PS&C
Prairie Soils &
Crops Journal

Productivity of Long-Term No-Till Plots – Lethbridge Alberta

Elwin G. Smith, Francis J. Larney, Darryl J. Nakonechny, José M. Barbieri, and C. Wayne Lindwall
Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge AB, T1J 4B1
Corresponding author e-Mail: Elwin.Smith@agr.gc.ca

Summary
A long-term no-till study was initiated in 1968 at the Lethbridge Research Centre. The study was initiated at the infancy of no-till management to better understand the long-term implications and the management problems that could arise with no-till. The crop rotations in this study included fallow-wheat or fallow-wheat-wheat/flax. Three tillage systems were selected for the study: (1) wide blade (cultivator) that leaves most of the crop residues on the surface after tillage, (2) heavy duty cultivator that buries more crop residues than the blade cultivator, and (3) no-till (chemical control of weeds during the fallow and crop year). The study provided industry with some early indications of the importance of crop residue management for no-till systems, and some specifications required for seeding equipment to ensure good seed placement. The study also showed that the soils would not become compacted over time, a concern of many early sceptics of no-till. Over the forty year period of the study, it was determined that no-till yields in a fallow-wheat rotation were lower than with tillage, but if a hoe opener was used at seeding the yield difference was less. In the three-year fallow-wheat-wheat/flax rotation, the no-till wheat yield after fallow was as high as with tillage, and the hoe opener resulted in higher total yield than a disc opener. There was no yield penalty for no-till in the past 10 years, an indication that no-till management of these systems has improved and changes to soil properties with no-till have been positive.

Introduction
Reducing the amount of tillage in cropping systems on the prairies has long been recognized as an important strategy to reduce soil erosion and degradation. Soils with minimal levels of crop residue on the surface are more susceptible to soil erosion, and the surface soil structure is less stable[5]. Conventional tillage systems using discs, one-way discers and heavy duty cultivators reduce surface crop residues. The frequency of tillage machine use and the type of machine, especially on summerfallow, are the main determinants of final surface crop residue levels[2]. The use of herbicides to control weeds during the fallow year has been shown to be an effective method of maintaining the crop residue cover during the fallow year[1]. Wheat grown after no-till fallow was found to have similar yield and protein concentration to systems with wheat grown after fallow using tillage, but there was less available soil nitrogen in the spring with no-till[1].

During the early years of no-till adoption, the industry was interested in no-till, but little was known about its long-term impacts. A study was initiated in 1968 at the Lethbridge Research Centre to determine the long-term feasibility of no-till in southern Alberta on large scale plots (1 acre) to complement related studies on small scale replicated plots.[9] When the study was initiated, wind erosion was very common on fallow fields. The objectives of the study were to examine problems (soil compaction, changes in soil physical properties, residue management, weed control) that could arise from no-till, to evaluate alternative management practices required for no-till to be successful and effective in reducing the risk of soil erosion, and to demonstrate to producers and the industry the feasibility of no-till.

Soil physical properties, including water holding capacity, bulk density, large pore porosity, hydraulic conductivity and infiltration rate were not impacted by tillage[5] but tillage did impact soil quality parameters. No-till systems have been found to alter the distribution of phosphorus and potassium in soil layers because there is limited physical mixing[3]. Soil organic carbon, and light fraction carbon and nitrogen, measures of soil quality, are higher with less tillage and with less summerfallow[7].

Detailed Description of Study
This dryland tillage study was established in 1968 on an Orthic Dark Brown Chernozem (Typic Haplustoll) soil developed on alluvial lacustrine parent material under native vegetation of tall and short grass species (49.708° N,

112.777° W). Surface soils have a loam texture (45% sand, 30% silt, 25% clay). Subsurface layers are calcareous. The size of the

main plots was 22.5 m by 185.4 m (0.4 ha, or 1 acre). There was a 2.1 m pathway between plots. Because this study had several objectives, the experimental design did not include replication. The study required large plots to help evaluate conventionally sized tillage and seeding equipment making it difficult or impractical to replicate. Also, replication was not considered essential for the objectives of studying residue management and the demonstration of no-till feasibility. To examine the impact of the systems on crop yield, the experiment was modelled as being replicated over time. There were also a number of complementary replicated studies nearby[7].

