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Tillage and crop rotation effects on the yield of corn, soybean and wheat in eastern Canada

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Abstract

Farmers in Canada are adopting no till (NT) production at a high frequency. Conventional tillage (CT) was compared to no till (NT) with corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and wheat (*Triticum aestivum* L.) grown in monoculture or annual rotation in a long term study established in Ottawa (1990). From 1996 to 2000 all plots reverted to NT conditions to study the transition effects from CT to NT. In transition from CT to NT, new-NT corn plots yielded significantly more than established-NT plots in the first year of transition only, while there were no transition effects for soybean or wheat. In 2001 the experiment was changed back to CT and NT. Over 15 years of the tillage-rotation trial (2001 to 2015) CT corn yields were ~20% higher than NT corn across all three rotations but the differences were not significant at the 5% level (p values 0.11 to 0.15). Fertilizer was not incorporated in all NT corn and wheat and may have limited NT yields. Yields did not differ between CT and NT for either soybean or wheat in any of the rotations. Wheat yielded 22% and CT corn yielded 8% more when grown in rotation than in monoculture. Soybean yield did not differ between rotation and monoculture. Crop order in the rotation (corn-soybean-wheat vs. corn-wheat-soybean) did not result in significant yield differences. An economic, agronomic or environmental advantage will be needed to justify NT corn production, in high-yielding environments of a humid continental agroecosystem.

Keywords: rotation, crop; tillage; transition.

In Canada, the percentage of land prepared for planting with conventional tillage (CT) consisting of fall or spring ploughing, followed by spring cultivation has decreased from 69 to 19% from 1991 to 2011 (Statistics Canada 2012). In Ontario from 1991 to 2006, the use of CT decreased from 78 to 44% while no-till (NT) planting increased from 4 to 31% (Statistics Canada 2007). Two-thirds of the soybean [*Glycine max* (L.) Merr.] crop grown in Ontario is produced with NT or reduced tillage systems, with similar farm yields reported between the NT and CT systems (Ontario Ministry of Agriculture and Food 2009).

No-till has been shown to reduce soil erosion, enhance soil biological activity, increase nutrient cycling, improve soil structure and the resulting water infiltration rates, and increase soil water holding capacity (Pittelkow et al. 2015). It can also lower production costs and fossil fuel use, thereby increasing total economic productivity through energy and labor savings. In a meta-analysis of 678 world studies Pittelkow et al. (2015) found that NT yields were similar to CT yields in legume crops while corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) showed 7.6 and 2.6 % reductions, respectively.

Traditional wisdom suggests that crop rotation with non-host species reduces insect and disease pests, allows the use of a broader range of weed control, and promotes yield. Crookston et al. (1991) conducted a 10 year rotation study in Minnesota and reported that there was a yield advantage when either corn or soybean followed several years of the other crop grown continuously, rather than just an annual rotation. A five year corn-soybean rotation in Wisconsin revealed that corn grain yield decreased by 5% when grown under NT in two of the five years while in the remaining years there were no significant differences in yield (Pedersen and Lauer 2003). In the same test they determined that there was no significant influence of tillage practice on soybean yield with NT yielding 6% more than CT on average, and that following five years of continuous corn, soybean yield increased by 8% over continuous soybean. In a five year study of a silage corn soybean rotation in Quebec, Whalen et al. (2007) found that CT silage corn was significantly higher yielding than NT silage corn in three of five

years and had similar yields in the other two years. They also determined that CT soybean had greater yield than NT soybean in two of five years and similar yield in three of five years and proposed that corn yields were reduced under NT due to root constraints rather than weed competition or insect or disease damage. The Rothamstead long-term experiments have demonstrated that wheat and barley (*Hordeum vulgare* L.) seed yield was maintained in monoculture with added fertility (Jenkinson 1991).

