RESEARCH SUB-PROGRAM

DETERMINING THE FACTORS RESPONSIBLE FOR, AND METHODS TO OVERCOME THE LIMITATIONS OF CONSERVATION CROPPING SYSTEMS ON CLAY SOILS

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A.** Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.
This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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DETERMINING THE FACTORS RESPONSIBLE FOR AND METHODS TO OVERCOME THE LIMITATIONS OF CONSERVATION CROPPING SYSTEMS ON CLAY SOILS

Final Report
March, 1998

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EXECUTIVE SUMMARY

Thirty field experiments were conducted in South Western Ontario on clay textured soils to examine the effects of up to eight tillage systems on:

1) rates of spring seedbed dry-down,
2) in-row seedbed physical properties,
3) corn and soybean yield following wheat or in a corn-soybean rotation, and
4) weed seedbanks.

The effect of selected weed management strategies on no-till soybeans planted on clay textured soils was also examined. Each experiment was conducted from 1994 to 1996 at two farm locations; conclusions below are based on six site-years of data.

** No-till corn yields following soybeans were not significantly different from yields after moldboard plowing at five of six sites when the corn planter was equipped with a 5-cm fluted coulter in addition to one fertilizer coulter and one residue removal attachment per row.

** Slot no-till (tined row cleaner and fertilizer coulter only) corn yields following soybeans were as much as 10% lower than those obtained in the moldboard system at three out of six sites. At those sites, less intensive tillage systems such as fall zone-till or field cultivation just prior to planting resulted in corn yields that were greater than no-till (slot or coulter) and similar to those obtained in the moldboard system.

** Chisel plowing soybean stubble was a poor conservation tillage choice on clay soils since it resulted in low residue cover, relatively coarse seedbeds and corn yields no better than those with the no-till (coulter) system.

** Narrow-row (38 cm) soybean yields were only marginally affected by tillage systems following corn in rotation. On silty clay loam soil, average yields for no-till were virtually identical to those obtained with either moldboard or chisel plowing. On a less productive clay soil, no-till yields were slightly less (0.17 t ha^{-1}) than with moldboard plowing, but similar to yields obtained with the other alternative tillage systems evaluated.

** No-till planting into winter wheat stubble (after baling) lowered corn yields by 0.66 t ha^{-1} (7%), relative to those with fall moldboard plowing. Fall discing or fall zone-tilling resulted in corn yields that were essentially similar to those obtained with either moldboard or chisel plowing and at least 0.49 t ha^{-1} (5%) greater than no-till.

** No-till planting soybeans in wide rows (76 cm) into baled wheat stubble resulted in average yields 0.31 t ha^{-1} (9%) lower than with moldboard plowing. Fall discing resulted in average yields that were greater than no-till, but not consistently equivalent to those obtained with moldboard plowing.

** No-till yield potential was affected by the amount of wheat straw present. Totally removing all wheat straw increased no-till yields, relative to where straw had not been baled, by 0.88 t ha^{-1} (10%) for corn (average of 1994-96) and 0.46 t ha^{-1} (17%) for wide-row soybeans (average of 1994-95). Baling wheat straw (i.e. leaving stubble of 20 to 30 cm) also increased no-till corn and soybean yields in most site-years. When all straw was removed, no-till corn and soybean yields were usually similar to most of the fall tillage systems evaluated.

** Regardless of the preceding crop (i.e. corn, soybeans or wheat), shallow fall tillage using zone tillage or tandem disc usually resulted in spring soil dry down rates (at least for the intended row area) that were faster than no-till and often similar to fall moldboard plowing. Fall zone tillage also resulted in finer aggregates and higher soil temperatures after planting than no-till systems.

** Spring-killed rye cover crops did not enhance weed control in no-till soybean production systems.

** A combination of preplant glyphosate followed by broadcast preemergence applied imazethapyr plus metribuzin was the most profitable weed control treatment when no-till soybeans were grown in narrow rows (18 cm). However, use of the glyphosate burn-down treatment alone provided 83% of the weed control, 85% of the maximum potential yield and 98% of the maximum potential profit for no-till narrow-row soybeans.

** An integrated weed control strategy using banded preemergence herbicide plus inter-row cultivation reduced herbicide use by 60% and was the most profitable treatment for no-till wide-row (76 cm) soybean production. However, substantial reduction in yield potential associated with wide-row soybean production made this practice considerably less profitable ($98 ha^{-1}) than the most profitable treatment in narrow rows.

Technology Transfer

Both preliminary and - after 1996 - final conclusions from this research were presented

(a) at over 15 extension events (ranging from field days to symposiums to agricultural conferences in Ontario),
(b) in over 10 articles in the farm press,
(c) in five peer-reviewed papers in scientific journals and
(d) in two Ph.D. theses (1 completed and 1 in progress).

SOMMAIRE

On a mené trente expériences de terrain dans des sols à texture argileuse du sud-ouest de l'Ontario pour examiner les effets d'un certain nombre de systèmes de travail du sol (jusqu'à huit) sur :

5. les taux d'assèchement des lits de semences,
2. les propriétés physiques des lits de semences dans les rangs,
3. le rendement en maïs, en soja succédant au maïs ou dans une rotation maïs-soja, et les banques de semences de mauvaises herbes.

On a également examiné l'effet de certaines stratégies de gestion des mauvaises herbes sur le soja planté sans travail du sol dans des sols à texture argileuse. Chaque expérience a été menée de 1994 à 1996 dans deux exploitations agricoles; les conclusions présentées ci-dessous reposent sur les données recueillies pendant six années-sites.

**Il n'existait pas de différence significative entre les rendements en maïs cultivé sans travail du sol et succédant au soja et les rendements enregistrés après labourage à la charrue à socs et versoirs à cinq des six sites lorsque le semoir à maïs était équipé d'un coutre cannelé de 5 cm en plus d'un coutre pour épandage d'engrais et d'un accessoire d'élimination des résidus par rang.

**À trois des six sites, les rendements en maïs semé sans travail du sol (nettoyeur de rang à rainure à dents fixes et coutre pour épandage d'engrais seulement) et succédant au soja pouvaient être jusqu'à 10 % inférieurs à ceux obtenus après labourage à la charrue à socs et versoirs. À ces endroits, l'emploi de systèmes permettant un travail moins intense du sol, comme le labourage par zone en automne ou la culture du sol juste avant les semis a donné des rendements en maïs supérieurs à ceux obtenus à la suite des semis sans travail du sol (nettoyeur de rang à rainure ou coutre) et semblables à ceux obtenus après labourage à la charrue à socs et versoirs.

**Les semis de soja sur chaume au moyen du cultivateur sous-soleur se sont révélés une mauvaise stratégie de culture de conservation du sol dans les sols argileux, car la couche de résidus était mince, les lits de semences étaient grossiers et les rendements en maïs n'étaient pas supérieurs à ceux que donnaient le système sans travail du sol (coutre).

**Les systèmes de travail du sol n'influaient que peu sur les rendements en soja semé en rangs étroits (38 cm) quand celui-ci succédait au maïs dans la rotation. Dans les sols à limon argileux fin, les rendements moyens procurés par les systèmes sans travail du sol étaient pratiquement identiques à ceux obtenus après utilisation de la charrue à socs et versoirs ou du cultivateur sous-soleur. Dans les sols argileux moins productifs, ces rendements étaient légèrement inférieurs (0,17 t/ha-1) à ceux obtenus après utilisation de la charrue à socs et versoirs, mais semblables à ceux obtenus après utilisation des autres systèmes de travail du sol évalués.