The study had five treatments made up of combinations of rotation and tillage. The treatments were: (1a) fallow (blade)-wheat (FW-B); (1b) fallow (chemical)-wheat (FW-NT); (1c) fallow (heavy duty cultivator)-wheat (FW-HD); (2a) fallow (blade)-wheat-wheat (FWW-B); and (2b) fallow (chemical)-wheat-wheat/flax (FWW-NT). From 1968 to 1987, and 2008 onward the third phase of the FWW-NT treatment included wheat rather than flax. Treatments 1b and 2b were no-till treatments. All phases of the rotations were present every year. The plots were split for seeding with one-half seeded by a hoe/shank opener and the other half seeded with a disc opener. It was expected the hoe opener would provide a more even depth of seeding, but plugging due to high crop residue levels could be a problem. The disc-type openers might not have problems with plugging but penetration into dry soil or through heavy crop residue could be problematic. The current disc opener drill was a no-till drill and should have been capable of good seed placement, though if too much crop residue was present "hair-pinning" could result. Hair-pinning is a term to describe a situation when crop residue is pushed into the soil by the discs rather than being cut, and the seed ends up being placed in the residue or remains near the surface instead of in contact with the moist soil. Germination and emergence can be low for seeds not placed in contact with moist soil.

Management Practices

Crop management practices evolved over time, reflecting current practices used by the farming community. Whenever possible, field operations such as tillage, seeding, fertilization and harvesting used field scale equipment. Crop cultivars were changed every four to six years to reflect the advancements in plant breeding. Herbicide use changed over time to reflect the changes in herbicide chemistry. The herbicides used in-crop were always a function of the weeds present. Seedbed preparation was done using appropriate tillage equipment (tilled plots), harrows and packers to control weeds, conserve soil moisture and produce a firm seedbed. Primary tillage was done on stubble plots which were to be seeded. For no-till, weeds on fallow were controlled with broadleaf herbicides and a non-selective herbicide. The non-selective herbicide was initially paraquat, but in recent years the less costly herbicide glyphosate, tank mixed with a broadleaf herbicide, was used to control weeds on the no-till plots.

Wheat was seeded at a rate of 85 kg ha^{-1}, and flax at 40 kg ha^{-1}. Ammonium nitrate nitrogen (N) fertilizer (34.5-0-0) at a rate of 50 kg N ha^{-1} was broadcast on the soil surface for those crops seeded on stubble. Mono-ammonium phosphate (11-52-0) at a rate of 30 kg P_2O_5 ha^{-1} was applied with the seed to all wheat plots. Weed growth on the conventional tilled fallow plots was controlled as required by using the tillage equipment specified by the treatment. Weed growth on the no-till fallow plots was controlled as required by using appropriate non-selective herbicides or mixes with broadleaf herbicides. Plots were monitored for insect pests and diseases, and controls were applied as required. The pathways between the plots were cultivated as required to control weed growth. Wheat was swathed at the hard dough growth stage (less than 35% moisture) and then combined with a field combine when the kernels reached a moisture content that did not require drying. Flax was desiccated when 75% of the bolls had turned brown. Grain harvested from each plot was weighed in the field with a truck equipped with a load cell, but before the load cell technology the truck was weighed for each plot. A grain yield sample was taken for each harvested plot. A sub-sample of grain was taken from each grain yield sample and dried in an oven at 60 °C for 7 days to determine the grain moisture content. Yields were adjusted to 12.5% moisture. The straw and chaff were spread as uniformly as possible over the harvested plot area.

Major findings of the study

Findings during the first nine years of this study determined there was a slight yield advantage for the no-till system for the three-year FWW rotation, but for most years, yields were similar between the conventional and no-till systems[16]. In some years, wild oat infestations depressed yield but the effect was uniform across all tillage systems. The profitability of no-till systems was lower than conventional tillage, primarily because the costs of herbicides for weed control pre-seed and on fallow exceeded the cost savings in machinery and labour in the early years[16]. The lower profitability of no-till system during the earlier years of this study was consistent with older studies on the economics of tillage systems[15]. Weed control costs in no-till, especially for difficult to control weeds such as foxtail barley, and the cost of non-selective herbicides resulted in lower returns from no-till. During the earlier years of the study, the cost of non-selective herbicides was several times higher than current costs.

