

# Monitoring corn and soybean agroecosystems after establishing no-tillage practices in Québec, Canada

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Whalen, J. K., Prasher, S. O. and Benslim, H. 2007. **Monitoring corn and soybean agroecosystems after establishing no-tillage practices in Québec, Canada.** Can. J. Plant Sci. **87**: 841–849. The conversion to no-tillage (NT) may seem risky to some producers who rely on tillage to control weeds, some insect pests and disease-causing pathogens that can reduce crop yield. Weeds, arthropods, and disease incidence were monitored in silage corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) agroecosystems with CT and newly established NT plots in Ste-Anne-de-Bellevue, Québec. During the first 2 establishment years, there were more annual grass and fewer annual broadleaf weeds in NT than in CT plots, but the surface area covered by weeds (broadleaf, grasses and perennials) was greater in CT than NT plots. Foliar arthropods were more numerous in soybean than corn plots in both years, but were unaffected by tillage. There were more ground-dwelling generalist predators, especially Coleoptera and Carabidae, in CT than NT plots, while spiders and harvestmen (Araneae and Opiliones) were dominant in NT plots. Crop damage from insect pests and diseases was below economic thresholds, but 5 yr of yield monitoring (2000–2004) revealed a trend of greater silage corn and soybean yields in CT than NT plots. The reduction in crop yield after establishing NT practices at this site was probably due to rooting constraints from inadequate seedbed preparation in the NT system, rather than from weed competition, insect damage or crop diseases.

**Key words:** Arthropods, crop disease, silage corn, soybean, tillage, weed control

Whalen, J. K., Prasher, S. O. et Benslim, H. 2007. **Surveillance aux agro-écosystèmes de maïs-ensilage et de soya convertis en semis-direct au Québec, Canada.** Can. J. Plant Sci. **87**: 841–849. Le système de semis-direct (NT) peut sembler risqué pour quelques producteurs qui comptent sur le labourage pour contrôler les mauvaises herbes, quelques insectes ravageurs et les pathogènes causant des maladies qui peuvent réduire la production végétale. Nous avons examiné des mauvaises herbes, des arthropodes, et l'incidence des maladies dans les agro-écosystèmes de maïs-ensilage (*Zea mays* L.) et soya (*Glycine max* L. Merr.), aux parcelles nouvellement converties en NT à Sainte-Anne-de-Bellevue, Québec. Pendant les deux premières années d'établissement, il y avait plus des mauvaises herbes annuelles et moins des dicotylédones annuelles avec NT que dans les parcelles avec CT, mais le degré d'envahissement par les mauvaises herbes était plus grand dans le CT que le NT. Pendant deux ans, les arthropodes foliaires étaient plus nombreux en soya par rapport au maïs-ensilage, mais ils n'étaient pas affectés par le labourage du sol. Il y avait plus de prédateurs de généraliste, particulièrement les coléoptères et les Carabidae, dans le CT que le NT, alors que les araignées et les faucheux (Araneae et Opiliones) étaient dominants dans les parcelles sous NT. La diminution du rendement de la récolte après l'établissement du NT sur ce site a été probablement due à la difficulté d'enracinement plutôt causée par une préparation inadéquate du semis avec la pratique NT que par la concurrence des mauvaises herbes, des dommages d'insecte ou des maladies végétales.

**Mots clés:** Arthropodes, indice de gravité de la maladie, maïs d'ensilage, soya, labourage du sol, malherbologie

According to the 2001 Census of Agriculture, about 4.8% of cropped land in Québec was directly seeded without tillage (NT) and an additional 18.5% was cultivated with conservation tillage systems (Statistics Canada 2002). The conventional tillage (CT) practiced on most cropped land in Québec involves plowing with a moldboard plow in the fall after harvest and harrowing in the spring before seeding. One barrier to establishing NT practices in Québec is that soils tend to be cold and wet in the spring, which can delay seeding in NT systems. Even on well-drained light-textured soils that warm up quickly in the spring, there is a perception that crop yields will be lower in NT than CT systems

due to the uncontrolled growth of weeds, some insect pests and disease pathogens. However, the lack of soil disturbance in NT systems may favor the development of more diverse biotic communities that control some of these pests. Monitoring crops and other organisms can provide information on the factors that affect production when agroecosystems are converted from CT to NT systems.

