Wheat residue management options for no-till corn

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Opoku, G. and Vyn, T. J. 1997. **Wheat residue management options for no-till corn.** Can. J. Plant Sci. **77**: 207–213. Corn (*Zea mays* L.) yield reduction following winter wheat (*Triticum aestivum* L.) in no-till systems prompted a study on the effects of tillage and residue management systems on corn growth and seedbed conditions. Four methods for managing wheat residue (all residue removed, straw baled after harvest, straw left on the soil surface, straw left on the soil surface plus application of 50 kg ha^{-1} N in the fall) were evaluated at two tillage levels: fall moldboard plow (MP) and no-till (NT). No-till treatments required at least 2 more days to achieve 50% corn emergence and 50% silking, and had the lowest corn biomass at 5 and 7 wk after planting. Grain yield was similar among MP treatments and averaged 1.1 t ha^{-1} higher than NT treatments ($P < 0.05$). Completely removing all wheat residue from NT plots reduced the number of days required to achieve 50% corn emergence and increased grain yields by 0.43 and 0.61 t ha^{-1} over baling and not baling straw, respectively, but still resulted in 8% lower grain yields than MP treatments. Grain yield differences among MP treatments were insignificant regardless of the amount of wheat residue left on the surface or N application in the fall. Early in the growing season, the NT treatments where residue was not removed had lower soil growing degree days (soil GDD) compared with MP (baled) treatment, and higher soil moisture levels in the top 15 cm compared with all other treatments. The application of 50 kg N ha^{-1} in the fall to NT (not baled) plots influenced neither the amount of wheat residue on the soil surface, nor the soil NO_3-N levels at planting. Our results suggest that corn response in NT systems after wheat mostly depends on residue level.

Key words: Winter wheat, straw management, no-till, corn, soil temperature, soil moisture

Opoku, G. et Vyn, T. J. 1977. **Choix de gestion des restes de culture du blé pour la production de maïs sans travail du sol.** Can. J. Plant Sci. **77**: 207–213. La baisse de rendement du maïs (*Zea mays* L.) observée après une culture de blé d'hiver (*Triticum aestivum* L.) en système de culture sans labour nous a inspiré une étude sur les effets du mode de travail du sol et de la gestion des restes de culture sur la croissance du maïs et sur l'état du lit de semence. Nous avons évalué quatre méthodes de gestion des restes de culture de blé : enlèvement total des résidus, mise en balle de la paille après la moisson, paille laissée à la surface du sol, la même chose avec épandage de 50 kg N ha^{-1} en automne. Ces traitements étaient combinés à deux régimes de travail du sol : labour d'automne à la charrue à versoir (Lcha) et semis direct (SD). En régime SD, le maïs requérait au moins 2 jours de plus pour arriver à 50 % de levée et à 50 % de floraison femelle. Et en outre sa biomasse à 5 et à 7 semaines après le semis était toujours la moins abondante. Le rendement grainier était du même ordre dans tous les traitements en régime de travail classique, soit 1,1 t ha^{-1} plus élevé que dans les traitements en régime de semis direct ($P < 0,05$). L'élimination complète de tous les restes de culture du blé dans les parcelles conduites en semis direct raccourcissait le délai de levée (50 %) et donnait lieu à un accroissement du rendement grainier de 0,43 t ha^{-1} par rapport à la mise en balle de la paille et de 0,61 par rapport à la paille laissée à la surface du sol. Le rendement, toutefois, restait encore inférieur de 8 % à celui obtenu dans les parcelles conduites en régime de labour classique. Les différences de rendement grainier observées parmi les traitements conduits en travail classique n'étaient pas significatives, quelques soient l'abondance des restes de culture de blé laissés à la surface ou l'apport de N en automne. Au début de la saison de végétation, les parcelles SD où les restes de culture étaient laissés sur place enregistraient des sommes de température du sol plus basses que les parcelles TC avec mise en balle de la paille ainsi que des niveaux hydriques du sol plus élevés dans les 15 premiers centimètres du sol que dans toutes les autres combinaisons de traitements. L'apport de 50 kg N ha^{-1} en automne aux parcelles SD (paille laissée sur place) n'avait d'influence ni sur la quantité de restes de cultures laissés à la surface ni sur la teneur en N nitrique du sol à l'époque du semis du maïs. Il ressort de nos observation que le comportement du maïs en régime de semis direct suivant une sole de blé dépend en très grande partie de l'abondance des résidus laissés sur place.

