Potato Rotation Study - Carberry, Manitoba (1997-2010)

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Summary
During the 1990's, Manitoba's processing potato industry experienced a period of unprecedented expansion. The Potato Rotation Study at Carberry, Manitoba was initiated to identify economically and environmentally sustainable rotations that optimized crop yield and quality, while maintaining or enhancing soil quality. Six potato rotations were established in 1998: 1) potato - wheat (P-W); 2) potato - canola (P-C); 3) potato - canola - wheat (P-C-W); 4) potato - oat - wheat (P-O-W); 5) potato - wheat - canola - wheat (P-W-C-W); 6) potato – canola (underseeded to alfalfa) - alfalfa - alfalfa (P-C-A-A). Declines in potato yield were observed in the 2-year rotations in 2007 and continued through 2010. Potato yield declines were associated with high levels of potato early dying (PED) in the two year rotations but these yield declines were not seen in the longer rotations. Yield declines in the short rotations were not associated with increased weed competition or declines in soil quality.

Introduction
For more than a decade beginning in the 1990's, Manitoba's potato industry experienced a period of unprecedented expansion, with planted area increasing from 50,000 acres (20,000 ha) in 1990 to a record high of 103,000 acres (42,000 ha) in 2003[1]. Since 2003, acreage has declined steadily to approximately 71,000 acres (29,000 ha) in 2010.

In the 1990's, pressure on the limited irrigated land base, the entry of growers new to the industry, and a dearth of published research information regarding irrigated potato production for the eastern prairies created a need for longer-term research. Growers, industry and government recognized sustainable cropping systems as the cornerstone to the long-term success of the growing potato processing industry, which would require a consistent supply of high-quality tubers. The intensive nature of potato production, characterized by irrigation, multiple pesticide applications to control diseases and insects, high rates of nutrient application, and repeated tillage operations, demanded robust cropping systems that were economically and environmentally sustainable.

Through 1997 and 1998, a series of consultations among growers, industry, and federal and provincial staff were conducted to plan the Potato Rotation Study. In 1997, a 5 ha site on an Orthic Black Chernozem soil immediately north of the Canada-Manitoba Crop Diversification Centre at Carberry, Manitoba was selected (49°54'37" N latitude, 99°21'39" W longitude). The area was seeded to barley in 1997 and sampled in detail to characterize the site with respect to soil characteristics, crop productivity and weed populations. In 1998, six rotation treatments were established (Table 1). Each phase of each rotation was present in each year resulting in 18 treatments. Only the potato phase of each rotation was grown under irrigation to reflect the production practices of the area. Please refer to the paper by Mohr et al. (2011)[2] for more details about the study.

From the outset of the planning process, it was recognized that this study alone would not provide answers to all of the production issues facing the potato industry, but rather would assess the impact of rotation on the long-term viability of irrigated potato systems and, potentially, raise questions that might be addressed in supplemental short-term, focused studies. With the passage of time, it was hoped that the study might have the capacity to address issues not considered at the time of its inception.

The six rotations were established in 1998 to determine the impact of rotation length on the long-term production and sustainability of irrigated potato systems in Manitoba. At the time the study was initiated, pressure on the limited irrigated land base in Manitoba, and the high value of potato relative to other crops, had created interest in the use of 2-year rotations, which had been employed in Manitoba to a limited extent and more widely in some other potato-growing regions. Longer 3- and 4-year rotations were included to reflect standard practices. Continuous potato with fumigation was rejected as a treatment, being viewed as unsustainable.

A range of rotational crops including wheat, oat, canola and alfalfa were selected to determine the impact of these crops on overall potato production. Specifically, canola was included as a rotational crop in the 2-, 3- and 4-year rotations to test the hypothesis that the inclusion of canola (a *Brassica* species) would reduce disease potential in potato. Alfalfa was included as a rotational crop in one 4-year rotation to assess the impact of a perennial legume on disease incidence, weed populations and soil properties, in comparison to a 4-year rotation of annual crops only. Wheat and oat reflected commonly-grown cereals in the region.

Over the course of the study, many factors were assessed including crop yield and quality, weed populations, disease incidence, wireworms, economics, and soil chemical, microbial and physical properties. The analysis of these results is still ongoing.

Major Findings

Potato yield and quality: Yield varied considerably among years of the study[2] (Table 2). This strong impact of environment was evident even though the same potato variety was grown under irrigation, in the same location, using similar management practices each year, and pests were well-controlled.