Tillage has long been used to manage and reduce weed competition with crops. The composition and diversity of weed communities are affected by the establishment and long-term maintenance of NT (Cardina et al. 2002; Sosnoskie et al. 2006). Weed seeds tend to accumulate at the

**Abbreviations:** CT, conventional tillage; DSI, disease severity index; NT, without tillage

soil surface in NT systems, but are distributed more uniformly in the plow layer of cultivated soils (Ball 1992; Cardina et al. 2002). As a result, weed species that require seed burial for germination and establishment are better adapted to CT than NT systems. NT systems often have more annual grasses, perennial weeds and volunteer species than cultivated systems because seed accumulation at the soil surface and minimal disturbance of vegetative propagules favors the survival of such species (Buhler 1995; Menalled et al. 2001; Streit et al. 2002). Converting to NT implies more reliance on chemical controls, which must be used prudently to avoid the establishment of herbicide resistant weed populations (D'Emden and Llewellyn 2006).

Western and northern corn rootworms (Coleoptera: Chrysomelidae) are economically important insect pests of corn in Québec (Meloche et al. 2005). European corn borer (Lepidoptera: Crambidae) is present in Eastern Canada, although it does not often cause a significant reduction in corn yield (Baute et al. 2002). The soybean aphid (Homoptera: Aphididae) was first detected in Michigan in 2000 and reported in Québec in 2002, and may be an economically important pest (Mignault et al. 2006). Natural enemies (often generalist predators) can reduce the populations of these and other insect pests, sometimes below economic thresholds (Clark et al. 1994), but how predator and prey populations are affected by tillage is hard to predict. Conservation tillage and NT systems are favorable to soil and litter-dwelling insects such as predatory carabid beetles (Carabidae) and spiders (Araneae). The surface crop residues found in such systems likely provide food for detritus-feeding prey and a preferred habitat for these generalist predators, which can help to maintain a large population of natural enemies (Sunderland and Samu 2000). Brust and House (1990) found more eggs of the southern corn rootworm on corn grown in NT than CT systems, but generalist predators such as mesostigmatid mites, carabid and staphylinid larvae were more active in the NT system, which led to less crop damage and higher corn yields. In contrast, the foliar-feeding soybean aphid was controlled effectively by leaf-dwelling generalist predators like lady beetles (Coccinellidae), regardless of tillage or other agricultural management practices (Costamagna and Landis 2006). It is hypothesized that ground-dwelling generalist predators will be more numerous and reduce pests that damage crop roots and stems more effectively in NT than CT systems.

Planting resistant cultivars is a highly effective method of reducing economically important corn and soybean diseases, as well as mycotoxin infection in corn grain caused by toxigenic fungi (Reid and Zhu 2001; Munkvold 2003), but tillage may provide control against certain pathogens. Many pathogens overwinter in crop residues and use these residues as a substrate for inoculum production during the growing season, suggesting that NT systems can contribute to the survival and growth of soilborne pathogens (Sturz et al. 1997). Yet, the incidence of *Pythium* and *Fusarium* root disease in corn was not affected by tillage (Soonthornpoch et al. 2000), and there are contradictory reports on how tillage affects *Sclerotinia* stem rot disease incidence in soybeans (Kurle et al. 2001; Mueller et al. 2002). If disease-causing

pathogens are controlled by natural enemies inhabiting the soil or surface litter, it is hypothesized that pathogens will be less damaging to crops grown in NT than CT systems.

The purpose of this study was to compare the populations of weeds, arthropods and generalist predators, and disease incidence in CT and newly established NT plots under corn and soybean production. The effect of tillage on crop yields during five growing seasons (2000–2004) was also reported.

## MATERIALS AND METHODS

The study site was located on the Macdonald Research Farm, Ste. Anne de Bellevue, Québec (45°28'N, 73°45'W). Annual temperature at the nearby Pierre Elliott Trudeau International Airport (Dorval, Québec) average 6.1°C, with mean annual precipitation of 967 mm. Table 1 provides mean daily temperatures and monthly precipitation during this study. The soil was a mixed, frigid Typic Endoaquent classified as a Courval sandy-loam, containing 15.4 g organic C kg<sup>-1</sup> and pH 6.1 in the 0- to 15-cm layer. From 1991 to 2000, when this study began, the site was a CT system under grain corn (*Zea mays* L.) production. Annual nutrient applications included about 30 m<sup>3</sup> ha<sup>-1</sup> of liquid dairy manure as well as 100 to 140 kg N ha<sup>-1</sup> from urea fertilizer. Further description of the site has been provided by Whalen et al. (2003) and Jiao et al. (2004).