Mots clés: Blé d'hiver, gestion de la paille, maïs en régime de semis direct, température du sol, teneur en eau du sol

Maintaining crop residues on the soil surface protects the soil from wind and water erosion, provides a source of plant nutrients, improves organic matter levels in the soil, and increases soil water content by reducing evaporation and increasing infiltration rate (Blevins et al. 1983; Chastain et al. 1995). Despite these numerous benefits, the management of crop residues has become a major problem to NT corn producers. For example, corn grain yield generally is reduced when corn is seeded into winter wheat stubble in Ontario. As a result, many NT corn producers in Ontario have excluded wheat from their rotations and simply rotate corn with soybeans. Other farmers have reverted to plowing wheat stubble prior to the corn year, while continuing their NT system for crops such as soybeans and winter wheat.

Reduced corn yield in NT was attributed by Karlen and Sojka (1985) to delayed emergence and slow early-season growth. Stand count in NT corn 7 d after planting was half that of a MP system. Karlen (1989) found that delayed corn

Abbreviations: GDD, growing degree days; **MP**, moldboard plow; **NT**, no till emergence in NT resulted from poor placement and coverage of the seed in heavy residue. Lindwall and Anderson (1977) reported that double and triple disk press drills were unable to penetrate NT soil with more than 3.7 t of wheat residue ha^{-1}. Reduced corn yield in NT systems have also been attributed to wet and cool in-row seedbed conditions. Maximum soil temperatures at a 5 cm depth have been shown to be 3°C lower in NT than in MP treatments (Izaurralde et al. 1986). Cochran et al. (1977) and Lund et al. (1993) attributed substandard crop growth after wheat to the presence of phytotoxic compounds secreted by, or produced during, decomposition of wheat residues.

Delayed corn growth and yield reduction following winter wheat have slowed the rate of adoption of NT systems in Ontario. In order to encourage corn producers to accept and adopt NT practices, this study was undertaken to determine (i) the effect of tillage and residue management systems on seedbed conditions, (ii) if wheat residue levels on NT plots affect corn performance, and (iii) whether N application in the fall would eliminate the harmful effects of wheat residues.

MATERIALS AND METHODS

Field experiments were established in 1994 and 1995 at the Elora Research Station, Elora, Ontario, Canada, on a Guelph silt-loam soil (Gray-brown Podzol) containing 4% organic matter in the surface 15 cm. Winter wheat (cv. Harus) was planted in early October of 1992 and 1993 and harvested between 25 July and 25 August of the preceding year. The wheat straw was baled, leaving a standing stubble about 20 to 30 cm high. This was the condition of the field in the fall before treatments were applied.

The experiment was arranged in a randomized complete block design as a four by two factorial with eight treatments and four replications. There were four residue management treatments: (i) wheat stubble was mowed and raked from plots in the fall, (ii) wheat straw was baled after harvest, leaving only the stubble, (iii) wheat straw was added back to plots in the fall to simulate no-till planting into a wheat field where straw had been spread and returned to the field while combining, and (iv) identical to (iii) except that 50 kg N ha^{-1} in the form of ammonium nitrate was applied in the fall. Each residue treatment was subjected to two tillage systems: either fall moldboard plowed to a depth of 15 cm, followed by two passes of field cultivator and packer in the spring, or no-tilled.