Differences among rotations developed slowly over time. In the first nine years, no single rotation or group of rotations consistently out-performed the rest but this changed as the rotations matured[2]. Over the period 2002-2009, canola-containing rotations produced higher yields in 2002, 2004 and 2005, but not beyond 2005. From 2007 onward, 2-year rotations produced a markedly lower yield than 3 and 4 year rotations. Similar trends were evident in 2010, although the yield difference between the 2-year rotations and the longer 3 and 4 year rotations appeared to diminish. No statistical differences were noted between the 3- and 4-year rotations, although P-C-W and P-C-A-A were most often among the higher-yielding rotations. While there was a trend toward lower average yields in the 3-year compared to the 4-year rotations in 2008 and 2009, there was little yield difference in 2010, so it is unclear at this point if yield differences will emerge between the longer rotations.

In general, rotation had little effect on tuber quality factors such as hollow heart, fry colour and specific gravity, likely because management (e.g. variety, nutrient management, irrigation) and environmental factors (e.g. air and soil temperature) that influence quality were consistent among rotations within a given year.

Potato diseases: The presence of canola in P-C promoted some diseases while suppressing others disproving the hypothesis that including canola in rotation would reduce potato diseases overall. Potato early dying (PED), a vascular wilt disease commonly found in established potato production areas, was more prevalent in the P-C than P-W rotation. Over the six years preceding 2010, the incidence of PED in P-C gradually increased before declining in 2010. By comparison, over the same time period, PED incidence in P-W increased but levelled off in 2009 and 2010, to a lower disease incidence than in the P-C rotation. In contrast to PED, fusarium dry rot was less common in P-C than P-W in some years. Based on pathogens isolated from the P-W rotation, it appeared that one of the *Fusarium* species that causes Fusarium Head Blight in wheat may also have infected potato.

Growing a perennial alfalfa crop in rotation with potato appeared to increase the potential for sclerotinia in potato, even in the 4-year rotations. Despite a 3-year break from potato in the P-C-A-A rotation, sclerotinia disease was favoured by two factors: growing sclerotinia-susceptible canola and alfalfa, and creating a microclimate suitable for disease development by underseeding canola with alfalfa in its establishment year.

Weed populations: Weeds were well-managed in the potato phase of all rotations through a combination of recommended herbicide applications and tillage, and for these reasons did not affect potato yield and quality.

Annual weeds were the main species present, although volunteer crops were often significant as well. Short rotations were not found to increase the weediness of potato phase. The inclusion of alfalfa in rotation with potato did not reduce weed numbers likely because the seeds of most annual weeds are long-lived in the soil, and therefore were not controlled in the 2-year alfalfa crop. Growing alfalfa in rotation with potato did, however, increase the occurrence of alfalfa, sweetclover and medic observed in the rotations.

Soil quality: The potential for soil erosion in these six rotations was always higher following potato in rotation. Crop residue cover was lower following a potato crop and below levels required to control soil erosion. However, the proportion of aggregates in the erodible fraction was lower than levels considered critical for wind erosion.

Soil organic carbon did not change during the 1998-2005 time frame of the study. Soil organic carbon levels (0-7.5 cm depth increment) ranged from 4.0% to 4.3%.

Soil microbial communities: Soil microbial communities were found to differ between soil depths, among rotations, and among phases within a rotation. It is hypothesized that these differences may be a function of the crop species in the rotation and management. Differences in microbial communities reflect the relative activity of the wide range of microbial populations present in the soil, including beneficial and pathogenic organisms, and can influence soil decomposition processes and nutrient cycling.

Wireworm incidence and damage: Feeding by wireworm larvae can result in shallow to deep holes in potato tubers thereby reducing quality. Higher wireworm larvae populations were typically measured where wheat rather than canola or alfalfa preceded potato. In most cases, a higher percent of damaged tubers was also observed where wheat preceded potato. Several factors are thought to have contributed to lower wireworm populations where canola had been grown prior to potato: the application of thiamethoxam (Helix Xtra) to canola seed and the production of glucosinolate degradation products in canola, both of which may deter wireworms and click beetles, and preference by wireworms for crops other than canola.