In May 2000, a factorial (tillage x crop rotation) experiment was established with two tillage treatments (NT or CT) and three crop rotations (corn/soybean, soybean/corn or continuous corn; only one crop per year), for a total of six factorial treatments. The factorial plots were 20 m by 24 m, and were arranged in a randomized complete block design with four blocks. The entire site was cultivated with a disk harrow (10-cm depth) just before the experiment began. No additional tillage was done on the NT plots, but CT plots were tilled with a tandem disk each spring before seeding and with a moldboard plow each fall after harvest. All plots were directly seeded with a John Deere 7100 Max Emerge seeder. Silage corn (*Zea mays* L. 'Cargill 2610') was treated with Maxim and Captan and planted with 75 000 seeds ha<sup>-1</sup> in 0.75-m rows. Soybean (*Glycine max* L. Merr. 'Cargill A0868TR') treated with Soy Select was planted at a rate of 400 000 seeds ha<sup>-1</sup> in 0.75-m rows. Seeding was completed between mid-May and the first week of June during five growing seasons (2000–2004).

## Weed Populations and Weed Control

Weed populations were assessed in 2000 and 2001. No pre-plant herbicides were applied in 2000 because the entire site was cultivated with a disk harrow (10-cm depth) before treatments were applied. In the spring of 2001, the CT plots were harrowed while the NT plots received a pre-plant application of Roundup (1.1 kg a.i. ha<sup>-1</sup> of glyphosate). Weed populations were determined in six 30 cm x 30 cm quadrats at about 1.5-m intervals along four 10-m transects in each plot on 2000 Jun. 20 and 2001 Jun. 12, prior to the application of post-emergence herbicides. The percentage of soil surface in each quadrat covered by annual broadleaf, annual grasses, and perennial weeds was assessed visually by a team of two observers (Donald 2006) and the species

**Table 1. Monthly precipitation and mean daily temperatures at the Pierre Elliott Trudeau International Airport climate station during the 2000–2004 field seasons (May to September). Long-term averages (1971–2000) for precipitation and temperature are also provided (Environment Canada 2004)**

Month	2000	2001	2002	2003	2004	1971–2000
Mean daily temperature (°C)						
May	13.3	15.3	11.3	13.4	13.4	13.3
June	17.2	20.0	17.5	18.8	17.5	17.9
July	20.1	20.2	22.1	21.6	21.5	20.9
August	19.8	22.5	21.8	21.6	19.3	19.5
September	14.1	16.8	18.3	17.7	16.4	14.4
Precipitation (mm)						
Month	2000	2001	2002	2003	2004	1971–2000
May	132.5	70.0	127.5	110.5	81.8	75.2
June	77.5	76.0	106.0	70.0	64.0	84.4
July	47.5	33.0	55.0	54.0	139.4	90.1
August	102.5	62.5	11.0	79.0	90.0	94.2
September	65.5	67.0	64.5	104.0	71.8	91.3
Cumulative	425.5	308.5	364.0	417.5	447.0	435.2

present were recorded. The mean percentage of soil surface covered by weeds was calculated. Weed control in plots under corn production was achieved with post-emergence herbicide applications of 25 g a.i. ha<sup>-1</sup> of nicosulfuron and 280 g a.i. ha<sup>-1</sup> of bromoxynil (2000 Jun. 27 and 2001 Jun. 18, about mid-June during the 2002–2004 growing seasons). Plots under soybean production received post-emergence applications of bentazon (1.1 kg a.i. ha<sup>-1</sup>) on 2000 Jun. 28. Diclofop-methyl (1.0 kg a.i. ha<sup>-1</sup>) was applied on 2001 Jul. 04 and early July of 2002–2004.

### Insect Populations

Foliar and ground-dwelling insect populations were assessed in 2000 and 2001. No insecticides were applied in any study year (2000–2004). Sticky traps and pitfall traps were placed in 12 random locations throughout each plot on two sampling dates in 2000 (Jul. 07 and Aug. 02) and two sampling dates in 2001 (Jul. 09 and Aug. 02). The sticky traps, 10 cm × 10 cm yellow plastic with glue on both sides, were placed on 0.75 m tall metal rods and positioned at the canopy level of corn (about 0.75 m, July only) and soybeans (about 0.3 m in July and about 0.75 m in August). In August, sticky traps were between 0.75 and 1.0 m below the corn canopy. Pitfall traps were 120 cm<sup>3</sup> specimen cups containing 60 mL of 5% glycerol solution placed in the soil so the opening (6-cm diameter) was level with the soil surface. After 48 h, traps were removed from the field and stored in plastic bags. The number of arthropods on each trap belonging to the Hemiptera, Thysanoptera, Lepidoptera, Diptera, Neuroptera, Coleoptera, Hymenoptera, and Orthoptera was counted in the laboratory. The arthropods trapped in each pitfall trap were transferred to vials containing 70% ethanol and 5% glycerol. Individuals belonging to the Araneae and the insect orders Coleoptera, Hymenoptera, Diptera, Hemiptera, and Orthoptera in each trap were recorded. The total number of individuals in each taxon was the sum of individuals collected from sticky ( $n = 24$ ) or pitfall ( $n = 24$ ) traps during the year.