The relative yields from this study by tillage and seeder opener differed over time and by the crop rotation. The two-year FW rotation (Figure 1) had greater yield differences by tillage than the three-year FWW rotation (Figure 2). For the two-year FW rotation, in the first 20 years of the study there was a tillage system by opener interaction (Table 1). The bolded values for 1968-1987 for tillage and the interaction of tillage and seeder-opener indicated that both of these factors impacted crop yield. For both disc and hoe openers the no-till yield was lower than the heavy-duty cultivator system, but equal to the blade, during the first 20 years (Figure 3). The yield for the disc opener was similar to the hoe opener for the cultivated and no-till systems, but less for the blade. In the last 20 years, the interaction of tillage and seeder opener was not significant (Table 1) and only the seeder opener type impacted yield for the FW rotation (Figure 4, Table 1 – bolded values for columns 1988-1997 and 1998-2007). The yield with the disc opener was less than the hoe opener (197 kg ha^{-1} yr^{-1}) over all tillage systems for the two-year rotation, but there was no significant difference for the three-year rotation. The lower yield with the disc opener could have been due to poor seed placement in some years because soil penetration with the disc was not adequate while the hoe opener could better penetrate the soil[8]. The yield differences by tillage system that occurred in the first 20 years carried on for the next 20 (Figure 1b), an indication that yields were similar across tillage systems for the past 20 years of the study (Table 1). However, the yield gap between hoe and disc openers increased during the last 20 years.

The yield pattern for wheat after fallow in the three-year rotation differed from the two-year rotation. There was no difference in yield by tillage system or by opener (Table 2). For the tree-year rotation, neither tillage not seeder-opener impacted yield, as indicated by the significance values in Table 2 all being greater than 0.05. During the first 20 years, cumulative yield from the no-till system tended to be higher than for blade (120 kg ha^{-1} yr^{-1}), and there was no difference by opener type (Figure 2a). However, in the last 10 years the yield for the no-till system with the disc opener tended to be lower (325 kg ha^{-1} yr^{-1}) than for the hoe opener. The tillage system and the opener type for the three-year rotation had no impact on wheat yield. The similarity of yield by tillage system could indicate similar N nutrient availability, which would agree with a study that found the tillage system did not impact the soil N cycle[4].

There was no yield penalty for wheat after fallow for the three-year no-till system when using a hoe type opener at seeding. During the last 10 years of the study the yield disadvantage for the disc opener continued despite the use of a no-till disc drill. The cumulative yield for the hoe opener systems increased more than for the disc opener and by 2007 the cumulative yield was highest for the no-till hoe opener system and lowest for the blade disc opener system (Figure 2b).

Spring soil moisture and early season precipitation could impact the yield performance of no-till. The no-till system could conserve soil moisture in dry years, but when it is dry penetration into the soil with disc openers can be difficult and result in poor seed placement. The yield of conventional tillage relative to no-till systems was found to have a weak relationship with May precipitation (r = 0.48), and no relationship to precipitation for other spring months. For disc openers, yield for conventional tillage systems expressed as a percent of no-till, was greater than 100% and there was no relationship to May precipitation (Figure 5a). Moisture conditions in the spring had a neutral effect on the yield of no-till relative to conventional tillage systems. The result was similar for the hoe opener, although the yield advantage for conventional systems was less (Figure 5b). The hoe opener for no-till had better consistency with seed placement across the range of soil conditions present during the 40 years of this study. There was no significant trend in relative yield for any of the system comparisons. There was no consistent yield pattern of conventional compared to no-till systems by May precipitation, nor by April or June precipitation.

The yield of wheat after fallow increased over time, and the increase was higher for the three-year rotation. For the blade system with hoe opener, the rate of increase for the three-year rotation was 13.4 kg ha^{-1} yr^{-1} higher than for the two-year rotation, and for the no-till disc it was 23.9 kg ha^{-1} yr^{-1} higher (Figures 1 and 2). While comparing crop rotations was not part of this study, it was observed that in the first 20 years wheat yield was similar for the two rotations. From 1988 to 1997 the wheat yield for the three-year rotation was about 10% higher than the two-year rotation and the difference increased to 20% for the last 10 years.