Economics: Due to the high value of potato relative to the other crops grown in rotation, the overall economic performance of each rotation was primarily a function of the frequency of potato in rotation and potato yield[3]. For the period 1999 through 2005, average annual net revenue of the rotations ranged from $149 to $403 per acre ($368 to $996 per hectare). The P-C rotation had the highest net revenue due to the high frequency of potatoes in rotation and higher marketable yields, and not due to the higher canola yields. P-C-W was also among the high revenue-generating rotations, while P-W-C-W had the lowest annual net revenue due to the low frequency of potato in rotation and lower marketable yield.

Net revenue derived from the potato crop also varied among rotations. For 1999 through 2005, potato in the P-C rotation generated a higher net revenue in three of seven years due to a higher marketable yield. However, the average net revenue from the potato crop (1999-2005) was similar for P-C, P-C-W and P-C-A-A rotations. Three- and four-year rotations did not differ in potato net revenue. In the years following 2005, the economic performance of two-year rotations declined due to declining yields. Results for the period 1999 to 2010 showed no difference in net revenue among potato rotations. Net revenue of potatoes also did not vary among rotations for the period 1999 to 2010. Net revenue trended higher for the 2-year rotations than the 3- and 4-year rotations but the net revenue differences were not significant.

In all rotations, high production costs were associated with potato production. The estimated cost of potato production was more than $1600 per acre ($4000 per hectare), with 36% allocated for machinery and fuel, 20% for chemicals, and about 6% for fertilizer.

Practical aspects of these findings: Two-year irrigated potato rotations represent a significant production risk to growers in the longer term due to the development of high levels of PED and consequent declines in marketable potato yield. Growing canola rather than wheat in a 2-year rotation with irrigated potato did not provide protection against PED and, in fact, appeared to increase the incidence of PED, although marketable yield was reduced in both P-C and P-W.

Disease, specifically PED, was the main driver influencing marketable potato yield as neither weed pressure nor declining soil quality were closely associated with observed potato yield declines in the current study. A combination of tillage and the use of recommended herbicides and rates, was found to effectively control weeds to prevent significant economic losses. Despite the lack of a close relationship between yield declines and soil quality in the initial years of the current study, impacts of rotation on soil quality and, in turn, on long-term productivity are worthy of consideration. Low levels of crop residue cover following potato increase the potential for soil erosion, which will lead to declines in soil quality and productivity especially for soils more prone to erosion. While soil organic carbon was not influenced in the short-term in the current study, the return of low levels of crop residue to the soil combined with intensive tillage have the potential to reduce soil organic carbon content in the longer term, resulting in detrimental effects on a range of soil physical, chemical and biological properties.

Despite the production risks associated with 2-year rotations in the longer-term, an economic argument can be made for using 2-year rotations in the short-term due to the high value of the potato crop. For the initial eight years after rotations were initiated, a high frequency of potato in rotation provided significant economic benefits especially in the P-C rotation. The challenge in using a 2-year rotation in the short-term is predicting when to change the rotation. As an example, marketable yield in the P-C rotation was >90% of the highest-yielding treatment in 2006, 70% in 2007 and only 60% in 2008. Once a soil is infested with PED and yield declines have begun, it is unclear if soils can be effectively remediated and, if so, at what cost. This may have long-term implications for potato production on an infested field.

Declines in marketable potato yield were not evident in the 3- and 4-year rotations during the first thirteen years after rotations were established. These longer rotations appeared to maintain their productivity relative to the 2-year rotations, although there was some evidence of PED in these rotations also. P-C-W and P-C-A-A were most consistently among the higher-yielding rotations. From 2002 to 2010, relative marketable yield (as a percent of the highest-yielding rotation) was >90% for P-C-A-A in all years, and for P-C-W in 8 of 9 years. It is interesting to note that the 3-year rotations had numerically lower total and marketable yields than P-C-A-A in 2008 and both P-C-A-A and P-W-C-W in 2009, suggesting that differences might be developing between the 3- and 4-year rotations; however, there was little difference in the average yield of 3- and 4-year rotations in 2010. These short-term yield variations emphasize the need for long-term monitoring of rotations to separate out short-term variations from long-term trends.

Future

Brandon Research Centre's involvement with the Potato Rotation Study ended in spring 2011, following fourteen years of research in cooperation with the Canada-Manitoba Crop Diversification Centre (CMCDC). The study (with its original treatments intact) was maintained for the 2011 growing season by CMCDC. The future of this study is currently under evaluation.

