Canadian Journal of Plant Science
Revue canadienne de phytotechnie

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Journal:	<i>Canadian Journal of Plant Science</i>
Manuscript ID	CJPS-2016-0053.R1
Manuscript Type:	Article
Date Submitted by the Author:	08-Jun-2016
Complete List of Authors:	Smith, Elwin; Agriculture and Agri-Food Canada, LeRoy, Danny; The University of Lethbridge, Economics Maccallum, Phyllis; The University of Lethbridge Janzen, Henry; Agriculture and Agri-Food Canada, Research Branch
Keywords:	Wheat, crop rotation, productivity, economic, risk

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**Will summer fallow re-emerge in the Dark Brown soil zone of the Canadian Prairie
as a response to net return risk?**

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Le Roy, D. G., Smith, E. G., MacCallum, P. J. and Janzen H. H. 2016. **Will summer fallow re-emerge in the Dark Brown soil zone of the Canadian Prairie as a response to net return risk?** Can. J. Plant Sci. **XX**: 000-000. We assessed the extent to which summer fallow in the Dark Brown soil zone is likely to return as a response to net return (NR) risk. An economic model was used to identify, delineate and quantify the effects of changes in product prices and input costs on the long-term economic performance of cereal, legume forage, and legume green manure rotations, based on a long-term study at the Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre at Lethbridge, Alberta. The analysis determined NR from the rotations and simulated NR in a stochastic risk model. Each rotation had a different yield distribution and cost profile. The NR risk for the rotations was evaluated using stochastic efficiency with respect to a function. A risk-free return was computed to rank the rotations. Continuous fertilized wheat was the most profitable crop rotation, followed by three-year rotations with fallow

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and either nitrogen fertilized wheat or livestock manure applied after fallow. Rotations with higher NR used less fallow but had higher risk. Summer fallow is unlikely to re-emerge as only rather risk averse and very risk averse growers would use summer fallow as a means of reducing NR risk.

Key words: crop rotation, risk, economic, productivity, summer fallow

Short title: Crop rotation as risk response

Abbreviations: ARAC, absolute risk aversion coefficient; CE, certainty equivalent, F, summer fallow; F_M, fallow with livestock manure applied in the fall; H, hay; L_{GM}, legume green manure; N, nitrogen; NR, net return; OP_M, oat-pea with manure application, SERF, stochastic efficiency with respect to a function; W, wheat;

Summer fallow has been an important but declining agricultural practice in the semi-arid regions of the Canadian Prairies. In the Dark Brown soil zone of Alberta and Saskatchewan, 39.3% of arable land was in fallow in 1976, this declined to 6.1% by 2011 (Statistics Canada 1978; 2015a). Across the Prairies, the area left idle as fallow has steadily declined from 10.9 million ha in 1976 to about 2.1 million ha in 2011 (Statistics Canada 2015c). Fallow allowed a crop to use the moisture and nutrients of more than one crop year, thus enabling a pattern of production that otherwise would have been physically impossible or uneconomic. Fallow facilitated the mineralization of soil organic matter, releasing nitrogen (N) for the subsequent crop and increased spring soil moisture during drier years. The decline in fallow area corresponded with the contemporaneous adoption of conservation practices such as zero tillage and direct seeding (86% of seeded

area in 2011, Statistics Canada 2015d), and increased cropping diversity with more oilseeds and pulse crops (area in these crops increased by 63% from 1995 to 2014, Statistics Canada 2015e). Growers have maintained and enhanced soil productivity by applying inorganic N fertilizer, by expanding production of N-fixing crops (annual legumes, alfalfa), and by applying livestock manure. Although changes in tillage were driven in part by the need to sustain soil quality (reduce soil erosion), many producers also enjoyed economic benefits from reduced operating costs and higher net return (NR) (Zentner and Campbell 1988; Zentner et al. 1996).

The frequency of summer fallow in crop rotations has been the object of study mainly in the semi-arid Brown soil zone of the Canadian prairies (Zentner et al. 2006). The primary source of N fertility was inorganic fertilizer, but Zentner et al. (2006) also considered green manure legume. Fallow in crop rotations in the less arid Dark Brown soil zone is less common. Consequently, it has not been a focus of much research, and organic sources of N have not been considered (Smith et al. 2015a). It would be expected that fallow in this region would generate fewer benefits, and organic sources of N would be more competitive with inorganic N because of less moisture stress.