Glyphosate [N-(phosphonomethy)glycine] was sprayed on no-till plots @ 1.3 kg a.i. ha^{-1} to burn down weeds in the spring before planting. The corn hybrid Pioneer 3905 was seeded in 76-cm rows on 19 May 1994 and 13 May 1995. Each plot was 6 m wide and 18 m long. Corn was planted using a John Deere 7000 Conservation planter equipped with a single 5-cm fluted coulter positioned directly in front of the seed disc openers plus a coulter for starter fertilizer. The no-till planter was also equipped with unit-mounted trash wheels. The seeding rate was 74 000 seeds ha^{-1}. Nitrogen at 14 kg ha^{-1} and P at 29 kg ha^{-1} as monoammonium phosphate were applied through the planter in a band near the row. Additional N (urea-ammonium nitrate) was injected between corn rows about 4–5 wk after planting at a rate of 150 kg N ha^{-1}. A pre-emergence application of cynazine (2-[[4-chloro-6-(ethylamino)-1,3,5-triazine-2-yl] amino]-2-methylpropanenitrile) @ 2.1 kg a.i. ha^{-1} and metolachlor [2-chloro-N-(2-ethy-6-methylphenyl)-N-(2-methoxyl-1-methylethyl)acetamide] @ 2.4 kg a.i. ha^{-1} were applied to all plots. Additionally, dicamba (3,6-dichloro-2-methoxybenzoic acid) was applied post emergence at a rate of 0.35 kg a.i. ha^{-1} to control broadleaf weeds.

Wheat residue biomass from no-till plots was determined in the fall (after fall tillage), before planting corn in May, and in the middle of June, by collecting all surface wheat residue from two 0.50 m^2 quadrants per plot. Volumetric moisture content in the seedbed (0 to 15 cm depth) was determined from early May to early June using a Time Domain Reflectometer (Topp et al. 1980). Measurements were made at five random points in each plot. After planting, however, all measurements were made in the row area. Percent residue cover was determined using the line transect method (Sloneker and Moldenhauer 1977). Three determinations were made per plot.

The number of days required to achieve 50% corn emergence was recorded in both years. Early season corn growth was quantified by determining the mean biomass of 15 plants at 5 and 7 wk after planting. The plants were dried to a constant weight at 80°C. The number of days from planting to 50% silk emergence was also recorded. Grain yields were determined on a 15.5% moisture content basis by hand harvesting corn from a 7.6 m^2 area from the centre of the plots in late October. Grain moisture content was also determined at harvest using a Dickey John (GAC II) moisture meter.

Soil samples were taken from NT (not baled and not baled + N) treatments before nitrogen application in the fall, and before planting corn in the spring to determine soil nitrate levels. Samples were collected at five random points in each plot with a 2.5-cm-wide soil probe to a depth of 30 cm. Nitrate was extracted from a 5.0-g soil subsample collected from a composite sample from each plot by shaking for 30 min in 25 mL of 2 M KCL. The solution was passed through a No. 4 Whatman filter paper and the concentration of NO_3-N (in mg L^{-1}) was measured using a Braun and Lube Traacs 800 (Keeney and Nelson 1982). The concentration of NO_3-N (in mg kg^{-1}) was calculated using the following formula:

$$NO_3-N(\mathrm{mg\,kg^{-1}}) = \frac{NO_3-N(\mathrm{mg\,L^{-1}})\times(0.025+(M\times 0.05))}{((1-M)\times 0.005)}$$

where M = (wet soil-dry soil)/wet soil.

Soil temperature was measured every 15 min and averaged hourly for some treatments (MP (baled), NT (bare), NT (baled), NT (not baled)) using thermocouples made from copper-constantin wire (Gordon Co., Richmond, IL). The thermocouples were inserted in the row at a depth of 5 cm from planting to about 5 wk after planting. Soil GDD were calculated using 30 and 10°C as the base maximum and minimum temperatures, respectively.