A meta-study by Pittelkow et al. (2015) showed that yields following NT establishment were less than CT for all crops, with the exception of corn, but the negative effects of NT decreased with time and were similar after 3 to 4 years for both legumes and cereals. They also found that the durations of the NT yield deficit depended upon seasonal precipitation and were longer in humid environments than arid ones. Early year yield reductions from the transition from CT to NT were attributed to the time required to stabilize soils prior to obtaining the benefits of improved soil C, soil aggregate stability and greater water holding capacity. Additionally, Nichols et al. (2015) found that in humid environments weed control may pose the greatest challenge in transitioning to NT and soil characteristics, weed populations and weed control may take four to 10 years to reach equilibrium.

Rasmussen et al. (1998) highlighted the need for long term (>20 years) experiments when assessing the sustainability of agricultural management practices. DeFelice et al. (2006) proposed that the validity of tillage and rotation results improve after several years of experimentation due to the time required for NT to establish soil tilth, porosity and drainage, and a stable microbial environment. Additionally, they emphasized that in comparison experiments NT fields are often treated with similar agronomic methods as CT fields which may result in a disadvantage or bias against NT.

Our objective for this study was to examine the long-term effects of tillage type and crop rotation on seed yield of crops grown in Eastern Canada. The influence of the transition from CT to NT on seed yield was also evaluated.

Materials and Methods

A tillage-rotation experiment was established in 1990 at the Central Experimental Farm, Ottawa (75°43' W 45° 22'N), with the original purpose of evaluating the effect of tillage and crop rotation on fusarium (*Fusarium graminearum* Schwabe) head blight in spring wheat (Miller et al. 1998). Briefly, a two replicate, split plot tillage-rotation experiment was established on land that had previously been in alfalfa for one year and corn prior to that for several years. Main plots for tillage effects were 89.1 x 45.7 m, while sub plots for crop rotation were 9.1 x 45.7 m. Main plots were either managed without tillage (NT) or conventionally tilled (CT) with a moldboard plough in early November, and cultivated in the spring with a mulch-finisher, followed by a combination harrow with rotatory baskets. Sub plots were allocated to three crops (corn, soybean or wheat) grown in two three-year rotations (corn-soybean-wheat or corn-wheat-soybean), or in monoculture. Both of the two rotations were initiated with plots of each of the three crops to allow for each crop to be grown in every year, for a total of nine subplots within each main plot. Within each main plot (tillage effect), the sub plots (crop by rotation) were duplicated in complete blocks. That is, each set of nine crop by rotation plots within each main plot within each replicate were re-randomized and duplicated in two separate blocks. The soil was a Matilda sandy loam (Melanic Brunisol *Canadian classification*) with pH (in CaCl₂) of 6.8.

Wheat plots were planted within the first two weeks of May at a density of 450 seeds m⁻² in 19 cm wide rows with a Sunflower 9312 Multifunction Drill (Beloit, Kansas, USA) equipped with disc openers. The seeder can be switched from CT to NT adjusting the depth of the discs with hydraulic pressure. Corn plots were seeded within the first two weeks of May at 7 seeds m⁻² in 76 cm wide rows with a John Deere 6 row corn planter with the NT option. It was equipped with trash whippers, conventional coulters and slot closers with manually adjustable disc down pressure to insure that planting depth was similar for both CT and NT plots. Glyphosate resistant soybean was seeded in the last two weeks of May at 55 seeds m⁻² with the Sunflower drill in 19 cm wide rows. Crop hybrid or

variety seed was commercially sourced each year and represented a sample of those available to local producers. Selected varieties were adapted to 2800 to 2900 crop heat units.

Corn plots received 224 kg ha^{-1} urea ha^{-1} pre-plant broadcast and 40 kg ha^{-1} 18-18-18, $\text{N-P}_2\text{O}_5\text{-K}_2\text{O}$ with the seed. Wheat plots received $100 \text{ kg N (urea) ha}^{-1}$ pre-plant broadcast while no fertilizer was applied to the soybean plots. Broadcast fertilizer was incorporated with spring cultivation in the CT plots but was not incorporated in the NT plots. Glyphosate was used to control weeds in commercial herbicide resistant varieties of corn and soybean from 1996 to 2015. Weeds were controlled in wheat with 0.2 L ha^{-1} Buctril-M at the seedling stage. At harvest the corn plots were combine harvested and the weights determined using a wagon equipped with a scale. A small plot combine was used to harvest a strip of each wheat and soybean plot 1.8 m wide, the length of the plot. A sample was retained from each plot for moisture determination and yields were adjusted to a 13% moisture basis. Since the continuous soybean plots did not receive any fertilizer since 1990, we sampled these plots in 2016 after the conclusion of the reporting period to ascertain K and P fertility levels. In the no-till plots Ontario Ministry of Agriculture, Food and Rural Affairs ratings for K were medium for the four plots, and for P were high, high, very high and excessive. In the tilled plots the ratings for K were low, high, medium and medium, and for P were high, excessive, high and very high.

