | .9100227 | 7.140944 | 0.13 | 0.899 | -13.39501 15.215 |
| > 05 | Corn | -6.428548 | 11.33603 | -0.57 | 0.573 | -29.13734 16.280 |
| > 24 | Oats | -35.89345 | 16.6163 | -2.16 | 0.035 | -69.1799 -2.6070 |
| > 07 | Soybeans | 4.878635 | 9.337761 | 0.52 | 0.603 | -13.82715 23.584 |
| > 42 | SWheat | -10.01199 | 8.71082 | -1.15 | 0.255 | -27.46186 7.4378 |
| > 78 | D1 | 0 | (omitted) | | | |
| | D3 | -5.241184 | 12.55406 | -0.42 | 0.678 | -30.38999 19.907 |
| > 62 | D4 | -15.28284 | 13.21952 | -1.16 | 0.253 | -41.76473 11.199 |
| > 05 | D5 | -19.23721 | 14.76087 | -1.30 | 0.198 | -48.8068 10.332 |
| > 37 | D6 | -39.14771 | 22.62587 | -1.73 | 0.089 | -84.47278 6.1773 |
| > 48 | D7 | 0 | (omitted) | | | |
| | D8 | 0 | (omitted) | | | |

| | | | | | | | |
|------|-------|-----------|-----------|-------|-------|-----------|---------|
| | AU | 0 | (omitted) | | | | |
| > 71 | AV | -40.62079 | 20.93087 | -1.94 | 0.057 | -82.55036 | 1.3087 |
| > 34 | AW | -37.30203 | 17.25504 | -2.16 | 0.035 | -71.86803 | -2.7360 |
| | AX | 0 | (omitted) | | | | |
| > 66 | AY | -91.63156 | 19.32713 | -4.74 | 0.000 | -130.3485 | -52.914 |
| > 93 | AZ | 59.94062 | 22.13348 | 2.71 | 0.009 | 15.60194 | 104.27 |
| > 41 | BA | 8.156589 | 12.22161 | 0.67 | 0.507 | -16.32624 | 32.639 |
| > 16 | BB | 1.460109 | 6.983707 | 0.21 | 0.835 | -12.52994 | 15.450 |
| > 65 | BC | -21.91556 | 10.37294 | -2.11 | 0.039 | -42.69506 | -1.1360 |
| > 44 | BD | -.9848557 | 9.257146 | -0.11 | 0.916 | -19.52915 | 17.559 |
| > 11 | BE | 14.49641 | 9.609778 | 1.51 | 0.137 | -4.754287 | 33.747 |
| > 37 | BF | 2.361187 | 8.823609 | 0.27 | 0.790 | -15.31463 | 20.0 |
| | SZ | | | | | | |
| > 52 | 6 | -17.75395 | 9.705509 | -1.83 | 0.073 | -37.19642 | 1.688 |
| > 81 | 7 | -13.17101 | 7.741551 | -1.70 | 0.094 | -28.6792 | 2.3371 |
| > 22 | 8 | -29.62277 | 10.41605 | -2.84 | 0.006 | -50.48862 | -8.7569 |
| > 31 | 9 | -2.113634 | 10.93126 | -0.19 | 0.847 | -24.01158 | 19.784 |
| > 83 | 10 | -25.71398 | 18.48795 | -1.39 | 0.170 | -62.74979 | 11.321 |
| > 87 | _cons | 111.2606 | 20.59566 | 5.40 | 0.000 | 70.00257 | 152.51 |