**Les semis de soja sans travail du sol dans le chaume de maïs d'hiver (après mise en balles) ont entraîné une baisse des rendements en maïs de 0,66 t/ha-1 (7 %) par rapport à ceux obtenus après labourage à la charrue à socs et versoirs en automne. Les rendements obtenus après disquage ou labourage par zone en automne étaient essentiellement comparables à ceux obtenus après utilisation de la charrue à socs et versoirs ou du cultivateur sous-soleur et supérieurs d'au moins 0,49 t/ha-1 (5 %) aux rendements obtenus après les semis sans travail du sol.

**Les semis de soja sans travail du sol en rangs larges (76 cm) dans le chaume de blé mis en balles ont

produit des rendements moyens de 0,31 t/ha-1 (9 %) inférieurs à ceux obtenus après labourage à la charrue à socs et versoirs. Le disquage en automne a produit des rendements moyens supérieurs à ceux résultant des semis sans travail du sol, mais non toujours équivalents à ceux obtenus après labourage à la charrue à socs et versoirs.

**Les rendements potentiels attendus des semis sans travail du sol dépendaient de la quantité de paille de blé présente. L'enlèvement de toute la paille de blé a eu pour effet d'accroître ces rendements, par rapport à ceux enregistrés aux endroits où la paille n'avait pas été mise en balles, de 0,88 t/ha-1 (10 %) dans le cas du maïs (moyenne sur 1994-1996) et de 0,46 t/ha-1 (17 %) dans le cas du soja semé en rangs larges (moyenne sur 1994-1995). Pendant la plupart des années-sites, la mise en balles de la paille de blé (c.-à-d. quand on laissait sur le champ une couche de 20 à 30 cm de chaume) a également fait augmenter les rendements en maïs et en soja semés dans travail du sol. Quand on enlevait toute la paille, ces rendements étaient généralement semblables à ceux résultant de l'utilisation de la plupart des systèmes de labourage d'automne évalués.

**Quelle qu'ait été la culture précédente (c.-à-d. maïs, soja ou blé), le labourage d'automne en surface ou l'emploi de machines à disques en tandem accélérait généralement l'assèchement du sol au printemps (au moins dans les rangs visés) par rapport à celui qu'on observait par suite de semis sans travail du sol, tandis que les taux d'assèchement étaient souvent semblables à ceux enregistrés par suite du labourage d'automne à la charrue à socs et versoirs. De plus, on observait des agrégats plus fins et des températures du sol plus élevées après les semis avec travail du sol dans certaines zones en automne qu'après les semis sans travail du sol.

**Les cultures de couverture de seigle détruites au printemps n'augmentaient pas l'efficacité de la destruction des mauvaises herbes dans les systèmes de culture de soja sans travail du sol.

**Un traitement de présemis au glyphosate suivi d'un traitement de prélevée par épandage à la volée d'imazethapyr et de métribuzine constituaient la stratégie la plus rentable de destruction des mauvaises herbes quand on avait semé du soja en rangs étroits (18 cm) sans travail du sol. Toutefois, dans le cas du soja semé par cette méthode, le traitement au glyphosate seulement assurait 83 % de la destruction et contribuait à 85 % des rendements potentiels maximums et à 98 % du bénéfice potentiel maximum.

**Une stratégie intégrée de lutte contre les mauvaises herbes comportant un traitement avec un herbicide de prélevée en rangs et
l'utilisation d'un cultivateur à plusieurs éléments a permis de réduire l'utilisation d'herbicide de 60 % et constituait le mode de traitement le plus rentable pour la production de soja en rangs larges (76 cm) sans travail du sol. Toutefois, la forte baisse du potentiel de rendement associée à cette forme de production rendait celle-ci beaucoup moins rentable (98 $/ha) que la production en rangs étroits, qui était la plus rentable.

Transfert de technologie

Les conclusions préliminaires et finales (après 1996) tirées des recherches ont été présentées :

a. en plus de 15 occasions (journées agricoles, symposiums, conférences agricoles tenus en Ontario),
b. dans plus de 10 articles publiés dans la presse agricole,
c. dans des articles revus par des pairs publiés dans des revues scientifiques,
d. dans deux thèses de doctorat (dont une a été déposée et l'autre est en voie de rédaction).

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OBJECTIVE A: CONSERVATION TILLAGE FOR CORN-SOYBEAN ROTATIONS

RESEARCH OBJECTIVES

Field experiments in this objective were designed to examine the effects of tillage for clay textured soils on 1) in-row seedbed physical properties (i.e. aggregation, porosity, soil strength, temperature and moisture) following both corn and soybeans and 2) corn and soybean yield response when in a corn-soybean rotation. Crop yield response under the various tillage systems were correlated with various selected in-row seedbed physical properties in an attempt to determine which seedbed physical properties need to be optimized by tillage operations to maximize corn and soybean yields.

Site cooperator(s) and location

Fingal
Cooperator: David House
Location: South Talbot Road East, Lot 8, Southwold Township, Elgin County.

Alvinston
Cooperators: Mike Chalupka and Kevin Marriott
Location: Concession 10, Lot 5, Brooke Township, Lambton County.

METHODOLOGY

Experimental design and treatment descriptions

The soil at Alvinston is a Brookston clay (44% clay, 42% silt, 14% sand with 3.9% organic matter) and at Fingal the soil is a Toledo silty clay loam (30% clay, 52% silt, 18% sand with 3.8% organic matter).

The experimental sites were split with one side cropped to soybeans and the other to corn, with an alternating corn/soybean rotation in three successive years. The same tillage treatments were maintained on the same plots for the duration of the study. The experimental design is a randomized complete block with 4 replications. The tillage treatments were:

1. **Fall Moldboard** (15 cm deep) plus secondary tillage.
2. **Fall Chisel** (12 cm deep) plus spring secondary tillage. The chisel plow was equipped with 10-cm twisted shovel teeth.
3. **Fall Disc** consisted of a single pass with a tandem disc (10 cm deep). For corn (following soybeans) spring tillage was restricted to the immediate row area using a single planter-mounted 5 cm fluted coulter positioned directly in line with the seed disc openers plus a fertilizer opener positioned 5cm to the side of the row (i.e. coulter configuration similar to the no-till (coulters) treatment). For soybeans (following corn), no spring tillage was performed.
4. **Spring Tillage Only** for soybeans (following corn) consisted of one pass with a tandem disc followed by one pass with a field cultivator and packer. For corn (following soybeans) tillage consisted of two passes with a field cultivator.

5. **Fall Zone-tillage** for corn (following soybeans) was restricted to the immediate row area (zone-till) by using a Trans-till (17 cm deep) in the fall plus spring no-till (coulters). For soybeans (following corn) fall tillage was performed using an **Aerway** (10 cm depth at maximum aggressiveness) with no additional tillage in the spring.
6. **Spring Aerway** (single pass, 10 cm deep at medium aggressiveness) before soybeans or no-till (coulter) corn.
7. **No-till (coulters)** restricted tillage to the immediate row area using one planter-mounted 5 cm fluted coulter positioned directly in line with the seed disc openers and Dawn Trash Wheels plus a Yetter fertilizer opener positioned 5 cm to the side of the row (for corn only).
8. **No-till (slot)** treatment minimized soil disturbance with no planter-mounted coulters but with Dawn Trash Wheels.