A weather station on the Central Experimental Farm was used to collect precipitation, and minimum and maximum daily temperature data. Growing degree days (base 10) were calculated as: $[(\text{maximum temperature} - \text{minimum temperature}) / 2 - 10]$. Growing degree days and precipitation were summed from May 1 to September 30 to characterize the growing seasons.

Following two cropping cycles (six years) of the initial fusarium head blight experiment, the emphasis of the trial switched to study long-term rotation and tillage effects on yield. From 1996 to 2000 all plots were converted to NT to study the transition from CT to NT over an extended duration. This permitted a comparison between established-NT plots (1990 to 1996) and new-NT plots, which

were initially CT, by calculating the yield difference between the two tillage methods (new-NT minus established-NT). During this five year period from 1996 to 2000, comparisons were made between the first year of new-NT to 7 year established-NT, up to five years of new-NT were compared to 11 years of established-NT in 2000. In the analysis of new-NT versus established-NT, single degree of freedom contrasts were used, within each year-rotation-crop treatment, to compare crop yields from tillage types. Effects were considered non-significant when $p \geq 0.05$. Seed yield differences between new-NT and established-NT treatments were plotted for five years (1996 to 2000).

In 2001, the experiment was changed to again include both CT and NT production systems. In the 15 year (2001 to 2015) tillage-rotation dataset, a combined ANOVA (Table 1) was carried out to identify significant effects using the Mixed Procedure of SAS (SAS Cary NC, USA). The trial was a two replicate, split plot design with tillage as main effect and tillage by year used as the main effect error term. Year and year by tillage were random effects with all other effects considered fixed. Least square means were calculated. Within each crop, single degree of freedom contrasts were used to evaluate the effects of CT versus NT, crop rotations versus monoculture, and differences between the two rotation sequences (corn-soybean-wheat or corn-wheat-soybean). Effects were considered non-significant where $p \geq 0.05$. The GLM Procedure of SAS was used to provide a coefficient of variation.

Results and Discussion

Tillage Transition

We used the period from 1996 to 2000 to observe the effects of transition from CT to NT on crop yield. The established-NT plots had six more years of NT than new-NT plots. The difference between new-NT and established-NT plots was plotted by year (Fig. 1). New-NT corn plots yielded more than established-NT plots in the first year only and the differences between established- and new-NT corn were not significant in years two through five (Fig. 1a). On average in the long term dataset, (2001 to 2015) CT corn yielded about 1900 kg ha⁻¹ more than NT (Table 2) but in the transition comparison, first year new-NT corn yielded about 1100 kg ha⁻¹ more than established-NT plots (Fig. 1a). Corn yields in new-NT plots declined over the five years until they were equal to those in the established-NT plots. This indicates that the benefits of six years of CT prior to the transition to NT may have carried over only to the first year of new-NT plots; after that the positive effect on yield disappeared. There was no influence of crop rotation on this trend. Nichols et al. (2015) reported that weed control is one of the most challenging aspects of NT and it is reasonable to assume that weed control, at least in the first year of NT would have been superior in the former CT plots than in established-NT ones. There were no consistent differences between new-NT and established-NT plots over the five years for soybean (Fig. 1b) or wheat (Fig. 1c). Data for wheat yields in the second year of the transition was lost.

