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New Rotation Study – Swift Current, Saskatchewan

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Summary
The "New Rotation" experiment was initiated in 1987 at Swift Current, Saskatchewan. The objectives were to evaluate, under conservation tillage management, the influence of crop and rotation type on crop productivity and grain quality, incidence of plant diseases and weed populations, a suite of soil and environmental parameters, economic performance and energy use efficiencies. The study provided clear evidence that an annual legume green manure (LGM) can be successfully used as a partial fallow replacement for the semiarid Canadian prairies. Increased cropping frequency in combination with appropriate fertilizer applications increased total annualized grain production, fostered improvements in soil quality and precipitation use efficiency. Overall, nitrate leaching risk was shown to be low when conservation tillage management is used.

Introduction
The "New Rotation" experiment was established in 1987 at the Agriculture and Agri-Food Canada Research Centre at Swift Current, Saskatchewan. The location of the study was purposefully chosen to be on similar soil and in reasonable proximity to the "Old Rotation" experiment. The soil is an Orthic Brown Chernozem with a silt-loam texture. Since the establishment of the Old Rotation experiment (1967) the agricultural management and production systems used in Saskatchewan have evolved remarkably. The New Rotation experiment was established to incorporate innovations such as conservation tillage, in-soil fertilizer placement (side-banding), a new type of spring wheat class [high yielding CPS wheat (HY)], new crop sequences, intermediate length rotations, flexible-type rotations, improved snow management through the use of uniform tall stubble created by direct combining, the use of annual legume green manure (LGM), and a perennial grass hay system [continuous crested wheatgrass (CWG)] (Table 1). Thus, the two studies are complimentary, and together provide long-term information and benchmarks covering a wide range of farming activities and approaches represented in the semi-arid prairie region of Western Canada. Specifically, the objectives of the New Rotation study were to evaluate, under conservation tillage management, the influence of crop and rotation type on yield and grain quality, nutrient balance, moisture conservation and water use efficiency, incidence of plant diseases and weed populations, impact on soil organic matter quantity and quality, and changes in soil chemical, physical, and biological properties. Economic returns and non-renewable energy use efficiencies are also being assessed.

Description and Management of Study
Over the years, herbicides and crop varieties have been updated as new and better options became available. Seven of the original treatments remain, having undergone only minor modifications, while two other rotations were replaced in 2006 with a single more diverse cereal-oilseed-cereal-pulse rotation (Table 2). The continuous wheat (ContW - if water) plots were fallowed in 1988, 1992, and 2008 due to inadequate spring soil water, while the ContW (if weeds) plots were fallowed in 1994 and 1996 due to high densities of foxtail barley based on systematic weed counts taken in the plots the previous July.

The crops in each rotation were fertilized with nitrogen (N) (urea fertilizer) based on soil nitrate levels (0–60 cm) determined from soil samples taken the previous fall, and with phosphorus (P) fertilizer rates based on the general fertilizer recommendation guidelines for the area as provided by Saskatchewan Advisory Council (Saskatchewan Agriculture 1988). Starting in 1997, we adopted the criterion of providing an 'N credit' for wheat grown after LGM, by adding to the soil test NO_3-N an amount equal to 20% of the N measured in the above-ground legume biomass of the previous year. The N fertilizer was side-banded and the P fertilizer was placed with the seed, except on the grass plots where the N & P was broadcast on the soil surface. In most years, glyphosate was applied as a pre-seed burnoff.

In 1989, 1992, and 1993 wheat plots being planted also received one preseed tillage operation to prepare the seedbed using a heavy-duty cultivator, but in all other years the plots were planted without seedbed preparation. All crops were planted using a no-till hoe drill (17.8 cm row spacing) in early- to mid-May, except for the legume green manure which was planted in mid- to late-April after 1992. Wheat and canola seed was treated with a seed applied fungicide to control soil-borne and seedling diseases (and also an insecticide in the case of canola), while the lentil and pea seed were inoculated with an appropriate *Rhizobium* culture prior to planting. Wheat received in-crop weed control each year using recommended rates of diclofop methyl or fenoxaprop-p-ethyl, and bromoxynil and MCPA, applied alone or in combination as required. Canola received glyphosate applied in-crop, while pea received imazamox plus imazethapyr. The LGM and CWG received no herbicide. Wheat and other annual crops were harvested at full maturity using a direct cut header combine leaving the stubble as high as possible (usually > 30 cm) to enhance overwinter snow trapping and water conservation. The remaining crop residues were chopped and uniformly spread across the plots with straw and chaff spreader attachments on the combine. Hay from the CWG plots was cut at full bloom, field dried, and baled, with one or two cuts taken depending on moisture conditions. From 1987-1992 the LGM crop was turned down at full bloom (usually between 14 and 25 July). Thereafter it was turned down in early July, in an effort to reduce soil moisture depletion by the legume, using either a wide V-blade cultivator or disc, with subsequent weed growth (if any) controlled with a wide V-blade cultivator.