No-till fallow was found to have relatively high earthworm populations, with few to none found in tilled plots[6]. The cause of the difference was not known, it could be a preference for undisturbed soil or differences in nutrients required by the earthworms. Soil physical properties were influenced by tillage. There were more soil pores, essential for rooting, in the subsoil with no-till, but porosity was higher in the surface soil for tilled soils[10,13]. The tilled soils had higher plant-available water-holding capacity. Differences in soil porosity and macropores could potentially result in preferential water movement and leaching of water and nutrients. However, in studies that examined leaching potential and hydraulic conductivity, no differences were found across tillage systems[11,12,14]. This indicated that no-till did not increase the potential for leaching of water and nutrients.

Future

Current plans are to continue this study. The importance of the study has shifted from evaluating no-till and understanding the management and equipment needs for successful no-till. Some current issues are to better understand the longer-term implications of no-till on stratification of nutrients in the soil and on the soil surface, soil physical properties and aggregate stability, and changes to soil carbon from eliminating tillage. There are nearly 45 years of no-till for this study, which should be adequate time for differences due to the tillage practice on soil physical and chemical properties to be evident.

Table 1. Probability of yield differences by tillage systems for wheat after fallow for the two-year rotation by three time periods

	Probability of Yield Differences[1]		
Effect	1968-1987	1988-1997	1998-2007
Tillage (T)	**<.0001**	0.0789	0.8163
Seeder-Opener (O)	0.1685	**0.0305**	**0.0019**
T X O	**0.0133**	0.1223	0.7589

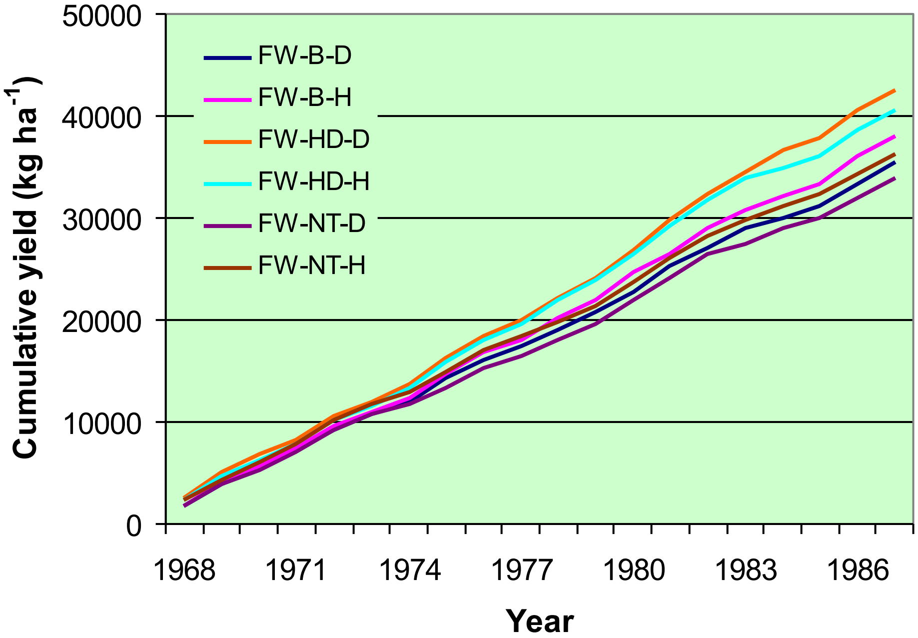
[1] Values that are less than 0.05 would indicate detectable differences. Highlighted numbers would indicate a detectable yield difference.

Table 2. Probability of yield differences by tillage systems for wheat after fallow for the three-year rotation by three time periods

	Probability of Yield Differences[1]		
Effect	1968-1987	1988-1997	1998-2007
Tillage (T)	0.2012	0.6930	0.7485
Seeder-Opener (O)	0.3384	0.0631	0.1081
T X O	0.9517	0.5091	0.0917

[1] Values that are less than 0.05 would indicate detectable differences.