Tillage and Crop Rotation

In the 15 years of the tillage and crop rotation study (2001 to 2015), the ANOVA identified significant differences for tillage, crop, and rotation treatments and the tillage by crop by rotation interaction (Table 1). As a result, means for tillage by crop by rotation are presented (Table 2). Annual variation in seed yield over the 15 years was evident with a range for corn of about 10,000 kg ha⁻¹; for soybean, 3500 kg ha⁻¹; and for wheat, about 5500 kg ha⁻¹ over tillage and rotation treatments (Fig. 2a to f). While

there were some years where one or two out of the three crops had low yields, there were no years where all three crops had low yields simultaneously. For example, in 2002, while corn yield was suppressed the yield of soybean and wheat was not (Fig. 2). Crop diversification has been suggested as a method to provide resilience in adapting to changes in climate (Lin 2011) because not all crops will respond in a similar manner to the environment and the risk of total crop failure is reduced.

Crop responses to tillage were not consistent. Over the 15 years of the tillage-rotation trial, CT corn yielded more (~20%), than NT corn across all three rotations; however the differences were not significant (p values ranged from 0.11 to 0.15). There were no significant differences in yield between CT and NT soybean or CT and NT wheat in any of the three rotations (Table 2). Yield comparisons of CT, NT or reduced tillage across environments and years have produced conflicting results. Several studies have found that CT corn yields were superior to those in NT (Brown et al. 1989; West et al. 1996; Wilhelm and Wortmann 2004; Ziadi et al. 2014). Soybean grown under CT was superior to NT (West et al. 1996; Ziadi et al. 2014), or there were no differences (Brown et al. 1989; Gaudin et al. 2015; Wilhelm and Wortmann 2004). It was reported that both corn and soybean were found to be lower yielding in CT in Arkansas (Edwards et al. 1988); this result was attributed to better water conservation with reduced tillage. A review by DeFelice et al. (2006) found that NT corn yield was superior in the southern US while CT was superior in the northern US and Canada. In-season (May to September) precipitation and thermal accumulation varied substantially over the 20 years of our experiment (Fig. 3) with minimum precipitation being 52% of the maximum year, and minimum thermal accumulation being 75% of the maximum year. Average in-season precipitation for the 20 years was ~360 mm which would classify the region as a humid continental climate, which favours CT. Pittelkow et al. (2015) conducted a world-wide meta-study comparison of 678 CT and NT studies and found that CT yielded higher than NT in wheat (2.6%) and corn (7.6%) while there were no differences between tillage systems involving legumes. They found that CT significantly out-yielded NT for corn and wheat in humid environments

while in arid environments CT and NT yields were more similar, indicating that the moisture conservation attributes of NT play a larger role in equalizing yield in arid environments. They determined that while NT did not exceed CT in any crop, the difference between CT and NT decreased with time and yields stabilized after three to four years with legumes and cereals but not corn. Our results were consistent with previous studies in north-eastern North America (DeFelice et al. 2006) and the meta-study (Pittelkow et al. 2015).

Responses to crop rotation versus monoculture were also not consistent among the three crops (Table 2). Wheat yields were 22 % higher on average when grown under rotation compared to monoculture over all tillage-rotation combinations. Corn yielded about 8 % higher in rotation compared to monoculture when grown with CT; however, there was no significant difference between rotation and monoculture in NT corn. Soybean yield did not differ between monoculture and crop rotations in either tillage system. The order of crops in the cropping sequence did not matter since none of the three crops yielded differently in corn-soybean-wheat versus corn-wheat-soybean rotations in either tillage system. In many previous studies, rotation yields were higher than monoculture yields for corn (Berzsenyi et al. 2000; Crookston et al. 1991; Drury and Tan 1995; Gaudin et al. 2015; Ma et al. 2003; Raimbault and Vyn 1991; West et al. 1996; Wilhelm and Wortmann 2004), soybean (Crookston et al. 1991; Kelley et al. 2003; Peterson and Varvel 1989; West et al. 1996; Wilhelm and Wortmann 2004) and wheat (Berzsenyi et al. 2000). When individual years were considered, corn and soybean yielded higher in rotation about two out of three years (Sindelar et al. 2015). In Pennsylvania, corn monoculture yielded similarly to a corn-soybean rotation but corn in longer rotations, similar to our three year rotations, out-yielded corn grown in monoculture (Grover et al. 2009).