Secondary tillage always consisted of two passes with a field cultivator and packer.

Cultural Practices for Corn

Corn was planted in 76-cm wide rows using a model 7000 John Deere Conservation planter at a seeding rate of 74,000 seeds ha^{-1}. Except for the no-till (slot) treatment, the corn planter was equipped with one 5 cm fluted coulter per row operating at a depth of 5 to 7 cm and positioned directly in front of the seed disc-openers. For all treatments, the corn planter was equipped with Dawn trash wheels and a Yetter no-till fertilizer coulter that was positioned 5 cm to the side of the row.

At both sites, the corn hybrid was Pioneer 3960 during 1994 and 1995 and replaced with Pioneer 3769 During 1996 as a comparable replacement (Pioneer Hi-Bred Ltd., personal communication) since Pioneer 3960 was commercially discontinued. Starter fertilizer (11-52-0) was applied through the planter at a rate of 125 kg ha^{-1}. The nitrogen source was U.A.N. applied at a rate of 150 kg N ha^{-1} in subsurface bands 8 cm deep and between crop rows.

Weed control in 1994 and 1995, at Alvinston and Fingal, consisted of a burn-down treatment of glyphosate within 2 weeks prior to planting applied at a rate of 1.8 kg a.i. ha^{-1}; dicamba and metolachlor were broadcast at 0.60 and 2.25 kg a.i. ha^{-1}, respectively. At Fingal in 1996, glyphosate and metolachlor were broadcast at 1.8 and 2.25 kg a.i. ha^{-1}, respectively. Bromoxynil was broadcast-applied at 0.28 kg a.i. ha^{-1} when corn development was at the six leaf stage. At Alvinston in 1996, a tankmix of metolachlor, linuron and glyphosate was broadcast-applied at 2.25, 4.40 and 1.80 kg a.i. ha^{-1}, respectively, immediately following planting.

Cultural Practices for Soybeans

Except for the no-till (coulter) treatment, soybeans were planted using a John Deere 750 drill. For the no-till (coulter) treatment, the John Deere drill was substituted with double disc-opener type drills equipped with 2.5 cm fluted coulters positioned directly in front of the disc-openers. The coulter-type drills used at Fingal were: United Farm Tool in 1994, and Great Plains in both 1995 and 1996. At Alvinston, a Krause drill was used in both 1994 and 1996; Great Plains was used in 1995. These drills were used to plant soybeans in the no-till (coulter) treatment because of the difficulty associated with mounting coulters onto the John Deere 750 drill. For all soybean plots with the exception of the Fingal no-till (coulter) treatment in 1996, soybeans were planted in 38-cm wide rows at a seeding rate of 52 seeds m^{-2}. Due to drill constraints, the no-till (coulter) soybean plots at Fingal in 1996 were planted in 15-cm-wide rows at the same seeding rate per m^2 as other treatments. No fertilizer was applied for soybeans.

Weed control for soybeans at Alvinston and Fingal in 1994 and 1995 consisted of a burn-down treatment of glyphosate within 2 weeks prior to seeding applied at 1.8 kg a.i. $ha^{-1.}$ During these same years, metolachlor and imazethapyr were broadcast-applied at 2.25 and 0.100 kg ha^{-1}, respectively. At Fingal in 1996, bentazon was applied at 1.00 kg a.i. ha^{-1} at the second trifoliate stage of soybean growth. At Alvinston, the same herbicides were applied to soybean as corn in 1996.

Soil Measurements

Pre-planting soil moisture content was determined by measuring the volumetric water content in the surface 15cm using Time Domain Reflectrometry (TDR) (Topp et al., 1980). Measurements were conducted prior to crop planting (early May) on various tillage systems. Soil moisture measurements were conducted randomly, except on the fall zone-till treatment where measurements were restricted to the loosened zones. At least five determinations of water contents were made to calculate the average volumetric water content per plot.

Soil temperature (T) was measured in selected tillage treatments just after planting. Due to equipment limitations, soil T was monitored in the fall moldboard, fall chisel, fall zone-till /Aerway, no-till(coulter), and no-till(slot) treatments. Two copper-constantan thermocouples per plot were placed 5 cm beneath the soil surface in-row, and parallel, to the crop row. Soil T was recorded hourly by a digital recorder for the first 40 days after planting. The accumulation of soil thermal units was quantified by summing soil growing degree days (GDD) calculated on a daily basis. Soil GDD was calculated by averaging the daily minimum (min) and maximum (max) temperature measured in ^{o}C and then subtracting 10. When GDD were calculated, any min or max temperatures less than 10^{o}C were substituted with a value of 10. Likewise, any max temperatures exceeding 30^{o}C were substituted with a value of 30.

Cross-row residue cover was measured within 2 weeks of planting using the line-transect method (Sloneker and Moldenhauer, 1977).

In-row aggregate size distribution and bulk density in the surface 5 cm was determined from soil samples collected within 2 weeks of crop planting using a specially designed sampling box. The box was 5 cm deep, 10 cm in width, and 30 cm in length. Two samples were taken per plot for all treatments. The soil samples were then oven dried at 30^{o}C until a constant weight was achieved. After the total mass of the sample was recorded, the samples were then sieved through a nest of sieves (>10 mm, 10 mm, 5 mm, 2 mm, 1 mm, < 1 mm in diameter) with a shaker and the mass of the various size fractions recorded after sieving was complete (Kemper and Chepil, 1965). Aggregate size distribution data for Objective A was summarized by calculating the percentage of aggregates, by mass, that were less than 5 mm in diameter.

Bulk density in the surface 5cm was calculated based on the total mass of dried soil samples used in aggregate size determinations. At deeper depth intervals, bulk density was measured for selected treatments using cylindrical cores 5 cm in diameter by 5 cm deep. All treatments were measured for in-row bulk density at the 5 to 10 cm depth interval, but only the fall moldboard, fall disc, no-till (coulter), and no-till(slot) treatments were measured at the 10 to 15 and the 20 to 25 cm depth intervals.

In-row soil resistance measurements were conducted using a Rimik hand-held recording penetrometer (Rimik PTY Ltd, Toowoomba, Australia). The cone at the tip of the penetrometer shaft had a surface area of 2 cm^2 with a 60^{o} angle. Soil resistance measurements during 1994 and 1996 were conducted within 3 weeks of planting but during 1995 measurements were delayed until early August due to dry conditions in June and July (large cracks present in profile) at both sites. All soil resistance measurements were done when the soil water contents were near field capacity. The penetrometer recorded soil resistance at 1.5 cm intervals up to a potential depth of 45 cm. Soil resistance data for Objective A was summarized by averaging 2 consecutive depth intervals up to 24 cm, resulting in 8 soil resistance values throughout the soil profile on an individual plot basis. The depth assigned to the averaged soil resistance values when presented in figures was the mean depth of the averaged resistances.

Crop Measurements

The number of days required for 50% emergence was determined by daily monitoring and recording the number of emerged seedlings on two 5 m sections of row per plot. The number of days required for 50% emergence was calculated by determining when at least 50% of the final seedling population emerged within each row segment and then averaging the results on a per plot basis. Within each of these row segments, 10 consecutive plants were selected for growth and development monitoring throughout the rest of the growing season.

About 6 weeks after planting, two sampling areas of approximately 1.5 m^2 were selected to represent each corn and soybean plot for aboveground crop biomass. Biomass samples were oven-dried for at least 3 days at 80 ^oC.