(a) 1968-1987



(b) 1988-2007

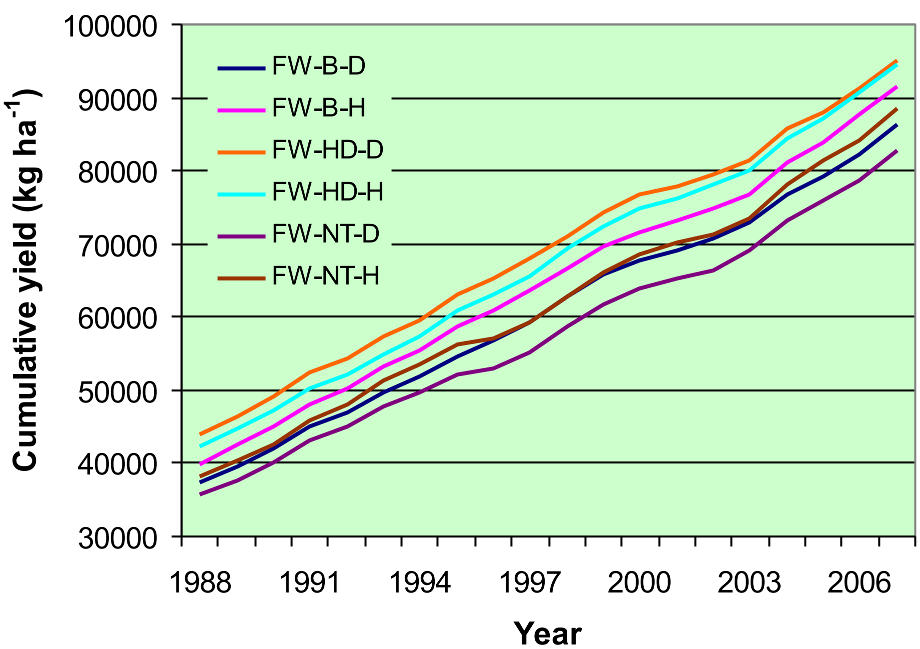
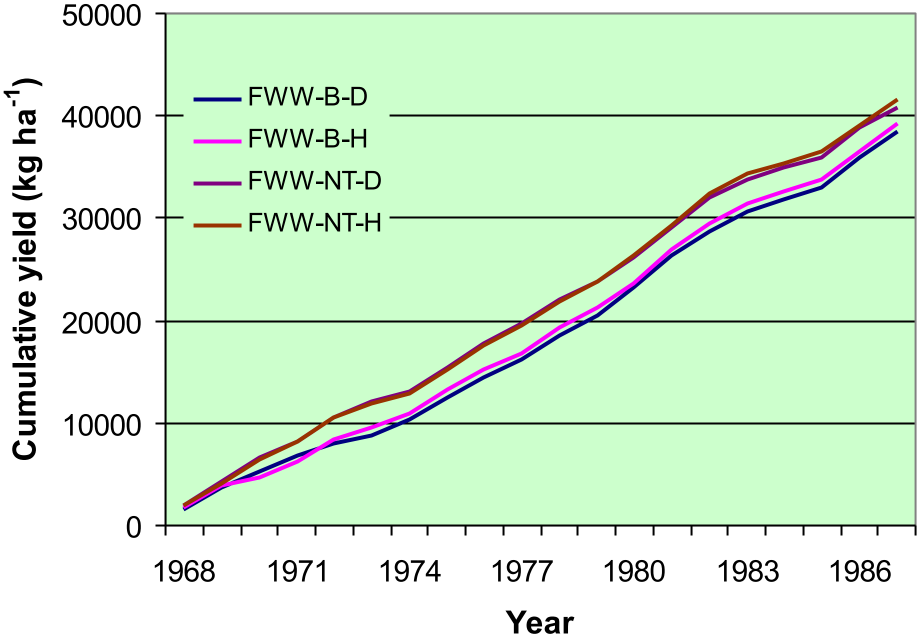


Figure 1. Cumulative grain yield for the fallow-wheat rotation, by tillage system (B = blade, HD = heavy duty cultivator, NT = no-till) and seeder opener (D = disc, H = hoe) for two different periods (a) 1968-1987 and (b) 1988-2007.