In the Brown soil zone, cropping the land more intensively to cereals and oilseeds has been shown to increase farm net income when product prices are high; but, with low product prices or high input costs these rotations often provide less net income than those containing higher proportions of summer fallow (Schoney and Thorson 1986; Zentner and Campbell 1988; Zentner et al. 1996, 2006). When faced with the prospect of falling grain prices, growers often protect profit margins by reducing the use of costly inputs such as N fertilizer and switching to rotations with lower costs of production. They

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operate within a highly competitive market under difficult growing conditions, narrow operating margins and increasingly variable input and output prices.

Realized net farm income in 2014 across the Prairie Provinces was only 3.35% of \$31.9 billion of total farm cash receipts (Statistics Canada 2015b). With small, variable and uncertain profit margins, an important research problem is to ascertain if and to what extent summer fallow in the Dark Brown soil zone of the Prairie region is a viable response of growers to price and production risk. Price risk could prompt risk adverse growers to select a production system with lower but more stable NR relative to product and price certainty. The lower the price risk of a particular input (such as plant accessible N through summer fallow), the greater the relative demand for that input by risk averse producers, *ceteris paribus* (Robison and Barry 1987). With regard to production risk, crop yields are the outcome of processes influenced by two discernible stochastic phenomena. The first is the effect of input on expected output; the second is the effect of input on variability of output. Unforeseen and unforeseeable environmental conditions, pestilence, the biological response to inputs, and other random events give rise to differences between expected and realized yield.

Although specific economic circumstances vary from grower to grower, an assessment of alternative and inherently risky production systems provides an improved understanding of the relevant and unavoidable trade-offs (Lien et al. 2007; Pendell et al. 2007; Fathelrahman et al. 2011; Williams et al. 2010, 2012). The objective of our research problem involved identifying, delineating and quantifying the effects of changes in product prices and input costs on the economic performance of feasible crop rotations with cereal, legume forage, and legume green manure in the Dark Brown soil zone of the

Canadian Prairies. The NR was determined for ten different crop rotations. The riskiness of these rotations was evaluated to determine the trade-off between average NR and acceptance of risk by the producer, to determine preferred crop rotations. The innovative contribution was to deduce and calculate how growers with different risk tolerances may respond to changing and uncertain economic circumstances with their choice of crop rotation and the implication of this choice with respect to the source of N. The basis of the analysis was a long-term study of the physical aspects of alternative dryland crop rotations at the Canadian Agriculture and Agri-Food Research and Development Centre at Lethbridge, Alberta. It is an appropriate dataset for analyzing risk over time.

MATERIAL AND METHODS

Field Study “Rotation 120”

A long-term crop rotation, “Rotation 120”, was initiated in 1951 at the Lethbridge Research and Development Centre, Lethbridge, Alberta (49.705°N, 112.775°W) to evaluate yields and soil fertility associated with common and potential crop rotations for the area (Smith et al. 2012; 2015b). The soil was an Orthic Dark Brown Chernozem developed on alluvial lacustrine parent material under native vegetation of tall and short grass species. Surface soils have a loam texture (450 g kg⁻¹ sand, 300 g kg⁻¹ silt, 250 g kg⁻¹ clay). Subsurface layers are calcareous. Plots were established on land that had been used for a mixed crop rotation with light manure applications every sixth year since being broken from native grass in about 1910.

Table 1 depicts ten of the crop rotations which were the focus of this scientific investigation. The rotations were wheat (*Triticum aestivum* L.)-based and included

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alternative methods to add N to the system. They included continuous wheat (W), fallow-wheat (FW), fallow-wheat-wheat (FWW) (without and with (+N) inorganic N fertilizer), oat (*Avena sativa* L.) plus field pea (*Pisum sativum* L.) for forage with applied livestock manure- wheat-wheat (OP_MWW), lentil (*Lens culinaris* Medikus) (green manure)-wheat-wheat (L_{GM}WW), fallow with fall applied livestock manure-wheat-wheat (F_MWW) and fallow-wheat-wheat-hay-hay-hay (FWWHHH). The hay was a crested wheatgrass (*Agropyron cristatu* L.)-alfalfa (*Medicago sativa* L.) mixture. Annual legumes and the alfalfa in the hay mixture received treatment with appropriate *Rhizobium* sp. for N fixation. The experiment was a complete randomized block design with four replicates. All phases of each crop rotation were present each year. For example, the six year rotation FWWHHH had six plots per replicate.