Herbicides were applied to summerfallow areas in early June using tank mixes of glyphosate plus dicamba and 2,4-D amine. In 1991, 1992, 1996, and 1997 the summerfallow plots received a second herbicide application in early- to mid-July, followed by one or two tillage operations as required using a wide V-blade cultivator. In other years tillage was not used and weeds were controlled with only herbicides. Chemical fallow plots generally received two to four herbicide applications. All plots received 2,4-D ester applied in the fall to control winter annual broadleaf weeds.

Results

Yields and Economic Returns: Annual Legume Green-Manure

During the first six years of the study (1988-1993), results showed that grain yields of wheat after the annual legume green-manure (LGM) partial fallow were generally lower than those after full fallow, primarily because the LGM reduced the reserves of available spring soil water[4]. This despite the fact that five of the six growing seasons had above average precipitation. Yields of wheat grown on stubble were unaffected by rotation. Grain N concentration was greater for wheat grown on LGM partial-fallow than for wheat grown on conventional fallow in the latter three years of the period, which was due mainly to the lower wheat yields in the LGM system.

Results during the first six years suggested that better performance on the LGM-W-W system might be achieved if the legume was seeded as early as practical (usually April in southwest Saskatchewan) and its growth terminated in early July rather than waiting until full bloom. After implementing these changes, spring soil water contents were similar for wheat grown after fallow compared to wheat grown after LGM-partial fallow. Consequently, during the next 6-yr period (1994-1999) wheat yields after LGM were equal to those after fallow. Further, there was a gradual increase over time in grain protein and in N yield of aboveground plant biomass of wheat in the LGM-W-W compared to the F-W-W system. This was accompanied by a gradual decrease in fertilizer N requirements of wheat in the LGM system indicating an improvement in the N supplying power of the soil[6]. The savings in N fertilizer, together with savings in tillage and herbicide costs for weed control on partial-fallow versus conventional-fallow areas, plus higher revenues from the enhanced grain protein of the wheat crop, more than offset the added costs for seed and management of the LGM crop. Specifically, net returns during the 1988–1993 period averaged \$68 ha^{-1} for F-W-W and \$37 ha^{-1} for LGM-W-W, but during the 1994-1999 period after the change in management of the LGM crop, net returns averaged \$69 and \$99 ha^{-1} for F-W-W and LGM-W-W, respectively. Future increases in the cost of N fertilizer and/or increases in the cost of fossil-fuel energy used for machinery operation and herbicide manufacture will likely further improve the relative profitability of the LGM system. Thus with careful attention to seeding and termination times, in combination with good snow management techniques to enhance water storage, and minimum or no-till to reduce evapo-transpiration, an annual LGM can be used successfully used as a partial fallow replacement for the semiarid Canadian prairies.

Yields and Economic returns: Crop Type and Cropping Frequency

During the first twelve years of the study, cropping frequency had no effect on grain yields of wheat (CWRS) when grown on fallow or stubble. On a rotational basis, extending cropping frequency from F-W-W to F-W-W-W resulted in a 9% increase in grain production and a 6% increase in grain N[5]. During this time period the ContW (if weeds) was fallowed twice (1994 and 1996) and produced 9% more grain than F-W-W, while the ContW (if water) was also fallowed twice (1988 and 1992), and produced 24% more grain and a 15% increase in grain N concentration. When grown on fallow, high-yielding CPS wheat (i.e., Hy) yielded more grain than CWRS wheat in 10 of 12 years, with CPS out yielding CWRS by 32% on average. When CPS wheat was grown on stubble, it out yielded CWRS wheat by about 17% with the difference in grain yield significant in 5 of 12 years (generally the wetter years). On a rotational basis, the F-Hy-Hy produced 26% more grain while the ContW produced 30% more grain than F-W-W, and about 20% more grain than F-W-W-W.