### Assessment of Disease and Pest Damage

Seeds were treated, but the crops were not sprayed to control diseases during the study. Corn and soybean diseases

were assessed visually by a team of two observers at 16 random locations in each plot on 2000 Sep. 13 and 2001 Sep. 02, approximately 1 wk before silage corn harvest. Corn plants (six to seven at each location) were examined for common smut [*Ustilago zeae* (Beckm.) Unger] as well as ear, leaf and stem diseases. A note was made if the plant, especially the stalks, ear shanks and ears, had damage that could be from European corn borer (*Ostrinia nubilalis* Hüber) and northern corn rootworm (*Diabrotica barberi* Smith and Lawrence). About 30 soybean plants at each location were monitored for leaf and stem diseases. A disease severity class (on a linear scale of 1 to 10) was assigned to each location; disease class 1 indicated that 0 to 10% of the aboveground biomass in these plants was affected, while disease class 10 corresponded to 91 to 100% of aboveground biomass exhibiting disease symptoms. The disease severity index (DSI) for each plot was calculated, based on the index of Kostandi and Geisler (1989) as:

$$DSI = \sum (DSC_i)/n \quad (1)$$

where  $DSC_i$  is the disease severity class for the  $i$ th location in each plot and  $n$  is the number of locations examined ( $n = 16$ ).

### Plant Populations and Yield

Plant populations were assessed by counting the number of corn plants along a 5-m transect at four locations in each plot, and the number of soybean plants along a 1-m transect at four locations in each plot, approximately 1 wk before harvest. At harvest, silage corn yield was determined by harvesting the grain and stover (stems and leaves) of 80 plants from each plot. Soybean grain yield was determined by combining four swaths, each 3 m wide by 20 m long, from each plot. Subsamples of grain and stover were dried (60°C for 48 h) and yields were expressed on a Mg dry matter ha<sup>-1</sup> basis.

### Statistical Analysis

Data were transformed to achieve homogeneity of variance using an arcsine square root transformation for weed popu-

lations,  $\log(x + 1)$  for insect populations, and a log transformation for disease severity (Steel et al. 1997). The data were then evaluated by analysis of variance in a general linear model (SAS System 9.1, SAS Institute, Inc., Cary, NC). Disease severity, weed populations and insect populations were significantly ( $P < 0.05$ ) affected by the tillage and crop grown, as well as the tillage  $\times$  crop interaction (2000–2001). Means were compared with a Student-Newman-Keuls test at the 95% confidence level (Steel et al. 1997). Data presented in the tables and figures are untransformed means. Analysis of variance was also used to assess the effect of tillage on soybean yield, and the effect of tillage  $\times$  crop interaction on silage corn yields for each of the five growing seasons (2000–2004). Means were compared with a Student-Newman-Keuls test at the 95% confidence level.

## RESULTS AND DISCUSSION

### Weed Populations

The weed population assessment was done in the spring soon after seeding, since these weeds could compete with emerging corn and soybean seedlings for sunlight, water and nutrients. The majority of weed species were annuals, and the dominant annual broadleaf species were lamb's quarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.) and redroot pigweed (*Amaranthus retroflexus* L.) (Table 2). Other annual broadleaf weeds found at the site were shepherd's purse (*Capsella bursa-pastoris* L.), common ragweed (*Ambrosia artemisiifolia* L.), velvetleaf (*Abutilon theophrasti* Medicus), green pigweed (*Amaranthus powellii* L.), hemp nettle (*Galeopsis tetrahit* L.), tufted vetch (*Vicia cracca* L.), knotweed (*Polygonum aviculare* L.), corn spurry (*Spergula arvensis* L.), purslane (*Portulaca oleracea* L.), and nodding beggarticks (*Bidens cernua* L.). The dominant annual grass species was barnyardgrass (*Echinochloa crusgalli* L.) (Table 2). Giant foxtail (*Setaria faberi* Herrm.) and fall panicum (*Panicum dichotomiflorum* Michx. var. *geniculatum* (Wood) Fern.) were observed. Perennial weed species included quack grass (*Elymus repens* L. Gould), common plantain (*Plantago major* L.), common milkweed (*Asclepias syriaca* L.), field horsetail (*Equisetum arvense* L.), and perennial sow-thistle (*Sonchus arvensis* L.).

No difference in weed populations at the site was expected in 2000 because the entire field was disked prior to establishing the experimental treatments, so data represents the spatial variability in weed populations at the site (Table 2).