The plots were small (3.2 m x 36.6 m), but field practices were similar to what commercial producers would typically use on a larger scale. Seeding rate, weed control, and field operations reflected industry standard practices. Phosphorus fertilizer was applied to all grain plots (25 kg P₂O₅ ha⁻¹) and when alfalfa was established (50 kg P₂O₅ ha⁻¹). The N fertilizer (ammonium nitrate) was applied at 45 kg N ha⁻¹, in early spring. Livestock manure that was one to two years old from a commercial feedlot was applied to fallow of the F_MWW rotation and after oat-pea of OP_MWW every second rotation (once every six years) in the fall at 11.2 Mg ha⁻¹ (wet weight). The manure was incorporated into the soil after application.

Seedbed preparation included a tillage pass. If conditions were dry, a chemical pre-seed burn-off of weeds was done in place of tillage. Phosphorus for the cereal crops was applied with the seed. Control of weeds on fallow was with a combination of non-

selective herbicides and tillage. In-crop weed control generally included a mixture of products to control broadleaf and grassy weeds. There was no in-crop weed control for hay, L_{GM} and OP_M . Hay plots were mowed in the establishment year if weeds or volunteer grain were shading the alfalfa. Post harvest weed control was done with a non-selective herbicide to control perennial weeds. Hay in rotation FWWHHH was terminated at the end of the rotation with a combination of herbicide and tillage. The L_{GM} was tilled into the soil in early July, after flowering commenced. It was not allowed to grow for maximum N fixation because a longer growth period would use soil moisture that would otherwise be available for the next crop (Zentner et al. 2004).

Wheat was harvested with a small plot combine. The wheat samples were cleaned and a sub-sampled was dried at 60°C for seven days to obtain the dry weigh of grain. Forage samples for the oat-pea and grass-alfalfa were taken with a plot forage harvester. A subsample of the wet harvested weight was dried at 60°C until a constant weight was obtained (usually seven to 10 days) to obtain the dry weight yield. The remaining forage on the plot was removed from the plot. A biomass sample of the lentil green manure crop was obtained prior to tilling the crop.

To show the impact of crop rotations on production, in Table 2 the annual mean production from each rotation was calculated as total output divided by the number of years of the rotation. Annual mean production was highest for the rotation of continuous wheat with applied inorganic N, W(+N), at 2401 kg ha⁻¹ yr⁻¹. The FW(+N) rotation had a lower annual mean wheat production (1558 kg ha⁻¹ yr⁻¹) as each year half the land was fallowed. With one-third of the land fallow and two-thirds in wheat production, FWW(+N) had an annual mean wheat production of 1888 kg ha⁻¹ yr⁻¹. Output from the

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OP_MWW and FWWHHH rotations included both wheat and forages. For FWWHHH, the annual mean wheat (1047 kg ha⁻¹ yr⁻¹) and forage (1661 kg ha⁻¹ yr⁻¹) production appear low because for this six year rotation wheat was produced for only two years and hay for only three. Annual mean wheat production was also low for the OP_MWW rotation and for the rotations without N added to the system (W, FW, FWW).

Conceptual Economic Framework

The aim of the conceptual framework was to deduce the effects of price and yield risk on a grower's choice of cropping system in contrast to outcomes under conditions of certainty. This framework was then used to structure the empirical analysis.

At the level of the individual enterprise, a grower in the Dark Brown soil zone faces a price elastic demand curve for their outputs, meaning they were price takers for wheat and hay. This was a reasonable assumption as prices for wheat are discovered through global markets and changes in the quantity supplied by any producer has no effect on world prices. Hay prices are discovered through regional markets characterized by steady demand from raw milk and cow-calf producers. Sellers in regional hay markets also supply other outputs. Similar to the situation for wheat, the quantity of hay produced by a single enterprise was small relative to total regional supply. Thus changes in the quantity supplied by a single hay seller were assumed to have no influence on hay price.