Corn grain yield was determined by hand harvesting 15 m of row per plot, mechanically shelling grain from ears and recording the mass and moisture content of the shelled grain. Corn grain yield was calculated to t ha^{-1} adjusted to a moisture content of 15.5%. Final corn population and lodging data were also obtained from each harvest area. For soybeans, at least 10 m^2 per plot was harvested with a plot combine and seed yield was calculated to t ha^{-1} adjusted to a moisture content of 14.0%.

Weather monitoring

Weather data was collected hourly on-site with a digital recording device. The data collected included precipitation, air temperature, solar radiation (hourly sum), and relative humidity.

Data presentation

Analysis of variance for each parameter was conducted both within and across years. Where possible, soil and crop data presented in either tables or figures are averaged over years. Thus, whenever the treatment by year interactions are not significant at the 0.05 level of probability, treatment means over years are reported. This helped to simplify presentation of the results.

RESULTS AND DISCUSSION

Weather Patterns

Higher than normal precipitation in early May delayed spring tillage until late May at both Alvinston and Fingal for all years. Both Fingal and Alvinston received rains within one week of planting. The intensity and timing of these rainfall events caused emergence problems (due to soil crusting) for corn at both sites in 1994 and for both crops at Alvinston in 1995.

Growing conditions were excellent for Fingal in all years, with the following exceptions:
1) In 1994 and 1995, above-normal precipitation caused some soil waterlogging during early June.
2) In 1996, dry conditions during July and early August caused some stress in both crops. However, normal amounts of precipitation returned during mid to late August and September.

There were more adverse weather conditions at Alvinston during all years compared to Fingal. Heavy rainstorm events at Alvinston shortly following planting in all years caused some water ponding in low areas and between sub-surface tile drains. Water ponding was most severe in early June 1995 and in late June 1996, especially in one replicate where soybeans were planted both years. These water damaged replicates were dropped (i.e. measurements not conducted). Rainfall was below normal during July and August for both 1994 and 1995. However, drought stress was most severe in 1995. During that year, there was no significant rainfall at Alvinston from early June until early August. As a result, both corn and soybeans exhibited severe drought stress symptoms, with the worst crop growth occurring in the no-till system.

Soil Properties After Corn and Soybeans

Fall tillage significantly increased spring soil dry-down rates in the surface 15cm as shown by the lower soil volumetric water contents when compared to where fall tillage was not performed(Table 1). Only the fall moldboard, fall disc, fall zone-till (following soybeans only), and no-till systems were monitored. Within fall zone-tilled strips, volumetric water content was less than where fall tillage was not conducted, indicating that fall zone-tillage could potentially have seedbeds that are dry enough for planting earlier than tillage systems where fall tillage does not occur (i.e. no-till, spring tillage with field cultivator only). Fall discing also often resulted in soil moisture conditions similar to fall moldboard plowing and drier than where fall tillage did not occur.

Cross-row residue cover determined just following crop planting indicated that all systems except fall moldboard left at least 30% residue cover when the preceding-year crop was corn (data not shown). Following soybeans, none of the systems provided 30% residue cover. However, the spring Aerway, fall zone-till, and the no-till systems did maintain at least 20% residue cover after soybeans.

Regardless of the preceding-year crop, the fall moldboard system produced the highest proportion of fine aggregates in the immediate row area after planting while minimal intensity tillage systems such as no-till and Aerway produced the lowest proportion of fine aggregates (Table 2). Tillage effects on aggregate-size distribution did not interact with year, therefore aggregate size data was averaged over years for each location. The addition of one coulter to the no-till system with corn or the use of a coulter-type drill for soybeans did not substantially change the in-row fineness of seedbeds when compared to the no-till (slot) treatment in both crops. One pass with an Aerway either in the spring (in corn or soybean residue) or in the fall (in corn residue only) did not increase the proportion of fine aggregates after planting. The fall disc, fall chisel, and fall zone-till (following soybeans) systems at Fingal had seedbeds in the row area that were significantly finer than no-till and similar to the fall moldboard system. At Alvinston, however, in-row seedbed fineness in the fall disc, fall chisel, and fall zone-till systems were less than the fall moldboard system and similar to no-till. Two cultivator passes in the spring (i.e. no fall tillage) produced a seedbed similar to fall discing, fall chisel, and fall zone-till at both Fingal and Alvinston. None of the tillage systems examined were consistently capable of producing in-row seedbed fineness that were similar and/or superior to the fall moldboard system.

Following corn planting (i.e. preceding crop was soybeans) at Alvinston, in-row bulk density at the 0 to 5 cm depth interval in the fall moldboard plow, fall zone-till, and fall disc systems was significantly lower than the no-till system (Figure 1). Tillage effects on in-row bulk density did not differ over years, therefore results presented are combined over years. At both locations, the fall zone-till and the moldboard plow systems had similar bulk density at the 5 to 10 and the 10 to 15 cm depth intervals. The fall disc and no-till plots had the highest bulk density at those depth intervals. Tillage system effects on in-row soil resistance following corn planting were similar to those observed for bulk density at both locations (Figure 2).

In-row bulk density (Figure 3) and soil resistance (Figure 4) following soybean planting (i.e.

preceding crop was corn) were lower in the moldboard plow system compared to any other system. Soil loosening by fall discing to a depth of 8 cm was not detected by bulk density and penetrometer measurements, with the exception of penetrometer resistance at Fingal. In general, bulk density and penetrometer resistance among fall disc, no-till(coulter), and no-till(slot) were not different at the same depth intervals.

Following corn planting at Alvinston in 1994, no in-row soil T differences were detected among tillage systems in June (Figure 5). However, tillage affected in-row soil T and accumulated GDD in 1995 and 1996. At this site, mean maximum soil T in the fall tillage systems were 1.1 to 1.8 C degrees higher than no-till systems. In-row soil T among the plowed systems were not significantly different from the fall zone-till treatment (within the tilled zone) at this site.

At Fingal the fall moldboard plow system had significantly higher in-row soil T and GDD than other tillage systems during 1996(Figure 6). No significant differences were detected at Fingal in other years among tillage systems.

In-row soil T and accumulated GDD following soybean planting was highest in the moldboard plow system when compared to any of the other tillage systems (Figure 7). The fall Aerway, fall chisel, and no-till(coulter) systems did not increase seedbed soil T compared to the no-till (slot) system. However, soil T averaged the lowest among the no-till(slot) and fall Aerway seedbeds.

Other seedbed properties measured included: in-row volumetric water content to 10 cm measured weekly for the first 5 weeks following planting (data not discussed); and a characterization of in-row porosity including air filled porosity. Correlations between measured soil seedbed properties and crop growth and yields will be included in a Ph.D. thesis expected to be completed by Dave Hooker (University of Guelph) in 1998.

Corn Response to Tillage After Soybeans

At Alvinston, rates of early season corn growth were greater in fall-till tillage systems when compared to when fall tillage was not performed (Table 3). When analyzed over years, this effect was highly significant ($P < 0.0001$, contrast not shown). Fall moldboard plowing resulted in significantly greater early season growth rates compared to the other tillage systems. Early season growth differences among the other fall tillage systems were not significant. Fall zone-tillage significantly improved early season corn growth when compared to the no-till (coulter) system ($P < 0.002$, contrast not shown). Early season biomass was correlated (n=32) with grain yield in 1994 ($r=0.46^{*}$) and in 1995 ($r=0.51^{*}$).