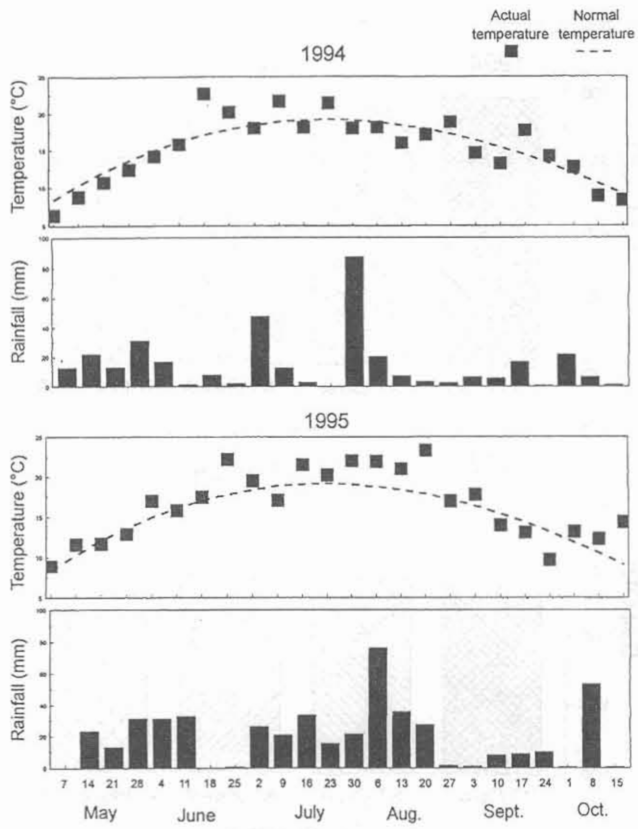

Fig. 1. Total weekly rainfall (mm) and mean weekly air temperature (°C) at the Elora Research Station, Ontario, for the 1994 and 1995 growing seasons.

Data were combined over years for analyses using the ANOVA procedure available from the SAS Institute, Inc. (1987). When there was a year-by-treatment interaction, analyses were done separately for each year. All treatment means were compared using the protected least significant difference (LSD) at the 5% probability level.

RESULTS AND DISCUSSION

Corn planting was completed around the middle of May in both years. The mean air temperature for May was higher in 1994 than in 1995 (Fig. 1). After this period, temperatures were mostly above average in both years. The total monthly precipitation early in the 1995 growing season was above average, and higher than in 1994 (Fig. 1). Cool and wet conditions prevailed in May 1995 and an intense rainfall in the first 2 wk of June 1995 (63 mm) detached and moved much of the wheat residues away from NT plots and onto the pathways between replications.

Effect of Tillage and Residue Management on Seedbed Conditions

The amount of wheat residue on the surface at each of three sampling times for NT (not baled) treatments did not differ regardless of N application in the fall, and was higher than NT (baled) treatment in both years (Table 1). On average, the amount of wheat residue on NT (not baled) treatments was 6.7 t ha^{-1}, and 3.6 t ha^{-1} on NT (baled) treatments in the fall. The amount of wheat residue present in mid-June 1994 was 50 to 70% of that present the previous fall. Faster losses were apparent in 1995; by mid-June only 30 to 35% of the wheat residue present the previous fall still remained.

Moldboard plow treatments maintained no more than 10% residue cover after planting corn in the spring (Table 2). By contrast, all NT treatments maintained more than 60% residue cover. The residue cover of NT (bare) treatment comprised mostly volunteer wheat left after herbicide burn down prior to planting.

Fall N application did not result in higher soil NO_3-N levels at planting in either year in the NT (not baled) treatments (data not provided). In 1994, the amount of NO_3-N in the fall before N application to NT treatments averaged 4 mg N kg^{-1}, but in 1995 differences existed between these treatments (17 vs. 8 mg N kg^{-1}). However, these initial differences did not affect soil NO_3-N levels before corn planting in the spring. Fall N application also did not advance wheat straw decomposition in either year. Addition of N to crop residues has been shown to hasten decomposition when conditions were favorable for decomposition (Allison and Murphy 1963). In this experiment, N was applied to NT (not baled + N) plots in late October each year when mean air temperatures were below 4°C. Cool temperatures in late fall, winter,

Table 1. The amount of wheat residue on the surface of no-till plots as influenced by residue management systems at three different times

Year/straw management	Fall	Spring	Mid-June
		(t ha^{-1})	
1994			
No-till (baled)	3.70*b*	3.47*b*	2.00*b*
No-till (not baled)	6.53*a*	6.30*a*	4.73*a*
No-till (not baled + N)	6.62*a*	6.29*a*	4.89*a*
1995			
No-till (baled)	3.40*b*	3.29*b*	1.05*b*
No-till (not baled)	6.80*a*	5.74*a*	2.36*a*
No-till (not baled + N)	6.87*a*	5.66*a*	2.40*a*

a,b Within columns, means followed by the same letter are not significantly different at the 5% level of probability.