Under conditions of certainty the objective of the grower was to maximize NR by choosing one of a number of mutually exclusive production systems, j :

$$\max_j NR_j = \sum_c (P_c Q_{c,j}) - wx_j - OC$$

183 where P is the price of the crop, c is the crop (wheat or forage), Q is total production, w is
 184 a vector of per unit input costs, x is a vector of input usage levels for production system j ,
 185 and OC are other costs incurred regardless of what outputs are produced (i.e., utilities,
 186 land taxes, insurance on capital assets, etc.)

187 With risk, output price, P , was not certain and was expressed as an expectation:

$$188 \quad P_c = E(p_c + \varepsilon), \text{ with } E(\varepsilon) = 0 \text{ and } Var(\varepsilon) = \sigma_\varepsilon^2$$

189 where $E()$ was an expected value and $Var()$ was variance. Per unit input prices, W_i , can
 190 also be uncertain, particularly in a multiyear cropping system, so:

$$191 \quad W_i = E(w_i + \gamma_i), \text{ with } E(\gamma_i) = 0 \text{ and } Var(\gamma_i) = \sigma_i^2 \text{ for } \forall i.$$

192 The stochastic production function approach pioneered by Just and Pope (1978) was
 193 applied to characterize the effects of inputs on the level and variability of output. The
 194 fundamental concept underpinning their approach was the partition of the production
 195 function into two components: the first depicting mean output and the second
 196 representing the variability of that output:

$$Q = f(x) + h(x)\delta$$

197 where $f'(x_i) > 0$, $f''(x_i) < 0$, $h'(x_i) \geq 0$, with $E(\delta) = 0$ and $Var(\delta) = \sigma_\delta^2$. With this
 198 general functional form, Just and Pope (1978) established seven conditions an economic
 199 model must satisfy for inputs in the model to be risk reducing. The marginal physical
 200 productivity of inputs, $f'(x_i)$, is positive but decreasing, reflecting that output increases
 201 at a decreasing rate as additional units of inputs are applied. Reductions in the variance
 202 in output, $\sigma^2(Q)$, from using a different amount of a risk reducing input, x_i , can change as
 203 the use of the risk reducing input changes. With price and yield uncertainty, the objective
 204 of the grower was:

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$$\max_j E(NR_j) = \sum_c \left(E(P_c)E(Q_{c,j}) \right) - E(w)x_j - OC$$

205 When confronted with uncertainty, risk adverse growers will attempt to reduce
 206 their risk exposure. One approach could be to adopt production systems with less risk,
 207 but these systems typically also have lower expected NR (Zentner et al., 2006; Smith et
 208 al. 2015a). A study by Miller et al. (2015) was an exception as they found a field pea
 209 based cropping system that had higher NR and less risk, a profit and risk dominant
 210 system. When there is a NR-risk trade-off, the producer needs to evaluate the trade-off.
 211 The degree of the trade-off is indicated by a risk aversion coefficient. Every individual
 212 has a different level of risk tolerance, for example risk neutral to extreme risk aversion,
 213 which is a product of personal preferences, availability of insurance and financial
 214 leverage of the farm. As individual producer risk preferences are difficult to quantify,
 215 alternative approaches have been developed. These approaches have included stochastic
 216 dominance (first and second degree), stochastic dominance with respect of a function,
 217 and stochastic efficiency with respect to a function (SERF) (Hardaker et al. 2004).

218 It was not always possible to determine the dominant system with stochastic
 219 dominance methods. The SERF method, by comparison, computes a certainty equivalent
 220 (CE) for each system and level of risk aversion. The CE is the amount of risk-free NR
 221 that would be viewed by the grower as being equally desirable to a potentially higher but
 222 uncertain NR. The CE subtracts the risk premium from the expected NR – a higher risk
 223 premium for high NR variability and higher aversion to risky outcomes. The set of risky
 224 alternatives are then ordered based on the CE (Hardaker et al. 2004). SERF required the
 225 assumption of constant absolute risk aversion over all levels of outcomes (Hardaker and
 226 Lien 2010). The specific formula for computing the CE was reported by Hardaker et al.