With conservation tillage, the impact of cropping frequency for wheat was comparable to the results from the conventionally tilled Old Rotation experiment. That is, wheat on stubble yielded about 25% less than wheat on fallow, but on a rotational basis grain production was considerably greater for more continuously cropped systems[5]. Yields however, were higher on the New Rotation versus the Old Rotation experiment for comparable treatments during the period 1988-2002. For example on the New Rotation experiment, average grain yield on well-fertilized continuous wheat (CWRS) was 1892 kg ha^{-1}, while for the same treatment on the adjacent Old Rotation experiment average yield was 1701 kg ha^{-1}. Similarly, on a rotational basis, annualized average yield for the well-fertilized F-W-W rotation was 1470 kg ha^{-1} on the New Rotation compared to 1390 kg ha^{-1} on the Old Rotation. Higher yields on the New Rotation no doubt reflect the advantages of conservation tillage and snow trapping practices to enhance soil water reserves.

Under conservation tillage management during the 1988-2002 period, the highest net return was earned with continuous wheat (CWRS) while net returns ranked second highest for F-Hy-Hy, F-W-W-W and the flex-crop management systems[7]. The F-W-W and LGM-W-W ranked lowest, although with improved management in the later years (discussed above) the green manure system outperformed F-W-W. On average, it was more profitable to produce CPS compared with CWRS wheat when the CPS/CWRS price ratio was greater than 0.8. Results are consistent with those from the Old Rotation experiment where, during years of relatively good rainfall conditions, net economic returns were highest for the ContW compared to the F-W-W system.

Water Use Efficiency

Water use efficiency (grain yield divided by crop water use) was higher for CPS than for CWRS wheat when grown on fallow (31% higher) and when grown on stubble (19% higher)[5]. This difference was primarily a reflection of the difference in grain yield between the wheat classes, since water use was generally similar. Cropping frequency had no effect on WUE. In the Old Rotation study, WUE for wheat grown on wheat stubble was lower than for wheat grown on fallow. The trend was similar in the New Rotation study but the difference between stubble and fallow grown wheat was not significant. Water use efficiency for wheat on fallow averaged 7.1 kg ha^{-1} mm^{-1}, similar to the Old Rotation experiment, and wheat grown on wheat stubble averaged 6.4 kg ha^{-1} mm^{-1}, slightly higher than in the Old Rotation experiment. The WUE for CPS wheat grown on fallow averaged 9.4 kg ha^{-1} mm^{-1} and when grown on stubble it averaged 7.5 kg ha^{-1} mm^{-1}.

Soil Organic Carbon (SOC)

The land on which this study was established had been maintained primarily under conventional till with a high frequency of fallow and a minimum of fertilizer applied for many decades. Converting the land to a minimum/no-till, well-fertilized, snow trapping management system with more frequent cropping had a positive impact on SOC status. During the first 17 years of the study, dry matter yields and thus carbon (C) inputs were greater for LGM-W-W than for the F-W-W system and this was reflected in the relative gains in SOC, with the gains in the LGM system being 2.44 times that under the F-W-W system (i.e. 329 versus 135 kg C ha yr^{-1}). Similarly, there was a direct association between C inputs and SOC gains with respect to increasing cropping frequency with gains of 135, 332 and 441 kg C ha^{-1} yr^{-1} for the F-W-W, F-W-W-W, and ContW systems, respectively [2]. Although CPS wheat had 26% greater grain yield compared to CWRS wheat, its C input was slightly lower due to its greater harvest index[5] and there was virtually no change in SOC status on the F-Hy-Hy system. The ContW (if water) treatment showed that just 2 years of fallow in 17 years was sufficient to depress the rate of SOC gains (36% less than for ContW). The pattern in SOC trends over time (Fig. 3) were not related to weather conditions, since trends in yield, which do reflect weather, were not closely associated with trends in SOC. However, after a decade or so of favourable growing conditions SOC appears to be approaching a new steady state (Figure 1).

Re-grassing of cultivated land is considered an important carbon sequestration strategy. Crested wheatgrass (CWG), an introduced grass species, which is more easily established and often provides greater dry matter production and livestock weight gains than native counterparts, has been used for a large acreage of seeded pastures on the Canadian prairies[3]. During the first 17-year period on this study, there was a 282 kg ha^{-1} yr^{-1} gain in SOC under CWG but most of the increase was realized in the latter 7 years[2]. This rate of C gain is considerably lower than on ContW, raising questions as to the effectiveness of re-grassing with CWG for C sequestration. However, confidence in the comparison is somewhat limited by issues regarding soil sampling methodologies that make the comparison of SOC between soils under annual crop versus perennial crops challenging. Further, grass production has increased following an increase in N fertilizer application rates during the more recent years of this study, indicating that better performance could have been realized on the CWG with more appropriate fertilizer application rates. Regardless, the CWG treatment deserves careful attention in future comparisons.