Table 2. Effect of tillage and wheat residue management systems on soil volumetric moisture content in the surface 15 cm measured at various times early in the season, and soil residue cover averaged over 2 yr

Tillage/straw management	Early May	Late May	Early June	Residue cover
		(cm^3 cm^{-3})		(%)
Fall moldboard (bare)	0.25*c*	0.22*c*	0.21*c*	4*d*
Fall moldboard (baled)	0.26*c*	0.21*c*	0.21*c*	4*d*
Fall moldboard (not baled)	0.26*c*	0.21*c*	0.22*c*	10*d*
Fall moldboard (not baled + N)	0.25*c*	0.23*c*	0.22*c*	10*d*
No-till (bare)	0.26*c*	0.23*c*	0.22*c*	18*c*
No-till (baled)	0.28*b*	0.26*b*	0.24*b*	63*b*
No-till (not baled)	0.29*ab*	0.29*a*	0.27*a*	77*a*
No-till (not baled + N)	0.30*a*	0.28*ab*	0.28*a*	75*a*

a-d Within columns, means followed by the same letter are not significantly different at the 5% level of probability.

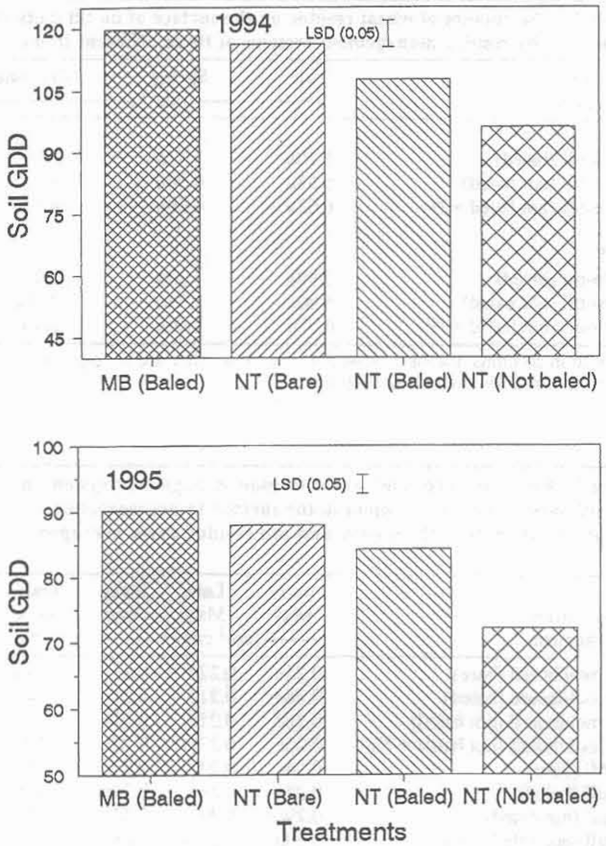

Fig. 2. Effect of tillage and wheat residue management systems on accumulated soil GDD from planting to first 20 d in 1994 and 1995 for MB and NT treatments.

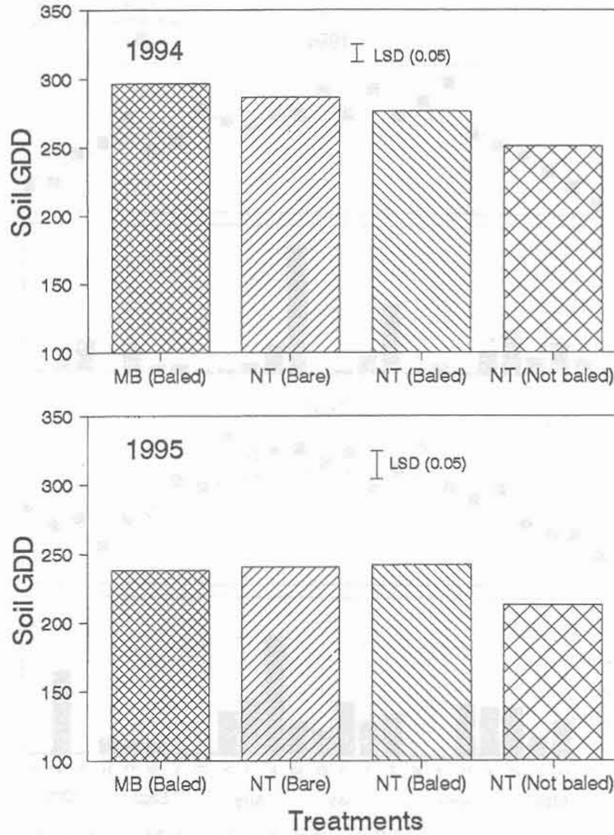

Fig. 3. Effect of tillage and wheat residue management systems on accumulated soil GDD from planting to 5 wk after planting in 1994 and 1995 for MB and NT treatments.