(2004) for a negative exponential utility function. The absolute risk aversion coefficient (ARAC) has a suggested upper bound of $(4/\text{average NR})$ (Hardaker et al. 2004).

Data Analysis

The NR and production cost were initially computed for each of the field observations. The NR used an average (1995-2014) wheat price of $\$258 \text{ t}^{-1}$, oat-pea forage of $\$97 \text{ t}^{-1}$ and alfalfa-grass hay of $\$108 \text{ t}^{-1}$ (AAF 2016). Fertilizer costs were average April prices (1995-2014), $\$1.30 \text{ kg}^{-1}$ of N and $\$1.13 \text{ kg}^{-1}$ of P_2O_5 (AAF 2016). Prices and costs were adjusted to real prices (2012=100) by the Farm Input Price Index (Statistics Canada 2016).

Production costs, other than fertilizer, were based on current costs for seed and seed treatment, herbicides, machinery (fuel, repairs, depreciation), and other overhead costs (land taxes, buildings, business overhead, utilities). Harvest cost depended on wheat and forage yield. Minimum tillage was used, with additional tillage to work in the legume green manure, livestock manure, and to terminate the alfalfa. Machinery operation costs were based on custom rates, less the profit margin to the custom operator (Government of Saskatchewan 2015). Rotation costs were lowest for rotations without fertilizer and highest for fertilized continuous wheat (Table 4). The non-fertilizer costs typically have limited variability over time. Diesel fuel cost can vary over time, but was kept fixed in this analysis because the largest variation in fuel cost would have impacted total costs by less than 2%.

When determining the NR for individual field observations, statistical differences in NR by rotation were determined using the PROC MIXED procedure of SAS (SAS

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Inst. 2015) with the rotation as the fixed effect and year and replicate as random. The price of wheat will impact the profitability of fallow in a rotation, and was varied to determine the price at which NR would include or not include fallow. The price of oat-pea forage and alfalfa-grass hay was varied to determine the price of forage required to compete with the wheat rotations.

Risk analysis

To evaluate the risk of the systems and determine the dominant system, yield, crop price and N fertilizer price were specified as stochastic in a spreadsheet simulation model (Richardson et al. 2008). Multivariate empirical distributions were specified from actual field data for crop yield, and price data for prices. Multivariate empirical distributions were used because they include correlations among variables. The crop rotation yields were not independent because rotations had the same weather conditions each year. Prices for crops and fertilizer could be dependent because of product substitutions and derived demand for fertilizer. An empirical distribution better describes data when there are limited observations (Richardson et al. 2000). The price distribution was estimated from the real 1995-2014 prices and fertilizer costs. The yield distribution was estimated using the mean replication yields for 2002-2014.

A shift in the price distribution for wheat and hay will impact the risk preferred rotation. Mean wheat prices of \$192, \$225, \$258, \$291 and \$324 t⁻¹ were used to evaluate the impact of a wheat price shift. The values represented the 10, 25, 50, 75 and 90 percentiles of the historic wheat yield distribution. The mean hay price was shifted to the 15 and 85 percentiles (\$73, and \$143 t⁻¹) of the hay price distribution to evaluate the hay

price impact on NR and risk for the FWWHHH rotation. The impact of higher N cost on fertilized rotation returns was evaluated with N prices of \$1.60 (maximum historic N price), and \$2.10 kg⁻¹ (an extreme). Higher N prices could occur because of higher natural gas prices and fertilizer production costs, for example. The preferred crop rotation under risk if livestock manure was not available or if the producer did not want to produce forage, was determined for the different mean wheat prices.

The risk simulation model drew yields and prices from the empirical distributions for each of 5000 model iterations. The macro SIMETAR (Richardson et al. 2008) was used within the spreadsheet budget model to perform the simulations and compute the CE over a range of absolute risk aversion coefficients (ARAC) for each production system. The risky alternatives were then ranked based on their CE over the range of ARAC. The outcomes of yield and prices were unknown to the decision maker. Crop yield insurance was not included and spot prices were used for outputs and fertilizer. The simulated expected yields and prices were comparable to those in the deterministic analysis of NR. The production costs for field operations (machine passes, herbicides, other costs) were the same as for the deterministic model.