The rate of C gain observed for F-W-W in the New Rotation experiment was similar to that observed for the same rotation in the conventionally tilled Old Rotation experiment between 1967 and 2003 (i.e., 140 kg ha^{-1} yr^{-1}). However, the rate of gain for ContW in the Old Rotation experiment was much lower than in this study (236 versus 441 kg C ha^{-1} yr^{-1}). The lower value for the Old Rotation may reflect the drier conditions experienced during the first two decades following the initiation of that study, although the somewhat higher C inputs (higher yields) on the New Rotations were no doubt a contributing factor.

Nitrate Leaching Risk

After 17 years under conservation tillage management, nitrate leaching risk was shown to be low[1]. The risk appeared slightly greater for the LGM-W-W system, and, contrary to results from the Old Rotation study (conventional management), the risk appeared slightly higher under ContW compared to fallow containing systems. This reversal may be at least partially explained by slightly higher fertilizer N additions on no-till ContW compared to conventional-till ContW during the same time period, combined with lower net soil nitrogen mineralization, particularly during the fallow phase, of no-till compared to conventional-till systems. Nitrate leaching was negligible under perennial grass. Similar to the wheat-lentil system on the Old Rotation study, there was a build up of nitrate in the lower soil depths in the LGM system suggesting that the soil-nitrate test, which is based on the 0- to 60-cm depth of soil, may not be appropriate for systems that include legumes, and a full rooting depth (0–120 cm) test may be more appropriate.

Agro-ecosystem modeling

Agro-ecosystem models are becoming increasingly important for site-specific analysis and development of site-adapted agricultural production systems, and on a regional or national scale for the evaluation of current land use and potential remediation measures through scenario simulations. The long-term data from the New Rotation study have proven invaluable for testing simulation models. These include crop growth simulation models (e.g., SPAW, DSSAT), models that simulate soil water and temperature dynamics, soil organic carbon changes (e.g., CENTURY, IBCM, Campbell model), soil nitrogen dynamics (e.g., LEACHM), and greenhouse gas emissions (e.g. DAYCENT, DNDC). Properly calibrated models are important empirical tools for assessing the impacts of new management strategies (e.g., removing residues for bio-energy uses) and climate change scenarios.

The Future

As it enters its twenty-fifth season, the tremendous value as a true "long-term" study is just beginning to emerge. Many questions can now be explored – water and nutrient use efficiency, yield trends, groundwater quality, soil fertility, economics, and energy efficiency to name only a few. Comparing results from this long-term conservation tillage study with those from the neighbouring conventionally tilled "Old Rotation" study will provide a rare opportunity to better understand the long-term influence of specific crop management strategies.

Within a few further years, we should begin to detect soil quality trends (if any) under the more diversified rotation that was introduced in 2006. This will be invaluable information because many producers are now growing a wider diversity of crop types more frequently in their rotations. There is very limited information regarding the long term impact of these changes. Data from this study will also be utilized to inform other relatively recent research questions, such as the impact of crop type, rotation, and management on the total CO_2 (carbon dioxide) footprint of the system, as well as lifecycle analysis for a suite of environmental parameters. Again, it will be of particular interest to compare these results to those from the neighbouring "Old Rotation" study. Without doubt, this "living laboratory" will offer future researchers the opportunity to address the many as of yet undefined research questions.

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Table 1. Crop rotations initially deployed in the Swift Current "New Rotation" study[a].

Crop sequence	Special Features	Notes
Fallow-Wheat[b]-Wheat (F-W-W)	-	-
Fallow-CPS Wheat[C]-CPS Wheat (F-Hy-Hy)	-	-
Green Manure-Wheat-Wheat (LGM-W-W)	-	-
Chemical Fallow-Winter Wheat-Wheat (CF-WW-W)	-	Discontinued after 2005
Fallow-Wheat-Wheat-Wheat (F-W-W-W)	-	-
Continuous wheat (ContW)	-	-
Continuous wheat (ContW [if moisture])	Fallow if low moisture reserves	-
Continuous Wheat (ContW [if weeds])	Fallow if weedy	Discontinued after 2005
Crested wheat grass (CWG)	-	-

[a] The soil is an Orthic Brown Chernozem with a silt-loam texture, has an organic carbon and nitrogen (N) content of 18 and 1.8 g kg^{-1} (0-15 cm depth), respectively, and a surface pH in water paste of 6.5. All phases of each rotation are present every year and each rotation is cycled on its assigned plots. Treatments are arranged in a randomized complete block design with three replicates. Plot size is 15 m by 45 m.
[b] Wheat = Canada Western Red Spring (CWRS) wheat.
[C] Hy = Canada Prairie Spring (CPS) wheat.