The major finding was more annual broadleaf weeds in the CT plots and more annual grasses in the NT plots during 2001 (Table 2). In corn agroecosystems, Streit et al. (2002) and Sosnoskie et al. (2006) also found more annual broadleaf weeds in CT systems, while annual grass species like *Echinochloa crus-gali* L. and *Poa annua* L., and perennial broadleaf weeds were more abundant in NT than CT systems. Buhler et al. (1994) reported more perennial weeds in NT than CT plots, but perennial weeds accounted for 3% or less of the surface area covered by weeds, probably because it takes more than 1 yr for perennial weed populations to build up after cultivated land is converted to a NT system (Table 2).

In plots with the same crop sequence, the surface area covered by weeds (broadleaf, grasses and perennials) was between 17 and 35% greater in CT than NT plots in 2001 (Table 2). This suggests that the pre-plant glyphosate application in NT plots was more effective at reducing weed populations early in the growing season than cultivation (to 10 cm) with a disk harrow. Studying the evolution of weed communities for more years after NT establishment would confirm this observation, but was not done due to financial constraints.

### Insect Populations

Ground beetles (Family Carabidae) were the most numerous generalist predator collected in pitfall traps, and a few Araneae, Opiliones and Hymenoptera were also recovered (Table 3). No difference was observed in 2000, the baseline monitoring year for this study, but more Coleoptera and Carabidae were trapped in the CT than NT plots during 2001 (Table 3). Many studies have reported larger carabid populations in reduced tillage than cultivated systems (Kromp 1999), but in some cases more carabids have been trapped in CT than in reduced tillage or NT systems (Cárcamo 1995; Halaj et al. 2000). Some possible explanations for these findings are that (1) carabid beetles move faster, or more easily, when there are fewer surface residues, as in cultivated systems, (2) the microenvironment of cultivated soils is more favorable to carabid beetles than that of NT soils, or (3) less competition for prey or intra-guild predation occurs in CT than NT systems (Cárcamo 1995).

During 2001, the generalist predator population collected from NT plots contained a larger proportion of Araneae and Opiliones per treatment than the CT plots. Spiders tend to be more numerous in agroecosystems where surface residue cover is diversified by planting intercrops and cover crops, retaining weeds or conserving crop residues (Sunderland and Samu 2000; Landis et al. 2005). Yet, there was no difference in the mean number of Araneae and Opiliones collected in the CT and NT plots (Table 3), suggesting that the microenvironment of cultivated soils was also favorable for spiders and harvestmen. Halaj et al. (2000) reported a reduction in the number of spiders in soybean fields following cultivation, but found that spider populations returned to pre-tillage levels after 1 mo. A more intensive sampling program, with collection times in the spring (May, June) and the fall (September), would have helped to clarify the effect of tillage on ground-dwelling arthropods, spiders and harvestmen, but this was not possible with the resources available for this study.

Foliar arthropods were sampled with sticky traps at the same time as pitfall trapping was done. Some important insect pests, including thrips (Order Thysanoptera), aphids (Family Aphididae), and leafhoppers (Family Cicadellidae) were more numerous in soybean than corn plots in 2000 and 2001 (Fig. 1). The soybean aphid *Aphis glycines* Matsamura, which was accidentally introduced to North America from Asia, was collected in 28 of 30 counties in southern Ontario by the summer of 2001 (Hunt et al. 2003). Yet, there were about 50% fewer aphids on soybeans in 2001 than 2000, perhaps because they were controlled by

**Table 2. Percentage of soil surface covered by broadleaf, grass and perennial weeds before post-emergence herbicide application in conventional tillage (CT) and newly-established no-till (NT) systems under corn and soybean production**

Tillage	Crop	Broadleaf <sup>z</sup>	Grasses <sup>y</sup>	Perennials <sup>x</sup>	Total
2000					
CT	Corn	10a	8b	3a	21a
CT	Soy	4b	9b	3a	16b
NT	Corn	5b	14a	2a	21a
NT	Soy	8a	11a	3a	22a
2001					
CT	Corn-Corn <sup>w</sup>	17a	4d	2a	23a
CT	Soy-Corn	12b	5cd	2a	19b
CT	Corn-Soy	16ab	3d	1b	20ab
NT	Corn-Corn	3d	13a	3a	19b
NT	Soy-Corn	6c	6bc	1b	15c
NT	Corn-Soy	6c	7b	2a	13d

<sup>z</sup>Mainly lamb's quarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.) and red root pigweed (*Amaranthus retroflexus* L.).

<sup>y</sup>Mostly barnyard grass (*Echinochloa crusgalli* L.).