We found that the yield of soybean grown in monoculture was similar to soybean grown in rotation with corn and wheat. These results are in contrast to many studies in the US and Canada showing the yield benefits of crop rotation. Since one of the main benefits of crop rotation is the

reduction in diseases, it is possible that using different soybean varieties or fungicide seed treatments in our experiment was sufficient to control diseases; therefore, no yield differences were identified. Kapusta and Krausz (1993) reported that there were no yield differences for soybean grown for 11 years in conventional or in reduced tillage conditions in southern Illinois and found no significant differences in weed populations between conventional tillage and reduced tillage. Whiting and Crookston (1993) determined that the apparent advantage of rotating soybean with corn did not appear to be due to the reduced incidence of plant diseases such as brown stem rot [*Phialophora gregata* (Allington and Chamberlain) W. Gams.]. Edwards et al. (1988) found that the yield of continuous corn grown under conventional tillage was similar to corn grown under no-till, while the resulting soybean cyst nematode (*Heterodera glycines* Ichinohe) population build-up and moisture stress from conventional tillage limited yield in continuous soybean. Their study also showed that rotation with corn slowed the soybean cyst nematode population build-up. Visual evidence for soybean cyst nematode infestation in our experiment was not found, although the disease is spreading northward in Ontario and crop rotation is one of the main recommended methods of control. A survey of soybean production fields in North-Central United States (Workneh and Yang 2000) found that sclerotinia stem rot [*Sclerotinia sclerotiorum* (Lib.) de Bary] was less prevalent in no-till fields than conventionally tilled fields and proposed that infected residue would remain on the surface where the infection bodies would be exposed to the elements and microbial attack in NT situations.

When annual CT yields are plotted against the difference between NT and CT yields, we see a negative relationship for corn (Fig. 4a) and wheat (Fig. 4c). CT corn and wheat increasingly outperform NT corn and wheat as seed yield potential (shown as CT yield) increases. Only in the lowest yielding environments were NT yields equivalent to CT for corn. This relationship was somewhat less strong for wheat and did not exist for soybean (Fig. 4b). These findings indicate that in CT systems corn yield is

more responsive than other crops to the positive factors (e.g., soil temperature and moisture) affecting yield.

Derpsch et al. (2014) made the case that there is an inherent bias towards CT in these types of studies because NT requires greater skill for weed, insect and disease control and agronomic practices such as seed placement and timing. They propose that a systems approach be followed for NT when conducting side by side comparisons. Our experiment may have suffered from this bias due to several reasons. Fertilizer was applied by broadcasting and in NT it remained on the soil surface while it was incorporated in CT. Rochette et al. (2009) found that volatilization was nearly 6 times greater when urea fertilizer was not incorporated. Depending upon the precipitation received after fertilizer application, this may have resulted in less available N for NT corn and wheat and reduced yields. It was evident from visual observations that weed infestation in cereals were greater in NT than CT plots and that perennial weeds were increasing.

The use of CT has recently declined in Canada (Statistics Canada 2007; Statistics Canada 2012) even when yields may be compromised. While reduced tillage has been recommended for soil conservation benefits, farm profit may be one of the main driving factors resulting in the switch from CT systems. Sijtsma et al. (1998) determined that when costs for seed, fertilizer and herbicide were similar, NT systems had reduced costs of production due to reduced tractor traffic and fuel consumption.

In conclusion, 15 years of a long-term rotation and tillage trial revealed that corn yielded more, but not significant at the 5% level, when grown with CT than with NT, while there were no yield differences for soybean and wheat between tillage methods. Corn yielded more in rotation when grown in CT but not when grown in NT. Wheat yielded more in rotation than in monoculture, while there were no differences between rotation and monoculture for soybean. There were no differences between the corn-soybean-wheat sequence and the corn-wheat-soybean sequence for any of the crops, in either tillage system. New-NT corn plots, which had previously been CT, were higher yielding than established-

NT plots the first year but the effects disappeared after the first year. Economic, agronomic or environmental advantages will be needed to justify NT corn production in eastern Canada, especially in high-yield environments.