(a) 1968-1987



(b) 1988-2007

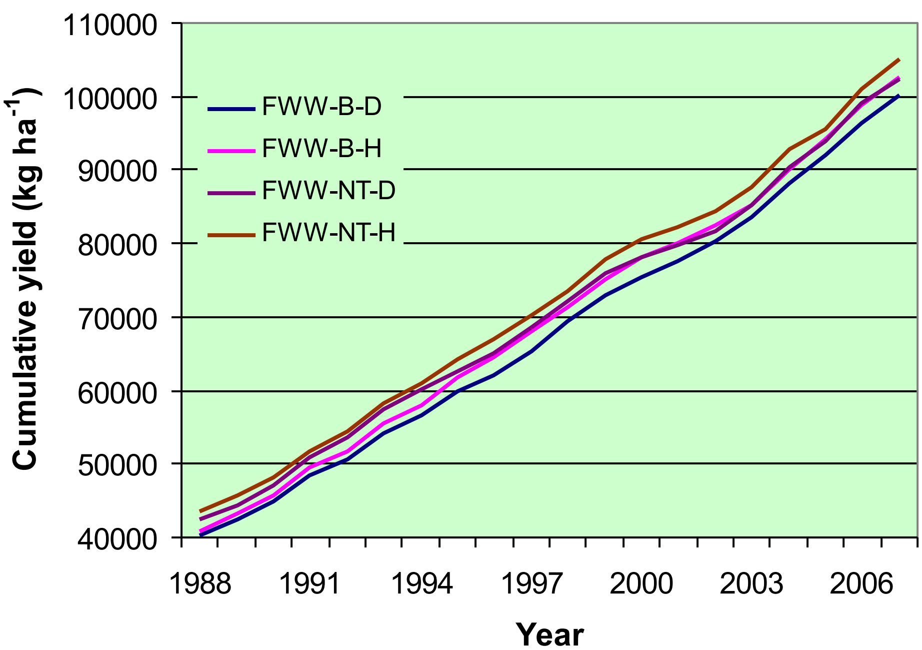


Figure 2. Cumulative grain yield for the fallow-wheat-wheat rotation, by tillage system (B = blade, NT = no-till) and seeder opener (D = disc, H = hoe) for two different periods (a) 1968-1987 and (b) 1988-2007.

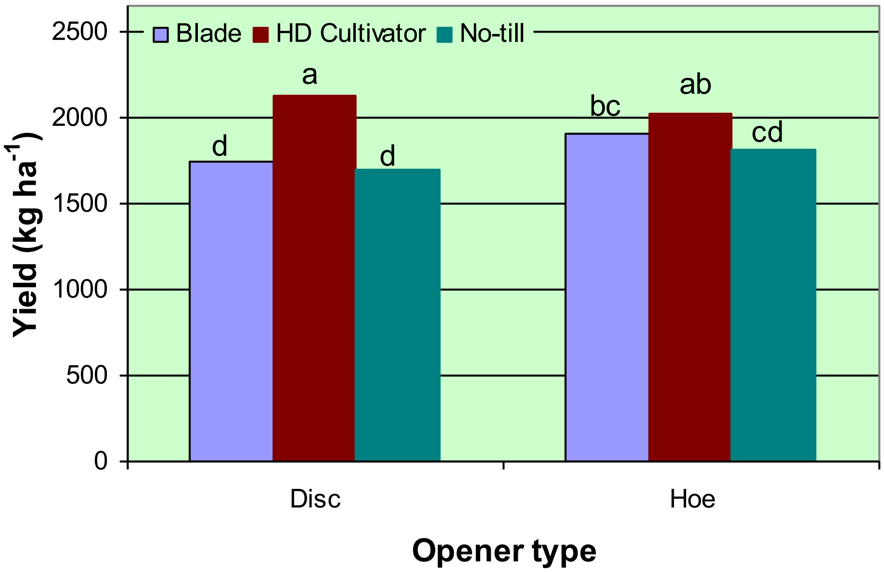


Figure 3. Average grain yield for the period 1968-1987 for the fallow-wheat rotation by opener type and tillage system. (The letters above the bars when they are different indicate a significant difference between openers and rotation).