Table 2. Crop rotations currently represented in the Swift Current "New Rotation" study.

Crop sequence	Special Features	Notes
Fallow-Wheat[a]-Wheat (F-W-W)	-	-
Fallow-CPS Wheat[b]-CPS Wheat (F-Hy-Hy)	-	-
Green Manure-Wheat-Wheat (LGM-W-W)	-	-
Fallow-Wheat-Wheat-Wheat (F-W-W-W)	-	-
Continuous Wheat (ContW)	-	-
Continuous Wheat (ContW [if moisture])	Fallow if low moisture reserves	-
Wheat-Canola-Wheat-Pea (W-C-W-P)	-	Established 2006
Crested wheat grass (CWG)	-	-

[a] Wheat = Canada Western Red Spring wheat (CWRS).
[b] Hy = Canada Prairie Spring (CPS) wheat

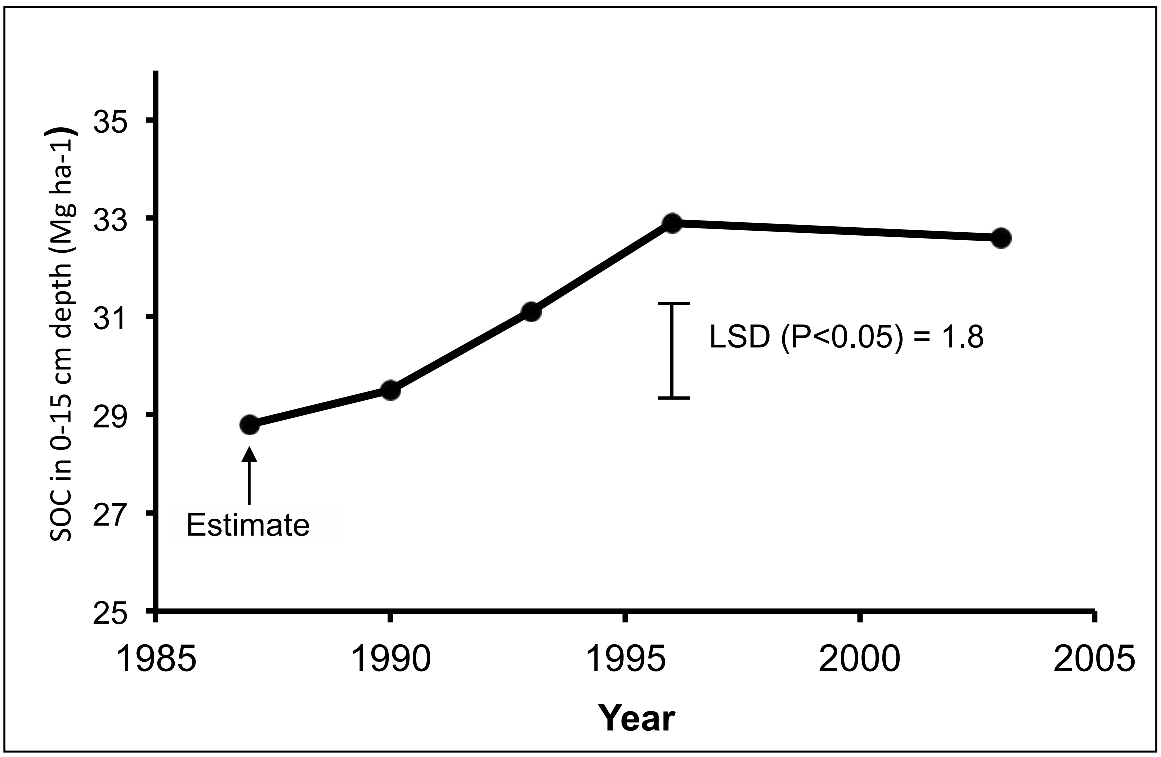

Figure 1. Trends in soil organic carbon (SOC) (1987-2003) averaged over rotations on the New Rotation experiment (redrawn from Campbell[2]).

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