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Table 1. ANOVA for the test of significance of year, tillage, crop, rotation, and subsequent interactions on seed yield of corn, soybean and wheat crops in tillage and crop rotation treatments grown at Ottawa, ON from 1996 to 2000 and from 2001 to 2015.

Effect	DF	Mean squares	Probability
<u>1996 to 2000</u>			
Year	4	61685627	0.8934
Till ^a	1	1626649	0.3837
Year*Till	4	1737121	0.8096
Crop	2	799562387	<0.0001
Rotation	2	11184065	0.0172
Crop*Rotation	4	3511530	0.2596
Till*Crop*Rotation	8	479445	0.9922
Year*Till*Crop*Rotation	58	153230304	<0.0001
<u>2001 to 2015</u>			
Year	14	51874809	0.0022
Till ^b	1	144234038	<0.0001
Year*Till	14	2915720	0.9617
Crop	2	3027244065	<0.0001
Rotation	2	29032436	0.0053
Crop*Rotation	4	5469882	0.4064
Till*Crop*Rotation	8	19801382	0.0006
Year*Till*Crop*Rotation	221	1266817203	<0.0001

^a Tillage treatments are established no-till and new no-till.

^b Tillage treatments are no-till and conventional tillage.

Table 2. Least square means and standard errors for crops in tillage and rotation and contrasts comparing effects of tillage or rotation from trials grown at Ottawa, ON from 2001 to 2015.

Crop	Rotation	No-till seed yield (kg ha ⁻¹)	Tilled seed yield (kg ha ⁻¹)	Contrasts for comparing tillage or rotation effects				
				No-till vs. tilled p value	Rotation vs. monoculture		Type of rotation CSW vs. CWS	
					no-till	till	no-till	till
					p value	p value	p value	p value
Corn	monoculture	7063	8565	0.15				
Corn	CSW	7426	9684	0.11	0.19	***		
Corn	CWS	7618	9563	0.12	*	***	0.11	0.67
Soybean	monoculture	2772	2841	0.93				
Soybean	CSW	2848	3010	0.75	0.84	0.49		
Soybean	CWS	2784	3035	0.66	0.95	0.43	0.79	0.92
Wheat	monoculture	2322	2619	0.44				
Wheat	CSW	3311	3474	0.77	***	*		
Wheat	CWS	2989	3425	0.45	*	*	0.83	0.89
Experiment wide coefficient of variation, %		15.2						

Note: ***, **, * indicate P values ≤ 0.001, 0.01, or 0.05, respectively. The actual p values for non-significant differences are given.

Figure Captions

Fig. 1. Yield differences between established no-till (NT) plots and new-NT plots within each year for a) corn, b) soybean and c) spring wheat in crop rotations (corn-wheat-soybean, CWS, or corn-soybean-wheat, CSW) or monoculture. Year 1996 is year one of new-NT versus six years of established NT until the year 2000 which is year five new-NT versus year 11 established- NT. Asterisks indicate significant differences (* $P \leq 0.05$, ** $P \leq 0.01$) between new and established NT treatments.

Fig. 2. Corn, soybean and spring wheat seed yield over 15 years (2001-2015), in crop rotations (corn-wheat-soybean, CWS, or corn-soybean-wheat, CSW) or monoculture under a, c, e) no-till or b, d, f) conventional tillage, at Ottawa, ON.

Fig. 3. In-season (May to September) precipitation and thermal accumulation (growing degree days₁₀) from 1996 to 2015, at Ottawa, ON. Mean precipitation and thermal accumulation are shown with the unfilled symbol.

Fig. 4. Yield difference between a) corn, b) soybean, and c) spring wheat no-till and conventional tillage (no-till minus tillage) versus tilled yield in monoculture or crop rotations (corn-wheat-soybean, CWS, or corn-soybean-wheat, CSW) from 15 years of cropping at Ottawa, ON, 2001 to 2015.

274x881mm (300 x 300 DPI)

259x370mm (300 x 300 DPI)

111x105mm (300 x 300 DPI)

270x534mm (300 x 300 DPI)