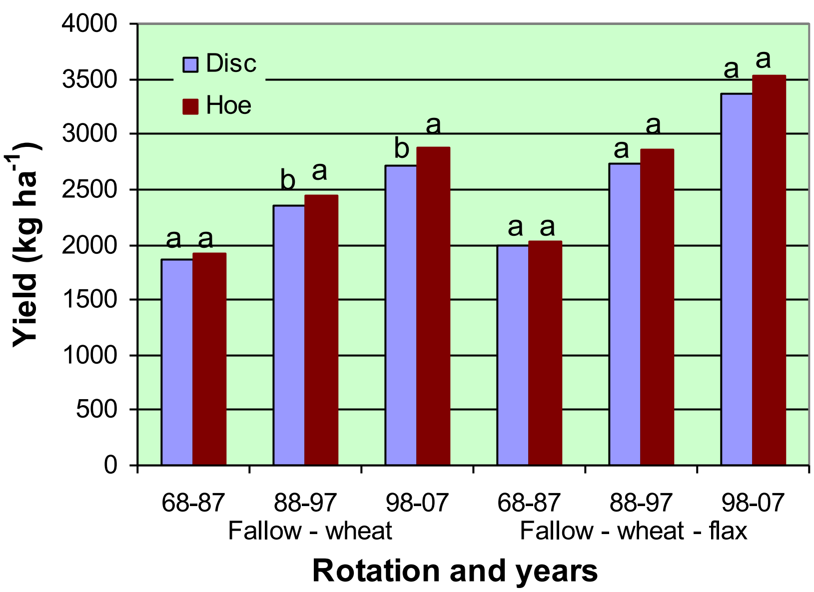
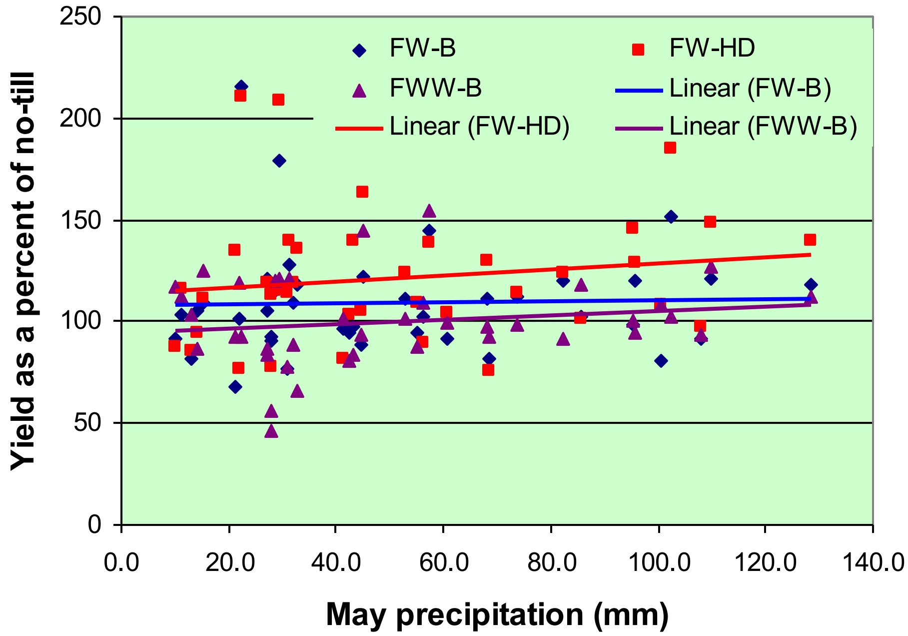


Figure 4. Average grain wheat yield after fallow for two rotations grouped by year and seeder opener. (The letters above the bars when they are different indicate a significant difference between disc versus hoe openers, for each combination of rotation and time period).