At Fingal, only a few significant corn growth differences occurred among tillage systems (Table 3). The spring Aerway tillage system produced the lowest mid-season biomass, which is attributed to less than desirable seed placement because of the creation of seedbeds containing many large clods. Uneven seeding depth and emergence was apparent in the system since most of the large clods were removed out of the row area by the trash wheels; seeds were placed in soil that was slightly wetter and less disturbed than the inter-row area. A less aggressive setting on the Aerway would have reduced the size and number of these clods. Early season biomass was correlated (n=32) with grain yield only in 1994 ($r=0.61^{*}$).

Corn grain yield response to tillage at Alvinston was not consistent over years (Table 5). The highest yields were obtained with moldboard plowing during 1994 and 1995, but moldboard treatment yields were significantly higher than most other tillage systems only during 1995. During 1995, moldboard plow corn yield was more than 1.0 t ha^{-1} higher than any of the other tillage systems except when the seedbed was prepared using only a field cultivator in the spring (i.e. spring tillage only).

Although not statistically significant, grain corn yield produced with spring tillage only during 1995 was 0.74 t ha^{-1} lower than with moldboard plowing. When analyzed over years, spring tillage only using a field cultivator yielded significantly higher ($P < 0.05$, contrast not shown) than the no-till systems and similar to moldboard plowing. Likewise, the fall zone-till yielded significantly higher (0.61 t ha^{-1}) than the no-till (coulter) system ($P = 0.02$). The failure of the other tillage systems to produce yields similar to the fall moldboard system in 1995 was attributed to the severe early to mid-season drought. The fall moldboard system was the last system that exhibited severe drought stress symptoms. In 1996, minimum tillage and no-till systems produced corn yields which averaged higher than the fall plowed systems, but yields were not significantly different.

At Fingal, consistent corn yield trends occurred during 1994 and 1995, and when combined over the two years, no-till (slot) produced yields that were significantly less than any of the other tillage systems (Table 4). The addition of one in-row coulter to the no-till system substantially improved corn yields, which were statistically similar to the other tillage systems. There were no significant yield differences among tillage systems in 1996.

The corn yield results indicate that, when soil moisture is not limiting on clay textured soils, modified no-till systems which involve additional coulters or limited fall tillage can produce corn yields greater than a no-till (slot) system and comparable to the moldboard system when planted following soybeans. When early season drought does occur, however, lower corn yields can be expected with reduced tillage systems on clay textured soils.

Soybean Response to Tillage After Corn

At Alvinston and Fingal, early season soybean biomass was slightly higher in tillage systems that were fall tilled ($P < 0.001$, contrast not shown) when data was combined and analyzed over years for each location (Table 3). Early season soybean biomass where the seedbed was prepared using a disc and field cultivator in the spring only was similar to the early season biomass present in the fall tilled systems. The no-till (slot), fall Aerway and spring Aerway systems produced similar early season soybean growth(Table 3). Also, early season soybean growth did not differ in the no-till (coulter) and no-till (slot) systems.

At both locations, general yield trends for each year were similar and when combined over years statistically significant yield differences could not be identified at either site(Table 6). At Alvinston, however, fall moldboard plowing produced the highest soybean yields which were 5 to 10% higher than any of the other systems evaluated. Soybean yield differences at Fingal did not occur among the tillage systems.

These soybean yield results indicate that tillage is not always necessary for producing top soybean yields following corn on clay textured soils. However, no-till can not be expected to produce soybean yields comparable to fall moldboard plowing on all clay textured soils. For example, the no-till system produced top soybean yields at Fingal but not at Alvinston. Also, a comparison of slot vs. double disc-opener type drills equipped with coulters indicated that drill type will have little impact on soybean yield potential when planted no-till.

CONCLUSIONS AND RECOMMENDATIONS

Shallow fall tillage using implements such as a tandem disc resulted in faster soil drying rates in spring and higher soil T than no-till; drydown rates and soil T with shallow fall tillage were often similar to fall moldboard plowing. Within a fall zone-tilled strip (evaluated following soybeans) spring soil dry down rates were also faster than no-till and often similar to fall moldboard plowing. Dry down rates are especially important for corn on poorly drained, fine-textured soils. Soils that dry faster in early spring may improve subsequent crop performance with timely planting and improved seedbed fitness for spring tillage and traffic.

Although there were small amounts of soybean residue on the soil surface from the previous year, soil T was higher in the row zone after planting in tillage systems that were fall tilled. Soil T was especially greater in fall tilled systems in 1995 and 1996 due to the accumulation of residue cover in the spring-till and no-till systems.

In general, shallow fall tillage improved early season corn growth and yields on the soil with the poorest drainage and highest clay content (i.e. Alvinston). Fall zone-tillage produced in-row soil seedbed qualities (e.g. soil T, bulk density, soil resistance, aggregation) that were similar to fall moldboard plowing at both locations. However, fall zone-tillage maintained at least 20% more residue cover compared to the other tillage systems that involved full width tillage.

Two passes with a field cultivator just prior to corn planting resulted in early season growth rates and grain yields that were similar to the fall-tillage systems. However, soil drying rates were comparable to no-till, which in some years may delay tillage and planting past critical planting dates.

In the no-till system, adding one coulter in-row increased corn yield to a level not statistically different from moldboard plowing on a highly productive silty clay-loam soil (i.e. Fingal). However, on the less productive clay soil (i.e. Alvinston) adding the coulter did not substantially increase no-till corn yield. This suggests that a greater amount of tillage than what is provided by a single planter mounted coulter (in addition to the fertilizer coulter and trash wheels) will be necessary on some clay textured soils to produce top corn yields.

Tillage performed using an Aerway in either the fall or spring did not improve seedbed quality or crop performance compared to the no-till (coulter) system. However, the addition of the Aerway in the spring may improve seedbed characteristics in the no-till (coulter) system where surface conditions are dry with hard, thick crusts. This scenario did not occur at either site during the three years of this study.

Tillage alternatives to fall moldboard plowing recommended for corn grown following soybeans on Ontario's clay textured soils include: 1) shallow fall discing plus no-till (coulter) plant, 2) fall zone-tillage plus no-till (coulter) plant, and 3) no fall tillage with two shallow passes with a field cultivator in the spring. Each of these alternatives often produced yields that were similar to those obtained with fall moldboard plowing. Fall chisel plowing after soybeans is not recommended due to the lack of corn response and low residue cover after planting (<10%) compared to the aforementioned alternatives to the moldboard plow.

Soybean yields did not respond to tillage in spite of the superior seedbed quality and early season growth rates often associated with the fall-tillage systems. Therefore, no-till is recommended for soybean following corn on Ontario's fine-textured soils.

Table 1. Fall tillage effects on early May volumetric water content in the surface 15 cm following corn and soybean at Alvinston and Fingal for 1995 and 1996 combined.

	Preceding Year Crop			
	Soybean		Corn	
Fall Tillage	Alvinston	Fingal	Alvinston	Fingal
	------------ Volumetric Water Content (%) ----------			
Moldboard Plow	25.0 a+	25.8 a	28.0 a	28.2 a
Disc	26.0 ab	27.4 ab	28.5 a	29.8 ab
Zone-Till	27.6 b	28.5 bc	-	-
None	30.0 c	30.4 c	31.4 b	31.3 b

+ Means within the same column followed by the same letter are not different according to the protected LSD test at the 5% level of probability.

Table 2. Tillage system effects on the proportion of fine aggregates in-row following corn and soybean planting 1994 to 1996 combined.