Appendix H4: Fixed Effect Model (LSDV) of Oats Yield in Risk Area 1 of Manitoba (2006-2018).

```

Linear regression      Number of obs   =      7
> 22                  F(34, 686)     =
> .                   Prob > F       =
> .                   R-squared     =    0.44
> 23                  Root MSE     =    20.6
> 01

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva |
|------|----------|-----------|------------------|-------|-------|--------------------|
| > 1] | | | | | | |
| > — | N | .291869 | .0667958 | 4.37 | 0.000 | .1607202 .42301 |
| > 79 | P | .0361825 | .1094185 | 0.33 | 0.741 | -.1786529 .25101 |
| > 79 | K | .4433182 | .1038555 | 4.27 | 0.000 | .2394054 .6472 |
| > 31 | S | .3659971 | .1800312 | 2.03 | 0.042 | .0125189 .71947 |
| > 54 | Barley | -7.314463 | 3.598605 | -2.03 | 0.042 | -14.38007 -.24886 |
| > 06 | Corn | -15.09289 | 3.009713 | -5.01 | 0.000 | -21.00225 -9.1835 |
| > 35 | Oats | -16.57128 | 2.940039 | -5.64 | 0.000 | -22.34384 -10.798 |
| > 73 | Soybeans | 4.582454 | 2.804805 | 1.63 | 0.103 | -.9245789 10.089 |
| > 49 | SWheat | -1.557203 | 2.416918 | -0.64 | 0.520 | -6.302648 3.1882 |
| > 42 | D2 | -9.003176 | 5.659129 | -1.59 | 0.112 | -20.11447 2.1081 |
| > 18 | D3 | -14.85902 | 4.877574 | -3.05 | 0.002 | -24.43579 -5.2822 |
| > 55 | D4 | -18.67247 | 5.073712 | -3.68 | 0.000 | -28.63434 -8.7106 |
| > 05 | D5 | -17.69066 | 5.328794 | -3.32 | 0.001 | -28.15337 -7.227 |
| > 96 | D6 | -25.7057 | 5.709159 | -4.50 | 0.000 | -36.91523 -14.496 |
| > 18 | D7 | -33.05623 | 5.983268 | -5.52 | 0.000 | -44.80394 -21.308 |
| > 51 | D8 | -35.76183 | 8.895763 | -4.02 | 0.000 | -53.22802 -18.295 |
| > 64 | D9 | -68.32393 | 8.171051 | -8.36 | 0.000 | -84.3672 -52.280 |

| | | | | | | | |
|------|---------|-----------|----------|-------|-------|-----------|---------|
| > 63 | AV | -15.04699 | 3.344827 | -4.50 | 0.000 | -21.61432 | -8.4796 |
| > 82 | AW | -10.10852 | 3.41405 | -2.96 | 0.003 | -16.81176 | -3.4052 |
| > 44 | AX | -14.97038 | 3.454994 | -4.33 | 0.000 | -21.75401 | -8.1867 |
| > 61 | AY | 19.9376 | 4.34801 | 4.59 | 0.000 | 11.4006 | 28.474 |
| > 74 | AZ | -19.23569 | 4.908567 | -3.92 | 0.000 | -28.87331 | -9.5980 |
| > 82 | BA | -38.96032 | 9.269758 | -4.20 | 0.000 | -57.16083 | -20.759 |
| > 11 | BB | -11.80256 | 6.958582 | -1.70 | 0.090 | -25.46524 | 1.8601 |
| > 02 | BC | 17.51254 | 5.198806 | 3.37 | 0.001 | 7.305056 | 27.720 |
| > 89 | BD | 1.748569 | 6.933446 | 0.25 | 0.801 | -11.86475 | 15.361 |
| > 13 | BE | -7.832499 | 4.697759 | -1.67 | 0.096 | -17.05621 | 1.3912 |
| > 71 | BF | 10.43763 | 4.075567 | 2.56 | 0.011 | 2.435545 | 18.439 |
| > 24 | BG | -1.019636 | 2.680852 | -0.38 | 0.704 | -6.283297 | 4.2440 |
| > 96 | SZ 5 | 43.91139 | 13.98348 | 3.14 | 0.002 | 16.45583 | 71.366 |
| > 58 | 6 | 4.652664 | 7.325922 | 0.64 | 0.526 | -9.731258 | 19.036 |
| > 53 | 7 | 9.993027 | 7.139299 | 1.40 | 0.162 | -4.024474 | 24.010 |
| > 06 | 8 | 7.693393 | 7.225965 | 1.06 | 0.287 | -6.49427 | 21.881 |
| > 72 | 9 | 3.148275 | 7.30429 | 0.43 | 0.667 | -11.19317 | 17.489 |
| > 84 | 10 | -10.8707 | 8.661884 | -1.26 | 0.210 | -27.87769 | 6.1362 |
| | _cons | 87.37277 | 8.813071 | 9.91 | 0.000 | 70.06894 | 104.67 |

Appendix H5: Fixed Effect Model (LSDV) of Soybeans Yield in Risk Area 1 of Manitoba (2006-2018).