(a) disc opener



(b) hoe opener

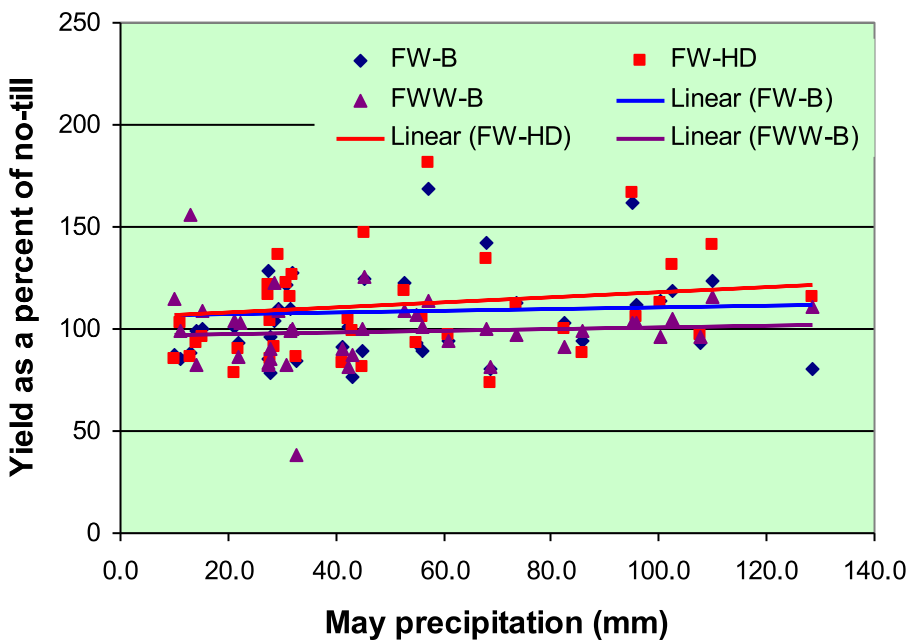


Figure 5. Fallow wheat yield for (a) disc opener and (b) hoe opener as a percent of no-till versus May precipitation for FW with blade (FW-B) and heavy duty cultivator (FW-HD), and for FWW with blade (FWW-B).

References

1. Anderson, C.H. 1971. Comparison of tillage and chemical fallow in a semiarid region. Can. J. Soil Sci. 51(3): 397-403.
2. Anderson, D.T. 1961. Surface trash conservation with tillage machines. Can. J. Soil Sci. 41(1):99-114.
3. Carter, M. R. and Rennie, D. A. 1982. Changes in soil quality under zero tillage farming systems: distribution of microbial biomass and mineralizable C and N potentials. Can. J. Soil Sci. 62:587-597.
4. Carter, M. R. and Rennie, D. A. 1984. Nitrogen transformations under zero and shallow tillage. Soil Sci. Soc. Am. J. 48:1077-1081.
5. Chang, C. and Lindwall, C. W. 1989. Effect of long-term minimum tillage practices on some physical properties of a Chernozemic clay loam. Can. J. Soil Sci. 69:443-449.
6 Clapperton, M.J., Miller, J.J., Larney, F.J., and Lindwall, C.W. 1997. Earthworm populations as affected by long-term tillage practices in southern Alberta, Canada. Soil Biol. Biochem. 29(3/4): 631-633.
7. Larney, F. J., Bremer, E., Janzen, H. H., Johnston, A. M. and Lindwall, C. W. 1997. Changes in total, mineralizable and light fraction soil organic matter with cropping and tillage intensities in semiarid southern Alberta, Canada. Soil Tillage Res. 42:229-240.
8. Lindwall, C.W. and Anderson, D.T. 1977. Effects of different seeding machines on spring wheat production under various conditions of stubble residue and soil compaction in no-till rotations. Can. J. Soil Sci. 57(2):81-91.
9. Lindwall CW and Anderson DT. 1981. Agronomic evaluation of minimum tillage systems for summerfallow in southern Alberta. Can. J. Plant Sci. 61:247-253.
10. Miller, J,J,, Kokko, E.G. and Kozub, G.C. 1998. Comparison of porosity in a Chernozemic clay loam under long-term conventional and no-till. Can. J. Soil Sci. 78(4):619-629.
11. Miller, J.J., Lamond, B.J., Sweetland, N.J. and Larney, F.J. 1999. Preferential leaching in large undisturbed soil blocks from conventional tillage and no-till fields in southern Alberta. Water Qual. Res. J. Can. 34(2):249-266.
12. Miller, J.J., Lamond, B.J., Sweetland, N.J. and Larney, F.J. 2000. Preferential leaching of water and chloride as affected by tillage and rainfall intensity. Water Qual. Res. J. Can. 2000 35(4):711-734.
13. Miller, J.J., Larney, F.J. and Lindwall, C.W. 1999. Physical properties of a Chernozemic clay loam soil under long-term conventional tillage and no-till. Can. J. Soil Sci. 79(2):325-331.
14. Miller, J.J., Sweetland, N.J., Larney, F.J. and Volkmar, K.M. 1998. Unsaturated hydraulic conductivity of conventional and conservation tillage soils in southern Alberta. Can. J. Soil Sci. 78(4): 643-648.
15. Smith, E.G., Peters, T.L., Blackshaw, R.E., Lindwall, C.W. and Larney, F.J. 1996. Economics of reduced tillage fallow-crop systems in the Dark Brown soil zone of Alberta. Can. J. Soil Sci. 76: 411-416.
16. Zentner, R.P. and Lindwall, C.W. 1978. An economic assessment of zero tillage in wheat-fallow rotations in southern Alberta. Can. Farm Econ. 13(6): 1-6.