Table 3. Effect of tillage and wheat residue management systems on days to 50% emergence, and corn dry weights at 5 and 7 wk after planting in 1994 and 1995

Tillage/straw management	Time to 50% emergence		Corn dry weights			
			At 5 wk		At 7 wk	
	1994	1995	1994	1995	1994	1995
	(d)		(g plant^{-1})			
Fall moldboard (bare)	10.0*e*	14.8*c*	2.45*a*	1.13*abc*	20.0*a*	23.9*a*
Fall moldboard (baled)	10.5*de*	14.8*c*	2.56*a*	1.11*abc*	18.4*a*	21.2*ab*
Fall moldboard (not baled)	10.5*de*	14.6*c*	2.26*a*	1.14*ab*	19.2*a*	20.8*ab*
Fall moldboard (not baled + N)	10.8*de*	14.7*c*	2.29*a*	1.17*a*	19.4*a*	24.0*a*
No-till (bare)	11.5*cd*	14.6*c*	1.35*b*	1.05*abc*	13.2*b*	19.5*b*
No-till (baled)	12.0*bc*	15.4*b*	1.19*b*	1.10*abc*	9.1*c*	15.4*c*
No-till (not baled)	13.0*ab*	17.6*a*	1.15*b*	0.85*c*	8.2*c*	13.1*c*
No-till (not baled + N)	13.3*a*	17.1*a*	1.01*b*	0.88*bc*	7.8*c*	13.7*c*

a-e Within columns, means followed by the same letter are not significantly different at the 5% level of probability.

and early spring can limit the decomposition of wheat residues; therefore soil N levels were not the limiting factor.

No-till treatments with wheat residue consistently had the highest soil moisture levels in the surface 15 cm at various times early in the season compared with MP treatments (Table 2). The MP treatments did not differ from NT (bare) treatment. No-till (bare) plots were drier in the spring than NT with wheat residue, indicating that high amounts of wheat residue on NT plots were contributing to high soil moisture contents. These results were consistent with those of Munawar et al. (1990) and Chastain et al. (1995) who reported higher soil moisture contents on high than low residue plots.

In both years, MP (baled) and NT (bare) treatments had higher soil GDD for the first 20 d after planting than the NT treatments with residue (Fig. 2a,b). Soil GDD for MP (baled) treatment was higher than NT (baled and not baled) treatments at 35 d after planting in 1994 (Fig. 3a) but differences existed between NT (baled) and NT (not baled) treatments in 1995 (Fig. 3b). Al-Darby and Lowery (1987) also reported higher soil GDD for MP than for NT. They attributed this

Table 4. Effect of tillage and wheat residue management systems on days to 50% silking and grain moisture content after harvest in 1994 and 1995

Tillage/straw management	Time to 50% silking 1994	1995	Grain moisture content 1994	1995
	(d)		(g kg^{-1})	
Fall moldboard (bare)	69.3*d*	73.5*c*	233*e*	224*b*
Fall moldboard (baled)	69.8*d*	74.0*b*	234*e*	223*b*
Fall moldboard (not baled)	71.0*cd*	73.8*bc*	235*de*	230*b*
Fall moldboard (not baled + N)	69.8*d*	73.8*bc*	237*de*	230*b*
No-till (bare)	72.0*c*	73.5*b*	248*cd*	230*b*
No-till (baled)	73.0*bc*	74.0*b*	253*bc*	231*b*
No-till (not baled)	74.5*ab*	74.8a	265*ab*	241a
No-till (not baled + N)	75.3a	74.8a	272a	244a

a-e Within columns, means followed by the same letter are not significantly different at the 5% level of probability.