	Corn		Soybeans	
Tillage System	Alvinston	Fingal	Alvinston	Fingal
	------------- Proportion <5 mm diameter (%) -------------			
Moldboard Plow	44 a	49 a	47 a	46 a
Chisel Plow	38 b	44 ab	34 b	36 b
Fall Disc	34 bc	40 bc	32 bc	35 b
Spring Tillage Only	39 b	42 b	34 b	34 bc
Fall Zone-Till/Aerway	35 bc	43 b	29 c	29 d
Spring Aerway	33 bc	35 cd	28 c	28 d
No-Till (Coulter)	30 c	39 bc	29 c	29 cd
No-Till (Slot)	31 c	31 d	29 c	31 bcd

+ Means within the same column followed by the same letter are not different according to the protected LSD test at the 5% level of probability.

Table 3. Tillage system effects on early season corn and soybean aboveground dry biomass at Alvinston and Fingal 1994 to 1996 combined.

	Corn		Soybeans	
Tillage System	Alvinston	Fingal	Alvinston	Fingal
	------------------------	g m^{-2}	------------------------	
Moldboard Plow	50 a+	92 ab	117 a	151 a
Chisel Plow	35 bcd	88 ab	112 ab	133 a
Fall Disc	39 bc	98 a	107 abc	138 a
Spring Tillage Only	32 cd	82 bc	108 abc	135 a
Fall Zone-Till/Aerway	44 ab	98 a	106 bc	125 a
Spring Aerway	36 bcd	73 c	102 bc	129 a
No-Till (Coulter)	29 d	89 ab	100 c	133 a
No-Till (Slot)	28 d	85 b	103 bc	128 a

+ Means within the same column followed by the same letter are not different according to the protected LSD test at the 5% level of probability.

Table 4. Tillage system effects on grain corn yield at Fingal in 1994 to 1996.

	Grain Corn Yields @ 15.5% Moisture		
Tillage System	1994/5	1996	Mean
	---------------	t ha^{-1}	---------------
Moldboard Plow	10.23 a	9.46 a	9.98 a
Chisel Plow	10.14 a	8.67 a	9.65 a
Fall Disc	10.23 a	8.63 a	9.7 a
Spring Tillage Only	10.23 a	9.04 a	9.83 a
Fall Zone-Till/Aerway	10.18 a	8.97 a	9.77 a
Spring Aerway	10.06 a	8.26 a	9.46 a
No-Till (Coulter)	10.02 a	9.04 a	9.7 a
No-Till (Slot)	9.35 b	9.11 a	9.27 a

+ Means within the same column followed by the same letter are not different according to the protected LSD test at the 5% level of probability.

Table 5. Tillage system effects on grain corn yield at Alvinston in 1994 to 1996.

	Grain Corn Yields @ 15.5% Moisture			
Tillage System	1994	1995	1996	Mean
	------------------- t ha^{-1} -------------------			
Moldboard Plow	6.61 a	6.52 a	4.84 a	6.06 a
Chisel Plow	6.43 a	5.51 d	4.52 a	5.47 a
Fall Disc	6.41 a	5.90 bcd	5.35 a	5.75 a
Spring Tillage Only	6.80 a	6.19 ab	5.57 a	6.02 a
Fall Zone-Till/Aerway	6.68 a	6.08 abc	5.68 a	5.97 a
Spring Aerway	6.76 a	5.95 bcd	5.11 a	5.72 a
No-Till (Coulter)	6.02 a	5.49 d	5.00 a	5.36 a
No-Till (Slot)	6.04 a	5.69 cd	5.68 a	5.69 a

+ Means within the same column followed by the same letter are not different according to the protected LSD test at the 5% level of probability.

Table 6. Tillage system effects on soybean yield at Alvinston and Fingal in 1994 to 1996 combined.

	Soybean Yields @ 14% Moisture+	
Tillage System	Alvinston 1994-1996	Fingal 1994-1996
	------- t ha^{-1} -------	
Moldboard Plow	2.71 a	3.64 a
Chisel Plow	2.51 a	3.66 a
Fall Disc	2.59 a	3.52 a
Spring Tillage Only	2.52 a	3.64 a
Fall Zone-Till/Aerway	2.40 a	3.45 a
Spring Aerway	2.51 a	3.74 a
No-Till (Coulter)	2.40 a	3.77 a
No-Till (Slot)	2.54 a	3.62 a

+ Means within the same column followed by the same letter are not different

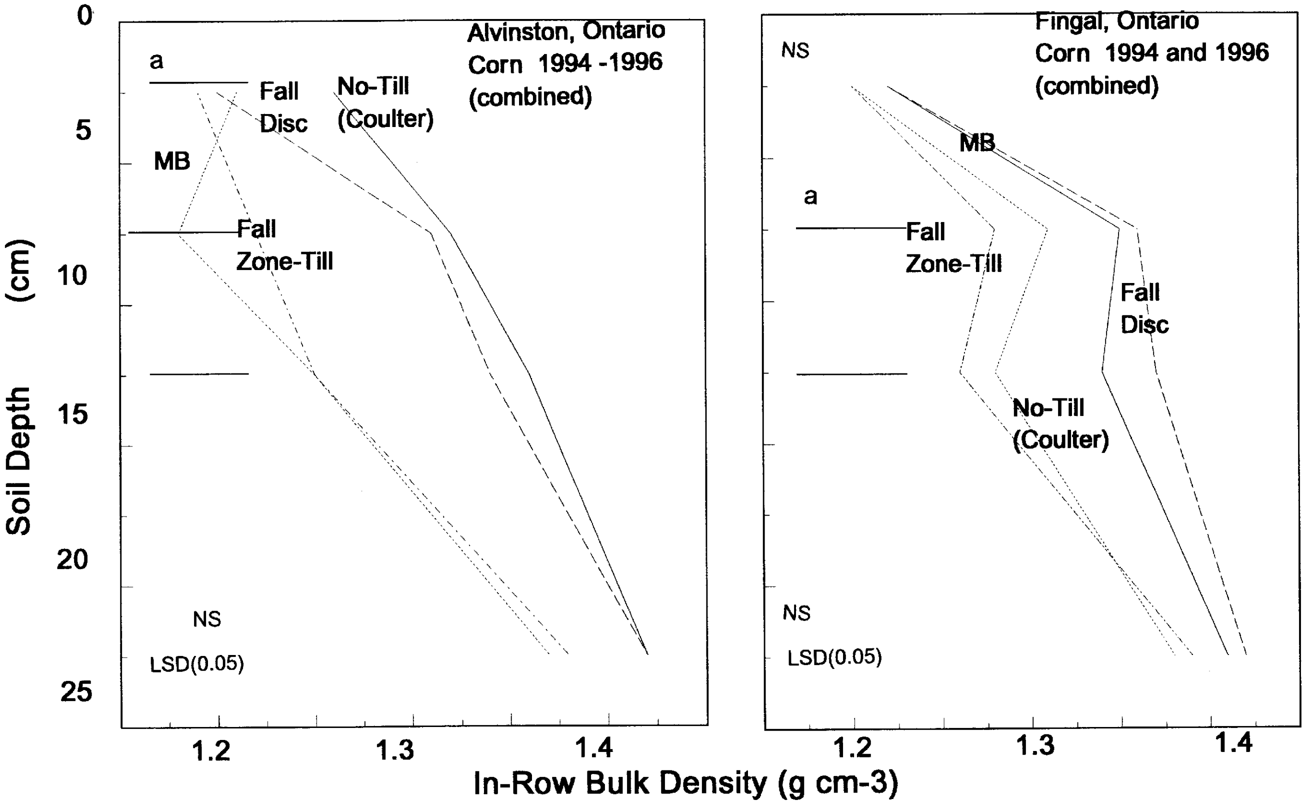


Figure 1. Tillage effects on in-row bulk density after corn planting at Alvinston and at Fingal .