<sup>x</sup>Couch grass (*Agropyron repens* L.) and common plantain (*Plantago major* L.) were dominant.

<sup>w</sup>The phase of the crop rotation grown in 2001 is underscored.

a–d For each year, means within a column followed by the same letter are not significantly different ( $P < 0.05$ , Student-Newman-Keuls).

**Table 3. Generalist predators (mean number per treatment) collected from pitfall traps in conventional tillage (CT) and newly-established no-tillage (NT) systems under corn and soybean production**

Insects (712) captured under corn and soybean production					
Tillage	Crop	Coleoptera		Araneae and Opiliones <sup>y</sup>	Hymenoptera <sup>x</sup>
		Total <sup>z</sup>	Carabidae		
2000					
CT	Corn	3a	3a	1a	1a
CT	Soy	3a	2a	1a	<1a
NT	Corn	3a	3a	1a	<1a
NT	Soy	3a	2a	2a	<1a
2001					
CT	Corn- <u>Corn</u> <sup>w</sup>	6b	4ab	2a	1b
CT	Soy- <u>Corn</u>	7b	6a	4a	2a
CT	Corn- <u>Soy</u>	9a	6a	4a	1b
NT	Corn- <u>Corn</u>	1c	1c	3a	<1b
NT	Soy- <u>Corn</u>	4b	2b	4a	<1b
NT	Corn- <u>Soy</u>	3b	3b	4a	<1b

<sup>z</sup>Includes individuals from the families Carabidae, Staphylinidae, Nitidulidae, Coccinellidae and Chrysomelidae.

<sup>y</sup>Araneae were mainly wolf spiders of family Lycosidae.

<sup>x</sup>Mostly wasps and ants.

<sup>w</sup>The phase of the crop rotation grown in 2001 is underscored.

a–c For each year, means within a column followed by the same letter are not significantly different ( $P < 0.05$ , Student-Newman-Keuls).

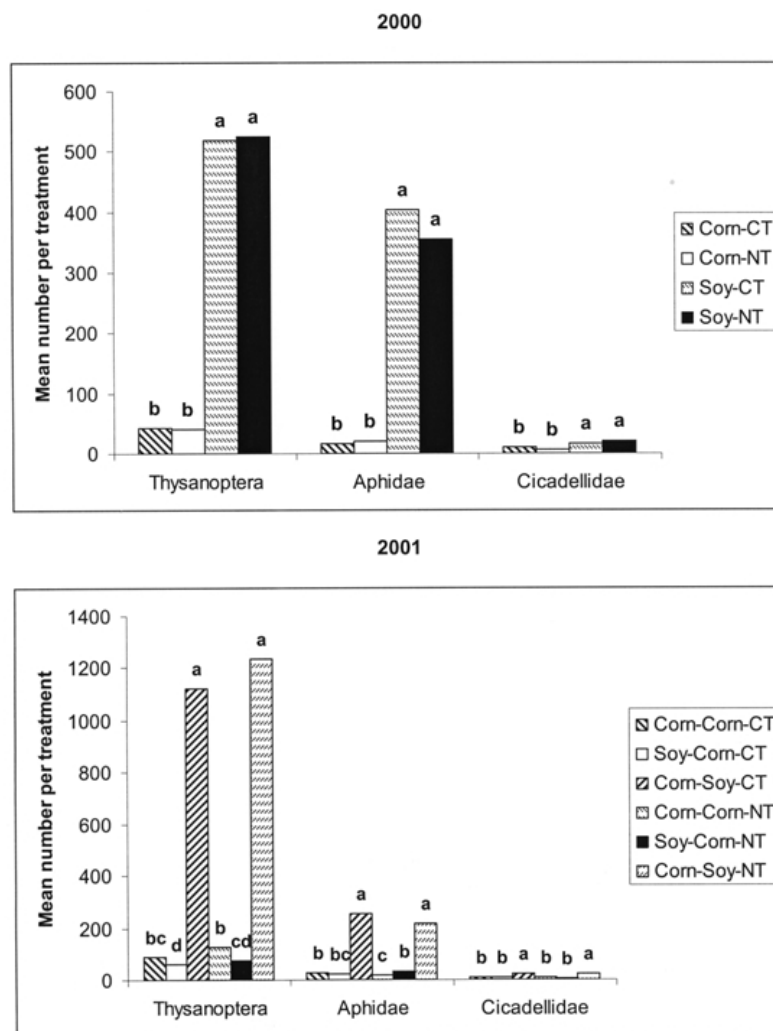
natural enemies like lady beetles (Coleoptera: Coccinellidae), which tended to be more abundant in 2001 than 2000 (Fig. 1, Table 4). It is possible that soybean aphid was not present in 2001, since this pest was first reported in Québec in 2002 (Mignault et al. 2006).