To test whether crop insurance or an approximation to hedging impacted the risk results, the simulation model was modified to include crop insurance with coverage at the 70% long-term yield by rotation, and a minimum wheat price that was at the 20 percentile of the wheat price distribution to prevent extremely low prices. Crop yields over the study period were not highly variable, so crop insurance was a net cost as indemnities were infrequent and of low value, less than 0.5% of the iterations for most rotations and 1.5% for the W(+N) rotation. The price hedge increased the average NR and reduced the

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variability of all rotations, but the reduction did not alter the risk results compared to no crop insurance nor hedging (data not shown). We therefore did not include crop insurance or the hedging approximation.

RESULTS AND DISCUSSION

Deterministic Results

The NR analysis by field observation determined the highest average NR was for the W(+N) rotation, but it was not significantly higher than F_MWW and FWW(+N) (Table 4). Production from W(+N) was higher, but production costs were also higher, especially N fertilizer cost. A lower wheat price of \$203^t resulted in W(+N) and FWWHHH having the same average NR (\$198 ha⁻¹), though not significantly different from FWW(+N), OP_MWW and F_MWW . W(+N) had significantly higher NR over all other rotations when wheat was priced higher than \$305^t. The lowest NR was for wheat rotations without N added to the system (W, FW and FWW) and for FW(+N). For the three-year rotation of fallow and two years of wheat, manure application on fallow was as profitable as applying N to each of the two years of wheat. The profitability of the W(+N) and FWW(+N) rotations relative to FW(+N) was consistent with the findings by Zentner et al. (2006) for the more arid Brown soil zone, and rotations with reduced fallow frequency were more profitable with high wheat prices (Zentner and Campbell 1988). The price of grass-alfalfa hay would need to be \$153 t⁻¹ for the NR of FWWHHH to be the same as W(+N), but only \$120 t⁻¹ to equal the NR of F_MWW . Smith et al. (1994) found the NR from F_MWW and FWWHHH to be similar for the period 1954-84.

The addition of N by annual legumes was less profitable than applying N fertilizer. The $L_{GM}WW$ rotation was less profitable ($\$104 \text{ ha}^{-1}$) than $W(+N)$, but more profitable ($\$63 \text{ ha}^{-1}$) than the rotations without N added to the system (Table 4). Zentner et al. (2006) also reported the NR from a legume green manure crop to be less than from fertilized continuous wheat and a rotation with fallow once every 4th year; however, when the legume crop was terminated in early July it was found that legume green manure was a viable production option (Zentner et al. 1994). In our study, green manure provided N to the system, but was less profitable than $W(+N)$ because of the foregone revenue the year of green manure, and costs were higher than fallow because of lentil seed, inoculum, and seeding costs. For the rotation with field pea (OP_MWW), most of the N produced by the field pea was likely removed in the forage, as indicated by the lower wheat yield following oat-pea compared to after L_{GM} (Table 2). The application of manure once every sixth year was inadequate to supply four years of wheat and two years of oat-pea. The price of oat-pea forage would need to be about $\$220 \text{ t}^{-1}$ for the NR of the OP_MWW rotation to equal that of $W(+N)$.

The cost of N fertilizer impacted the NR of the three fertilized rotations. At an N price of $\$1.60 \text{ kg}^{-1} \text{ N}$, the $FWWHHH$ rotation was as profitable as the $W(+N)$, and at $\$2.10 \text{ kg}^{-1} \text{ N}$, the NR of $L_{GM}WW$ and OP_MWW rotations were not different from $W(+N)$. The price of N fertilizer would need to be at historical prices, or higher, before it would be profitable to supply crop N by legume crops.

The rotation NR varied by year, depending on the growing conditions. In dry years, rotations with fallow had relatively higher NR but in years with adequate moisture fallow penalized NR because crop yields on fallow and stubble and were similar. The

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fallow-weather relationship in this study was consistent with that reported by other crop rotation studies (Zentner and Campbell 1988; Zentner et al. 2006; Smith et al. 2015a).