```

Linear regression                               Number of obs   =           7
> 53                                           F(24, 726)     =
> .                                           Prob > F       =
> .                                           R-squared      =           0.38
> 33                                           Root MSE      =           7.22
> 15

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva |
|------|----------|-----------|------------------|-------|-------|--------------------|
| > 1] | | | | | | |
| > 72 | N | .0453446 | .0226323 | 2.00 | 0.045 | .0009121 .08977 |
| > 36 | P | .005315 | .0234911 | 0.23 | 0.821 | -.0408036 .05143 |
| > 88 | K | -.0153953 | .0232036 | -0.66 | 0.507 | -.0609494 .03015 |
| > 58 | S | .046053 | .0212368 | 2.17 | 0.030 | .0043602 .08774 |
| > 99 | Barley | -.0917967 | 1.610654 | -0.06 | 0.955 | -3.253892 3.0702 |
| > 98 | Corn | 1.766259 | 1.903662 | 0.93 | 0.354 | -1.97108 5.5035 |
| > 27 | Oats | -2.04102 | .9022586 | -2.26 | 0.024 | -3.812368 -.26967 |
| > 42 | Soybeans | .9867834 | .753672 | 1.31 | 0.191 | -.4928533 2.466 |
| > 44 | SWheat | .7601393 | .6742458 | 1.13 | 0.260 | -.5635649 2.0838 |
| | D1 | 0 | (omitted) | | | |
| | D2 | 0 | (omitted) | | | |
| > 29 | D4 | -1.602826 | 2.216113 | -0.72 | 0.470 | -5.953582 2.7479 |
| > 37 | D5 | -3.046315 | 2.164632 | -1.41 | 0.160 | -7.296 1.203 |
| > 62 | D6 | -5.836969 | 2.195409 | -2.66 | 0.008 | -10.14708 -1.5268 |
| > 83 | D7 | -8.838113 | 2.659756 | -3.32 | 0.001 | -14.05984 -3.6163 |
| | D8 | 0 | (omitted) | | | |

| | | | | | | | |
|------|-------|-----------|-----------|--------|-------|-----------|--------|
| | AU | 0 | (omitted) | | | | |
| | AV | 0 | (omitted) | | | | |
| | AW | 0 | (omitted) | | | | |
| > 83 | AX | -5.853001 | 4.146053 | -1.41 | 0.158 | -13.99269 | 2.2866 |
| | AY | 0 | (omitted) | | | | |
| > 28 | AZ | -19.93639 | 1.626697 | -12.26 | 0.000 | -23.12999 | -16.74 |
| | BA | .9963128 | 1.663391 | 0.60 | 0.549 | -2.269318 | 4.2619 |
| > 43 | BB | 4.366335 | 1.916743 | 2.28 | 0.023 | .6033145 | 8.1293 |
| > 56 | BC | 2.980025 | 3.055452 | 0.98 | 0.330 | -3.018551 | 8.9786 |
| > 02 | BD | 9.968642 | 2.725853 | 3.66 | 0.000 | 4.617146 | 15.320 |
| > 14 | BE | 13.06579 | .8540776 | 15.30 | 0.000 | 11.38904 | 14.742 |
| > 55 | BF | 5.988565 | .6041831 | 9.91 | 0.000 | 4.802411 | 7.174 |
| > 72 | | | | | | | |
| | SZ | | | | | | |
| > 61 | 6 | -5.289369 | 2.930826 | -1.80 | 0.072 | -11.04327 | .46453 |
| > 56 | 7 | -2.934253 | 2.894204 | -1.01 | 0.311 | -8.616262 | 2.7477 |
| > 46 | 8 | -2.743092 | 2.932524 | -0.94 | 0.350 | -8.500331 | 3.0141 |
| > 89 | 9 | -4.977595 | 2.975435 | -1.67 | 0.095 | -10.81908 | .8638 |
| > 28 | 10 | -5.206342 | 4.351828 | -1.20 | 0.232 | -13.75001 | 3.3373 |
| | _cons | 33.54871 | 3.659891 | 9.17 | 0.000 | 26.36348 | 40.733 |

Appendix H6: Fixed effect model (LSDV) of spring wheat yield in Risk Area 1 of Manitoba (2006-2018).

```

Linear regression
> 75
> 03
> 00
> 04
> 47
Number of obs   =    2,9
F(35, 2939)    =    81.
Prob > F        =    0.00
R-squared       =    0.43
Root MSE       =    10.0