[a] Differences less than the error bar at each sampling depth are not different according to the Protected LSD Test at P=0.05.

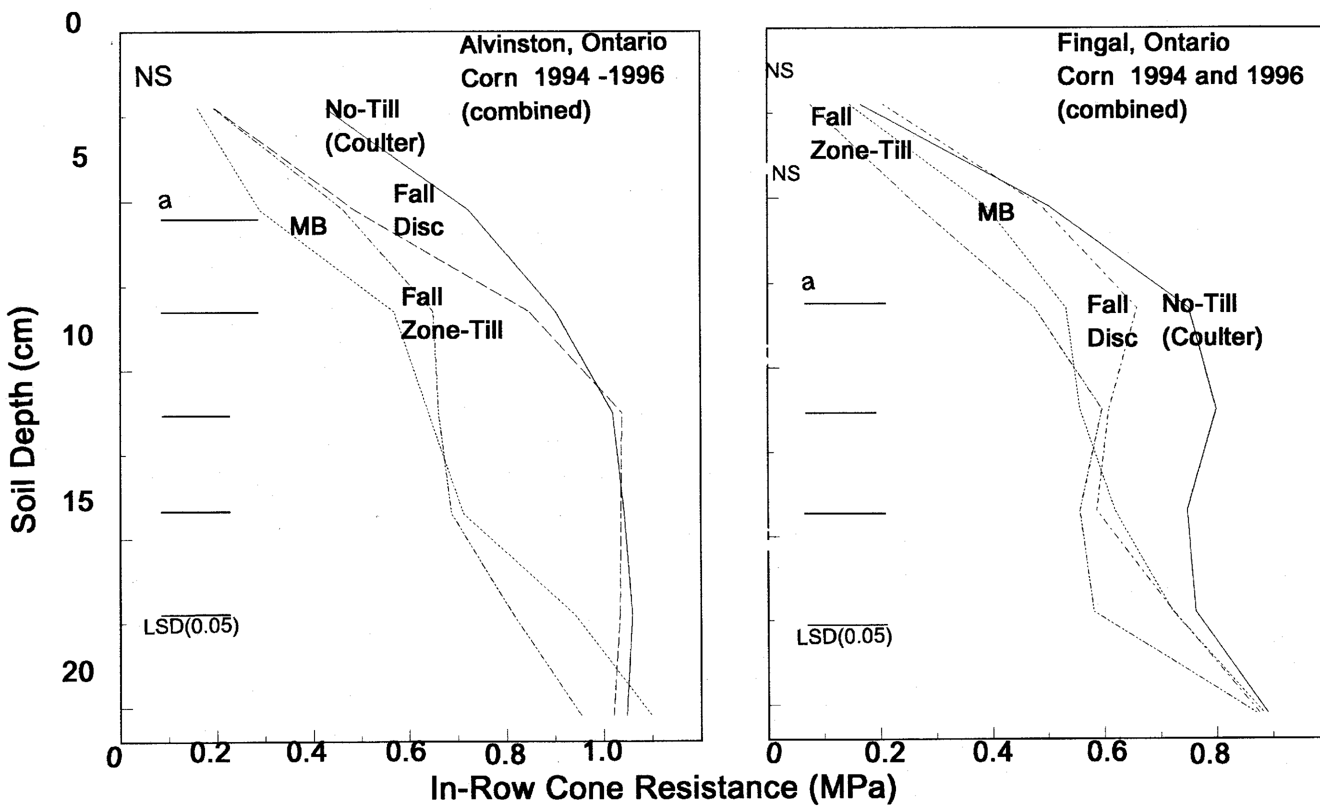


Figure 2. Tillage effects on in-row penetrometer resistance after corn planting at Alvinston and at Fingal .

[a] Differences less than the error bar at each sampling depth are not different according to the Protected LSD Test at P=0.05.

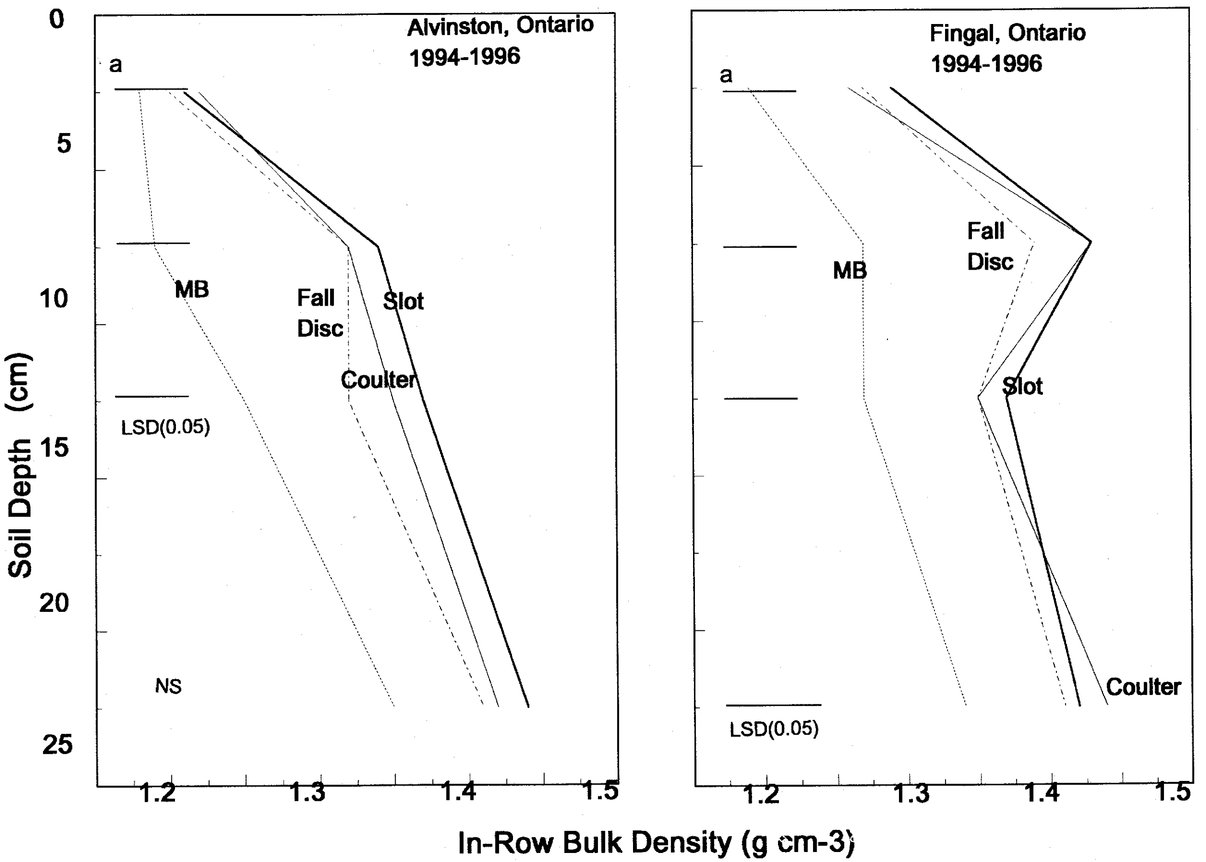


Figure 3. Tillage effects on in-row bulk density after soybean planting at Alvinston and Fingal for 1994 to 1996 combined.