Risk Results

The risk model simulated NR for the 10 crop rotations. The average simulated NR was consistent with the NR reported in Table 4. The rotation W(+N) had the highest expected NR, followed by F_MWW and then FWW(+N). The rotations FW and FWW had the lowest expected NR. The standard deviation of the simulated NR was highest for W(+N), about 40% higher than for FWW(+N) and F_MWW, and lowest for FW, FWW, FW(+N), and FWWHHH.

The NR and riskiness of the NR were converted to a CE. The CE values computed for each rotation and level of risk aversion were reported as the risk premium relative to rotation FW(+N) (Figure 1). When ARAC was 0 (risk neutral), the risk premium was the difference in the expected NR between FW(+N) and the other nine rotations. When risk was more of a concern, higher ARAC, the CE of risky rotations was reduced relative to FW(+N). For this study, an ARAC of up to 0.0045 indicated somewhat risk averse, from 0.0045 to 0.009 rather risk averse, from 0.009 to 0.013 very risk averse, and from 0.013 to 0.018 paranoid about risk (Hardaker et al. 1997). A rather risk averse producer would prefer FWWHHH over W(+N), giving up about \$75 ha⁻¹ in average NR to have less risk. This assumed the producer would be willing to grow hay. If a producer did not want to produce hay because of equipment or other preferences, then the F_MWW rotation would be preferred over W(+N) by rather risk averse producers. If livestock manure was not available, then FWW(+N) would be the next best rotation

option, but only for very risk averse producers. Some crop rotations were never preferred, regardless of the level of risk aversion (W, FW, FWW, FW(+N), OP_MWW, L_{GM}WW). The rotations without an N source (W, FW, FWW) were the least preferred, followed by FW(+N), OP_MWW and L_{GM}WW. The L_{GM}WW rotation had lower NR primarily because of the cost of seed and seeding the green manure legume, plus the foregone crop revenue during the L_{GM} phase year. The 2-yr FW(+N) rotation was never preferred over the longer 3-yr FWW(+N) rotation.

The price of wheat and of hay directly impacted the preferred crop rotation. Regardless of hay and wheat price, and risk, the rotations a producer would consider were W(+N), F_MWW, FWWHHH and FWW(+N). When the mean hay price was \$108 t⁻¹, and the mean wheat price ranged from \$192 to 324 t⁻¹, the preferred rotation was W(+N) with high mean wheat price and low risk aversion, FWWHHH with high risk aversion and a mean wheat price less than \$275 t⁻¹, and F_MWW with a mean wheat price greater than \$275 t⁻¹ and high risk aversion (Figure 2a). When the mean hay was 73 t⁻¹, FWWHHH was the preferred rotation only with low mean wheat price and high risk aversion, W(+N) was preferred with higher mean wheat price and low risk aversion, otherwise it was F_MWW (Figure 2b). At a high mean hay price of \$143 t⁻¹, the FWWHH was the preferred rotation except W(+N) was preferred when the mean wheat price was high and risk aversion low (Figure 2c). When neither hay production nor the application of manure were production options, W(+N) was the preferred rotation when mean wheat prices were \$192 t⁻¹ with less than 'rather risk averse' preferences, and when wheat prices were greater than \$210 t⁻¹ with less than 'very risk averse' preferences (Figure 2d). Summer fallow was preferred only for low mean wheat prices and by producers who were rather

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to very risk averse. Smith et al. (2015a) also found rotations with fallow to be less profitable but preferred by highly risk averse producers.

The field study used in this analysis was of wheat-based rotations, as are most long-term studies on the Canadian Prairies. Rotations of cereals with oilseed and pulse crops, an increasing practice in the region, could alter the NR and risk of crop rotations and of summer fallow. Miller et al. (2015) found field pea-wheat rotations dominated the conventional wheat-based rotations, an indication that more diverse crop rotations need to be evaluated.