Other foliar arthropods included members of the Diptera, Coleoptera (mostly Coccinellidae) and Hymenoptera (Table 4) and a few individuals of the Orders Hemiptera and Lepidoptera (data not shown). There were significantly ( $P < 0.05$ , Student-Newman-Keuls) more Diptera and Hymenoptera on sticky traps collected from plots under corn than soybean production in 2001 (Table 4). In general, foliar arthropods were affected more by the crop grown (soybean or corn) than by tillage systems.

### Disease and Pest Damage

Common rust (*Puccinia sorghi* Schwein), Fusarium ear rot [*Fusarium verticillioides* (= *Fusarium moniliforme* J. Sheld)

and *F. proliferatum* (T. Matsushima) Nirenberg] and common smut (*U. zeae*) were found on corn in 2000 and 2001. There was also some Fusarium stalk rot [*Fusarium proliferatum* (T. Matsushima) Nirenberg] on corn stalks in 2001. In soybean plots, downy mildew [*Peronospora manshurica* (Naum.)] and Sclerotinia stem rot [*Sclerotinia sclerotiorum* (Lib.) Korf and Dumont] were detected in both years. However, the disease severity index did not exceed 20% for any pathogen during the establishment of the NT system, and there was no effect of tillage on disease incidence (data not shown). No damage from European corn borer, northern corn rootworm or soybean aphid was observed at the site during 2000–2001. Thus, it was not possible to test hypotheses about biological control by natural enemies in the NT and CT plots because there was very little crop disease and pest damage at the study site. Due to the spatial and temporal variability in pest outbreaks, researchers might deliber-



**Fig. 1.** Foliar arthropod pests from the Order Thysanoptera, Family Aphidae and Family Cicadellidae (mean number per treatment) collected from sticky traps in conventional tillage (CT) and newly established no-tillage (NT) systems under corn and soybean production. The phase of the crop rotation grown in 2001 is the second crop in each legend title. Bars with the same letter are not significantly different ( $P < 0.05$ , Student-Newman-Keuls).

ately introduce pests into agroecosystems with NT and CT systems, within field cages or enclosures, but such manipulation experiments were beyond the scope of this study. Another possibility is to survey many fields rather than work on a single site, which could be considered for the future.

### Silage Corn and Soybean Yields

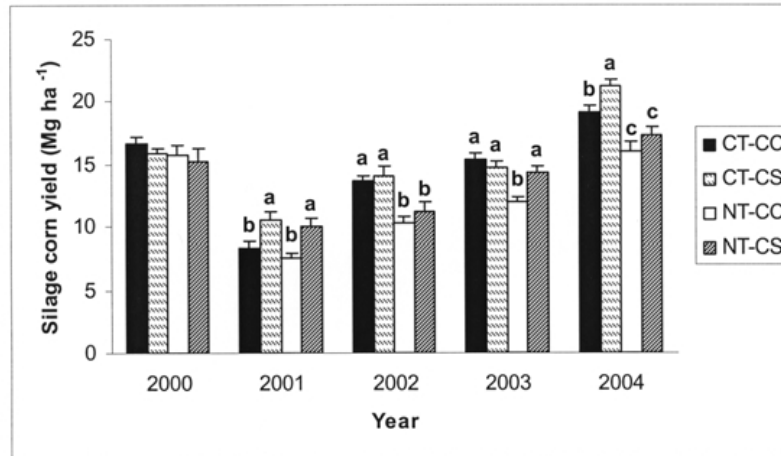
Monitoring of weed populations, insect populations, diseases and pest damage ceased after 2001 due to financial constraints and also because there was no evidence that weeds, diseases and pests affected plant populations (data not shown) or crop yield. Yet, silage corn and soybean yields were greatly affected by weather conditions during these years. Silage corn yields were 35 to 51% greater in 2000 than 2001 due to a prolonged drought (35 d without significant precipitation) in July and August of 2001 (Fig.