While the Potato Rotation Study has yielded considerable information since its inception in 1997, it is likely that the most interesting findings have yet to emerge. Going forward, this study has the potential to address a number of important questions regarding the sustainability of potato systems in Manitoba, among them - *Are 3- and 4-year rotations economically and environmentally sustainable in the long-term? Is declining productivity in potato rotations a function solely of rotation length, or rather of the number of potato crops grown at a given site? Can disease-infested soils be returned to economically viable levels of production?* Only long-term monitoring of cropping systems studies can reliably identify shifts in the relative performance of rotations over time, and yield answers to these important questions which provide the foundation upon which to build sound agronomic advice and the environmental policies of the future.

Beyond the questions surrounding sustainability, this study has the potential to address more fundamental questions regarding the functioning of these cropping systems – *How are soil microbial communities impacting plant pathogens? Can soil microorganisms be "managed" to aid in the control of soilborne pathogens affecting potato, or to otherwise benefit the cropping system?* Long-term cropping systems studies afford a unique opportunity to assess naturally occurring microbial populations in an environment reflective of the production region, and for which a full history and archived samples are available for assessment.

In 2010, Brandon Research Centre scientists proposed that the Potato Rotation Study be continued in a modified format in order to assess the potential for remediation of the 2-year rotations, and to determine the long-term viability of all rotations. The disease-infested 2-year rotations provide a unique opportunity to determine if soils that have developed high disease levels can be remediated using fumigation (chemical or biological) and, perhaps more importantly, if yields can be returned to their former level or at least to a more economically viable level. Preliminary evidence during the 2010 growing season suggesting possible declines in vascular wilt and yield improvements in these 2-year rotations raises another interesting prospect – might these soil systems have the potential to become suppressive to vascular wilt and, if so, to what degree can this inherent disease-suppressiveness reduce disease incidence and increase yield? The Potato Rotation Study is ideal for addressing these issues because, not only is naturally-occurring disease inoculum present, but also the full history of the rotation is available to aid in interpretation of the findings. Information regarding the relative efficacy of remediation treatments and of disease-suppressive soils would be especially useful in Manitoba where significant declines in productivity due to early dying have been observed in potato-growing areas.

Continued assessment of modified 2-year rotations and the original rotations was proposed in order to assess their agronomic, economic and environmental sustainability in the longer term (14+ years after establishment). Further, it was recognized that continuation of this long-term study would allow testing of the hypothesis that declining productivity in potato is a function of the number of potato crops grown in a field rather than the frequency with which potato is grown in rotation. An understanding of the impact of rotation on long-term sustainability, and the potential to remediate “unsustainable” rotations, will provide guidance for the refinement of existing cropping systems, whether that be with traditional rotations of a given duration, stacked rotations, the inclusion of specific rotational crops or biofumigants, or some combination of these.

Table 1. Treatments in the Potato Rotation Study at Carberry, Manitoba

Rotation[1]	Abbreviation	Duration (years)
Potato-wheat	P-W	2
Potato-canola	P-C	2
Potato-canola-wheat	P-C-W	3
Potato-oat-wheat	P-O-W	3
Potato-wheat-canola-wheat	P-W-C-W	4
Potato-canola(underseeded to alfalfa)-alfalfa-alfalfa	P-C-A-A	4

[1]Treatments were arranged in a randomized complete block design (RCBD) with four replicates.

Table 2. Marketable (>2" diameter) yield of potato (Mg ha^{-1}) in the Potato Rotation Study at Carberry, Manitoba (2002-2010)[1]

Rotation	2002	2003	2004	2005	2006	2007	2008	2009	2010
P-W	37.3	46.7	21.7	29.1	43.8	33.8	28.9	22.9	37.3
P-C	44.7	47.4	28.4	31.0	42.7	29.5	24.9	23.1	33.1
P-C-W	40.7	48.3	27.1	34.7	44.1	42.3	34.5	33.4	41.4
P-O-W	35.8	45.8	24.2	31.0	44.8	38.8	36.7	32.7	38.2
P-W-C-W	37.8	44.2	22.8	34.4	47.1	39.4	34.7	36.8	42.1
P-C-A-A	41.2	46.4	28.8	36.2	44.0	40.0	41.8	35.9	39.2
S.E.[2]	2.14	1.89	2.02	1.30	1.54	2.37	2.23	2.59	1.36

[1]Yield data (2002-2009) were reported previously in the paper by Mohr et al. (2011)[2].
[2]Standard error of the mean for each rotation is indicated. For P-W-C-W in 2002, S.E. was 2.45.

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