CONCLUSIONS

Growers with different risk tolerances respond to evolving economic circumstances through their choice of crop rotation which, in turn, affects how these growers source N. This study revealed that crop rotations with additional N generated the highest NR. Rotations with no or infrequent summer fallow had higher NR than rotations with frequent fallow. Only growers with very high risk aversion and a lack of alternatives to mitigate price and product risk will use crop rotations with some summer fallow as a risk reduction strategy. Rotations with less variability in NR, either due to summer fallow or lower price and yield variability would be preferred by these risk intolerant individuals. Returns from hay production were less variable than wheat, but growers would either need to accept much lower NR, or hay prices would need to increase substantially before hay rotations would be adopted. Thus, under most circumstances only very risk averse growers in the Dark Brown soil zone would choose crop rotations that include summer fallow.

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ACKNOWLEDGMENTS

412 We thank those who assisted with this study including Linda Kremenick, Darryl
413 Nakonechny, Paul DeMaere, the field crew, and summer students for applying the
414 treatments, seeding and maintaining the plots, and recording the yield data and field
415 observations. We also wish to acknowledge the constructive comments provided by two
416 anonymous reviewers. Any remaining errors are our own.

417

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Crop rotation as risk response

510 Table 1. Long-term rotations from 2001 through 0214, and the year established.^a

Number	Long-term rotation	Designation	Established
1	Continuous wheat	W	1951
2	Fallow-Wheat	FW	1951
3	Fallow-Wheat-Wheat	FWW	1951
4	Continuous wheat, plus N	W(+N)	1985
5	Fallow-Wheat, plus N	FW(+N)	1985
6	Fallow-Wheat-Wheat, plus N	FWW(+N)	1985
7	Oat-pea (+manure)-Wheat-Wheat	OP _M WW	2001
8	Lentil (green manure)-Wheat-Wheat	L _{GM} WW	1985
9	Fallow (+manure)-Wheat-Wheat	F _M WW	1951
10	Fallow-Wheat-Wheat-Hay-Hay-Hay	FWWHHH	1951

511 ^a The +manure was applied in the fall during the fallow phase for F_MWW, and for
512 OP_MWW it was applied in the fall after oat-pea every second occurrence in the rotation.

Table 2. Average, minimum and maximum production by rotation and crop.

Rotation	Crop	Production (kg ha ⁻¹ yr ⁻¹) ^a		
		Average	Minimum	Maximum
W	wheat	1603	896	2721
FW	wheat	1206	769	1900
FWW	wheat	1330	869	2433
W(+N)	wheat	2401	1217	3762
FW(+N)	wheat	1558	1138	2112
FWW(+N)	wheat	1888	1258	2984
OP _M WW ^b	oat-pea	764	606	1204
OP _M WW	wheat	1400	918	2455
L _{GM} WW	wheat	1698	1005	2586
F _M WW	wheat	1872	1245	3026
FWWHHH ^c	wheat	1047	714	1459
FWWHHH	mixed hay	1661	1415	1960

^a Production was for the average for the entire rotation and included fallow and hay establishment, with zero yield.

^b Total wheat and forage production was averaged over the three years of the rotation.

^c Total wheat and forage production was averaged over the six years of the rotation.

Crop rotation as risk response

Table 3. Average, minimum and maximum historical real prices for crop outputs and fertilizer

Product	Price (\$ t ⁻¹)		
	Average	Minimum	Maximum
Wheat	258	188	395
Mixed hay	108	62	183
Urea	596	453	712
Mono-ammonium phosphate	721	587	1228

For Review Only

Table 4. Net return and cost by rotation.^a

Rotation	Net return (\$ ha ⁻¹)	Cost (\$ ha ⁻¹)
W	182 de	232
FW	146 e	165
FWW	157 de	187
W(+N)	329 a	291
FW(+N)	208 cde	194
FWW(+N)	260 abc	226
OP _M WW	229 bcd	206
L _{GM} WW	225 bcd	213
F _M WW	273 ab	210
FWWHHH	255 bc	192

^a The letters following yields indicated significant differences within the wheat yields and within the hay yields.

Crop rotation as risk response

Figure 1. Risk premiums with increasing absolute risk aversion for 10 crop rotations, with FW(+N) as the base rotation.

Crop rotation as risk response

Figure 2. The preferred crop rotation for different risk aversion levels (ARAC) and wheat prices, for (a) hay priced at \$108 t⁻¹, (b) hay priced at \$73 t⁻¹, (c) hay priced at \$143 t⁻¹, and (d) when rotations F_MWW and FWWHHH were not included as production options.