```

| | YLDbu | Coef. | Robust Std. Err. | t | P> t | [95% Conf. Interva | |
|------|----------|-----------|------------------|-------|-------|--------------------|---------|
| > 75 | N | .1574336 | .0139401 | 11.29 | 0.000 | .1301003 | .1847 |
| > 03 | P | -.0921273 | .0205613 | -4.48 | 0.000 | -.1324433 | -.05181 |
| > 00 | K | .1064522 | .0227421 | 4.68 | 0.000 | .0618603 | .15104 |
| > 04 | S | -.0156245 | .0378986 | -0.41 | 0.680 | -.0899349 | .0586 |
| > 47 | Barley | -3.900131 | 1.045242 | -3.73 | 0.000 | -5.949612 | -1.850 |
| | Corn | 1.673057 | 4.508373 | 0.37 | 0.711 | -7.166831 | 10.512 |
| | Oats | -6.024047 | .8932138 | -6.74 | 0.000 | -7.775435 | -4.2726 |
| | Soybeans | -1.274651 | .6357945 | -2.00 | 0.045 | -2.521299 | -.02800 |
| | SWheat | -2.767772 | .5932692 | -4.67 | 0.000 | -3.931037 | -1.6045 |
| | D2 | -1.886742 | 1.010689 | -1.87 | 0.062 | -3.868473 | .09498 |
| | D3 | -5.242147 | .9962929 | -5.26 | 0.000 | -7.19565 | -3.2886 |
| | D4 | -7.098452 | 1.021689 | -6.95 | 0.000 | -9.101751 | -5.0951 |
| | D5 | -9.347019 | 1.107682 | -8.44 | 0.000 | -11.51893 | -7.1751 |
| | D6 | -9.209268 | 1.28942 | -7.14 | 0.000 | -11.73753 | -6.681 |
| | D7 | -14.20595 | 1.809902 | -7.85 | 0.000 | -17.75475 | -10.657 |
| | D8 | -8.647343 | 1.718546 | -5.03 | 0.000 | -12.01702 | -5.2776 |
| | D9 | -6.842718 | 2.248775 | -3.04 | 0.002 | -11.25205 | -2.4333 |

| | | | | | | | |
|------|-------|-----------|----------|--------|-------|-----------|---------|
| > 33 | AV | -14.52982 | .742818 | -19.56 | 0.000 | -15.98632 | -13.073 |
| > 18 | AW | -17.33543 | .7911427 | -21.91 | 0.000 | -18.88668 | -15.784 |
| > 85 | AX | -13.26269 | .8148997 | -16.28 | 0.000 | -14.86052 | -11.664 |
| > 54 | AY | -2.408772 | .7509066 | -3.21 | 0.001 | -3.881128 | -.93641 |
| > 55 | AZ | -20.62855 | .7910139 | -26.08 | 0.000 | -22.17955 | -19.077 |
| > 31 | BA | -32.16503 | 2.163292 | -14.87 | 0.000 | -36.40675 | -27.923 |
| > 65 | BB | -10.61702 | 1.23342 | -8.61 | 0.000 | -13.03548 | -8.1985 |
| > 39 | BC | -8.998774 | 1.014618 | -8.87 | 0.000 | -10.98821 | -7.0093 |
| > 74 | BD | -13.39134 | 1.316119 | -10.17 | 0.000 | -15.97195 | -10.810 |
| > 75 | BE | -13.16031 | .9519492 | -13.82 | 0.000 | -15.02686 | -11.293 |
| > 47 | BF | -9.700486 | .7724196 | -12.56 | 0.000 | -11.21502 | -8.1859 |
| > 83 | BG | -4.259408 | .7049395 | -6.04 | 0.000 | -5.641633 | -2.8771 |
| | SZ | | | | | | |
| > 84 | 5 | 6.113355 | 4.287336 | 1.43 | 0.154 | -2.293131 | 14.519 |
| > 54 | 6 | -7.252189 | 3.053306 | -2.38 | 0.018 | -13.23902 | -1.2653 |
| > 25 | 7 | -3.960131 | 3.060763 | -1.29 | 0.196 | -9.961587 | 2.0413 |
| > 15 | 8 | -4.275344 | 3.066017 | -1.39 | 0.163 | -10.2871 | 1.7364 |
| > 41 | 9 | -6.929222 | 3.08759 | -2.24 | 0.025 | -12.98328 | -.87516 |
| > 43 | 10 | -13.22989 | 4.284051 | -3.09 | 0.002 | -21.62993 | -4.8298 |
| > 33 | _cons | 56.4782 | 3.340079 | 16.91 | 0.000 | 49.92907 | 63.027 |