**Table 4.** Foliar arthropods from the orders Diptera, Coleoptera and Hymenoptera (mean number per treatment) collected from sticky traps in conventional tillage (CT) and newly established no-tillage (NT) systems under corn and soybean production

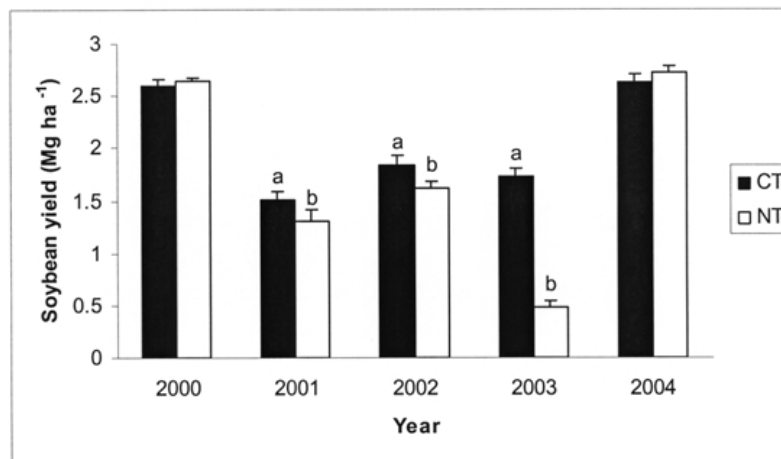
Tillage	Crop	Diptera	Coleoptera	Hymenoptera
2000				
CT	Corn	122a	4a	44a
CT	Soy	71c	4a	40a
NT	Corn	103ab	5a	44a
NT	Soy	91bc	4a	39a
2001				
CT	Corn-Corn <sup>z</sup>	135ab	14a	48b
CT	Soy-Corn	147a	7bc	53a
CT	Corn-Soy	82c	7bc	28b
NT	Corn-Corn	117b	7bc	44a
NT	Soy-Corn	120b	4c	45a
NT	Corn-Soy	76c	10ab	24b

<sup>z</sup>The phase of the crop rotation grown in 2001 is underscored.

a-c For each sampling date, means within a column followed by the same letter are not significantly different ( $P < 0.05$ , Student-Newman-Keuls).



**Fig. 2.** Silage corn yields in conventionally tilled (CT) and no-till (NT) agroecosystems, 2000–2004. The plots were under continuous corn production (CC) or a corn-soybean rotation (CS). For each year, bars with the same letter are not statistically different ( $P < 0.05$ , Student-Newman-Keuls test).



**Fig. 3.** Soybean yields in conventionally tilled (CT) and no-till (NT) agroecosystems, 2000–2004. For each year, bars with the same letter are not statistically different ( $P < 0.05$ , Student-Newman-Keuls test).

2). The drought in 2001 occurred as soybean entered its reproductive development stages, causing a 42 to 50% reduction in yield compared with 2000 (Fig. 3).

During the period 2002–2004, the silage corn yields in plots under continuous corn production were always greater in CT than NT systems; in plots with a corn-soybean rotation, the silage corn yield was greater in the CT than the NT system in 2 of 3 yr (Fig. 2). Greater soybean yields were measured in CT than NT systems in 3 of the 5 yr (Fig. 3).

Tillage loosens the soil and may permit crop roots to penetrate and extract water from deeper in the soil profile, particularly in soils with poor structure or plow pans. Crops with a well-developed rooting system are expected to have less water stress than those with shallow roots. NeSmith et al. (1987) reported that soybeans extracted more water from the 15- to 45-cm depth of CT (moldboard plow and disk) systems than disk tillage or NT systems. Water stress

becomes critical when there is limited rainfall during grain development and grain-filling stages (Waggoner and Denton 1992). It is interesting that the yield reductions persisted after conversion to NT, as NT systems tend to have greater soil water availability from increased infiltration within a few years of their establishment (Lal 1994). A long-term tillage experiment adjacent to our study site found few differences in the grain yield from silage corn and grain corn plots under NT, reduced tillage and CT during the period 1991–2002 (Dam et al. 2005). This is probably due to more favorable weather for corn production during the establishment of these long-term NT plots and the development of a macropore structure over the years that permitted adequate root penetration and growth, even in growing seasons with below-normal rainfall (2001, 2002). It is proposed that the lack of seedbed preparation in the NT plots impeded root growth and water extraction, leading to lower silage corn

and soybean yields in NT plots than CT plots. However, this remains to be confirmed experimentally.

The potential reduction in crop yields may dissuade producers from converting from CT to a NT system, but one option that remains to be investigated in Québec is the use of strip (zone) tillage. In this system, the planted row (15 to 20 cm wide, to a depth of perhaps 20 cm) is cultivated before planting, but the rest of the field is left undisturbed. The goal of the tillage operation is to speed soil warming and moisture evaporation in the spring and facilitate crop root growth; this conservation tillage system may also protect soils from erosion and conserve soil organic carbon reserves better than a CT system (Vyn and Raimbault 1992). Strip tillage systems can produce higher corn yields than NT systems in some cases (Vyn and Raimbault 1992; Beyaert et al. 2002), although further work is needed to develop a strip tillage system that produces consistently high soybean yields (Janovicek et al. 2006).

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