Table 5. Effect of tillage and wheat residue management systems on corn grain yield in 1994 and 1995

Tillage/straw management	1994	1995
	(t ha^{-1})	
Fall moldboard (bare)	11.69*a*	10.75*abc*
Fall moldboard (baled)	11.04*a*	11.29*a*
Fall moldboard (not baled)	11.23*a*	11.00*abc*
Fall moldboard (not baled + N)	11.10*a*	11.17*ab*
No-till (bare)	10.24*b*	10.40*c*
No-till (baled)	9.52*c*	11.00*abc*
No-till (not baled)	8.76*d*	10.58*bc*
No-till (not baled + N)	8.76*d*	10.74*abc*

a-d Within columns, means followed by the same letter are not significantly different at the 5% level of probability.

difference to the presence of crop residues on NT plots, similar to the results of this study. The soil GDD advantage for MP relative to NT was dependent on wheat residue level on the soil surface, and this was more apparent in the first 3 wk than when averaged over five weeks following planting.

Effect of Tillage and Residue Management on Corn Performance

Residue management had no effect on the number of days for MP corn to achieve 50% emergence (Table 3). No-till treatments with high residue cover took the longest time to achieve 50% corn emergence. For the NT treatments with wheat residue, corn required at least 2 more days to reach 50% emergence relative to MP treatments. Completely removing all wheat residue from NT plots reduced the number of days taken to achieve 50% corn emergence by 1 to 2 d and, therefore, emergence rate was not different from all the MP treatments. Generally, corn required about 4 to 5 more days to achieve 50% emergence in 1995 relative to 1994 because corn was planted early in 1995 when soil temperatures were low compared to later planting in 1994.

Moldboard plow treatments consistently resulted in the largest plants at 5 and 7 wk after planting compared to NT treatments (Table 4). Differences among MP treatments were insignificant. Within the NT treatments, there were no differences in corn biomass after 5 wk in 1994. After 7 wk, however, NT (bare) had larger plants than NT treatments with wheat residue. Similar results were obtained in 1995. Corn growth for the first 5 wk in 1995 was slower than in 1994 due to early planting in 1995 with moist conditions and lower than average temperatures (Fig. 1). Lower corn biomass early in the season with NT compared with MP treatments has also been observed by Phillips (1983) and Al-Darby and Lowery (1987).

No-till treatments resulted in delayed silk emergence compared with fall MP treatments in both years (Table 4). Differences among MP treatments were, in most cases, insignificant. On average, removing wheat residue from NT plots reduced the number of days to 50% silking by 1 to 2 d. In 1994, NT (not baled and not baled + N) treatments required at least 4 more days to achieve 50% silking, but only 1 more day was required in 1995, probably due to the low amounts of wheat residue left on the soil surface after the intense rains in early June. Vyn and Raimbault (1993) reported that NT corn required an extra 1 to 2 d to achieve 50% silking compared with MP when corn followed corn. Faber (1995) observed 2 d delay in days to 50% silking for NT corn following winter wheat underseeded with red clover compared with MP. In their study, Al-Darby and Lowery (1986) also observed a 2- to 3-d delay for NT corn to achieve 50% silking.

No-till (not baled) treatments had the highest grain moisture contents (Table 4), indicating a delay in corn maturity under the NT treatments. In 1994, there were no differences among MP treatments, but these were all lower than NT with wheat residue treatments. There were no differences among MP, NT (bare), and NT (baled) treatments in grain moisture contents in 1995; the latter moisture levels were lower than NT (not baled and not baled + N) treatments. In both years, removing wheat residue reduced NT grain moisture content compared with NT (not baled and not baled + N) treatments. Higher grain moisture content with NT compared with MP have been reported by others (Al-Darby and Lowery 1986; Vyn and Raimbault 1993; Wicks et al. 1995). Griffith et al. (1988) also obtained 2% higher grain moisture content with NT than with MP system.

Grain yields were not different among MP treatments in both years (Table 5). This showed that residue levels did not influence grain yield in MP systems. In 1994, grain yields for MP treatments were higher than those of NT treatments (by 17%), but in 1995, differences among them were, in most cases, insignificant (MP treatments higher by only 3%). Within the NT system, removal of all residue resulted in higher grain yields than either baling or not baling straw in 1994. However, in 1995, differences in grain yield among the no-till treatments were insignificant, probably due to less wheat residue cover later in the season. Some of the NT (bare) plots were adjacent to the high residue plots so most of the detached wheat residues settled on these plots. This might have contributed to the reduced grain yields from NT (bare) plots in 1995. Vyn and Raimbault (1993) obtained 14% yield reduction with NT compared with MP on a long-term study involving a similar soil type for continuous corn. Results from another long-term study (Sojka and Busscher 1989) demonstrated that corn yields were always lower with

NT systems relative to reduced or conventional tillage. No-till corn yielded 10 to 30% less than corn followed plowed treatments when corn followed winter wheat underseeded with red clover (Ziza 1995).

Relationship Between Corn Performance and In-row Seedbed Condition

The presence of wheat residue on NT plots was responsible for the delayed growth and reduced corn yields observed in this study. The residue cover shaded the surface of NT plots, increased seedbed moisture contents early in the season, depressed soil temperature, delayed corn emergence, reduced corn biomass at 5 and 7 wk after planting, and reduced yields. Soil residue cover was correlated to grain yield in 1994 ($r = -0.95$, $P < 0.01$) but not in 1995. Corn growth in NT plots with wheat residue was delayed and resulted in reduced yields (on average) because seedbed conditions were unfavourable early in the season.

Moldboard plow and NT (bare) treatments were drier than NT with wheat residue early in the spring, indicating that these treatments could have been planted much earlier than NT treatments with wheat residue. On average, NT treatments required more soil GDD (65) than MP treatments (53) to attain 50% corn emergence. Carter and Barnett (1987) found that for continuous NT corn production in Wisconsin, soil temperatures were cooler, emergence percentage and stand establishment were lower, crop growth was delayed and grain moisture at harvest was increased compared with corn produced using a MP system.

In our study, delayed corn emergence with NT was not associated with soil GDD alone, as evidenced by the fact that accumulated soil GDD from planting to 50% corn emergence was not significantly correlated to days taken to achieve 50% emergence ($r = 0.65$ in 1994; $r = 0.58$ in 1995). However, soil GDD was correlated to corn biomass 5 wk after planting ($r = 0.75$, $P = 0.05$) in both years. Therefore, other factors might be involved in the corn response to NT treatments observed in this study.

Other researchers have shown that reduced soil temperature and increased soil moisture levels did not completely account for the delay in corn plant development under NT conditions. Phytotoxic chemicals (e.g. phenolic compounds) released into the seedbed during the decomposition of wheat residues could inhibit corn growth and reduce grain yields (Cochran et al. 1977; Lund et al. 1993). These compounds might have contributed to the delayed corn growth and reduced yields observed in this study. Removal of wheat residue from NT could increase corn yields. However, despite similarity in soil GDD and soil moisture contents early in the season between MP and NT (bare) treatments, corn growth differences still existed between them early in the season. As a result, MP treatments outyielded NT (bare) treatment by 8% on average. This showed that some amount of tillage would be beneficial for the NT system to achieve comparable yields with MP system on this soil type.

The application of N in the fall to not baled treatments influenced neither grain yield nor residue levels in NT plots. There is, therefore, no advantage in applying N in the fall for these purposes.

CONCLUSIONS

Fall tillage and management of wheat residues affected seedbed conditions for corn growth. No-till seedbeds were wet and cold early in the season, and provided an unfavorable soil environment for corn growth. On average, NT yield reductions relative to plowed treatments averaged 13% when all wheat residue was retained, and 8% when wheat straw was baled or when all wheat residue was completely removed. Grain yield differences among MP treatments were not affected by the amount of wheat residue left on the soil surface after harvest. Our results suggest that corn response in NT systems after wheat depends on residue level; however, some additional minimum tillage would enhance corn yields. Future research should be directed towards the evaluation of some minimum tillage systems that would reduce residue levels in the row-zone and improve seedbed conditions, while maintaining corn yields. More research is also needed to help explain the possible role of phytotoxic compounds in reducing crop yields in NT systems. Such information could be useful in developing strategies to overcome NT yield suppression when corn follows winter wheat.

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