[a] Differences less than the error bar at each sampling depth are not different according to the Protected LSD Test at P=0.05.

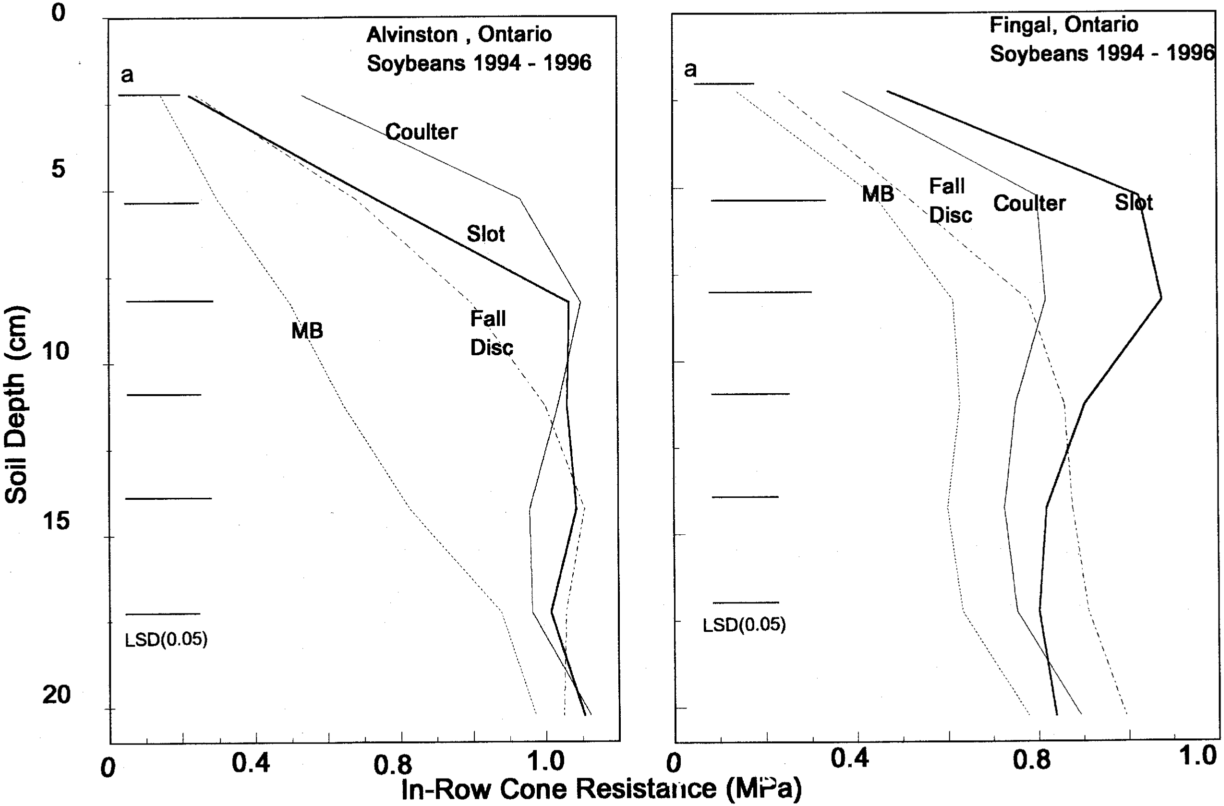


Figure 4. Tillage effects on in-row penetrometer resistance after soybean planting at Alvinston and Fingal for 1994 to 1996 combined.

[a] Differences less than the error bar at each sampling depth are not different according to the Protected LSD Test at P=0.05

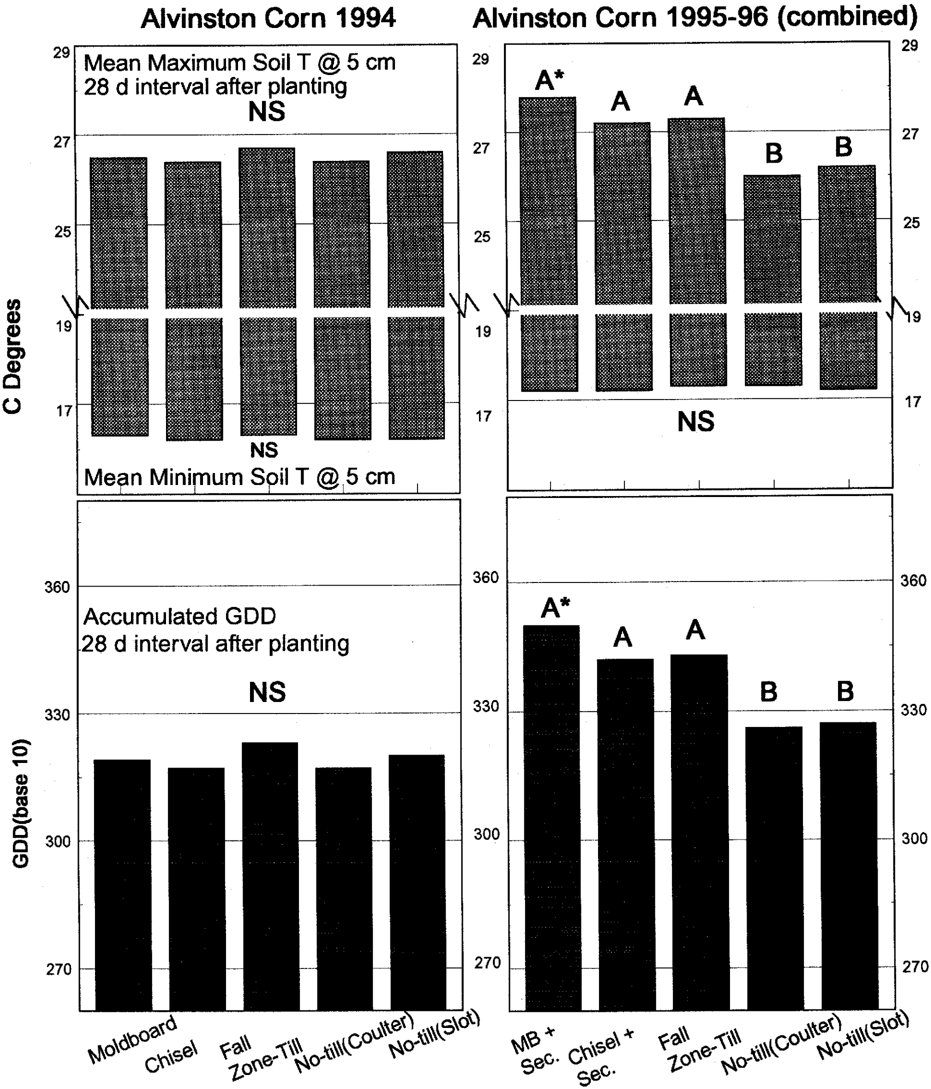


Figure 5. Tillage effects on mean maximum and minimum soil temperatures and accumulated growing degree days (GDD) at the 5 cm depth in-row during a 28 d interval following corn planting at Alvinston.

*Bars with the same letter within each figure are not different according to the Protected LSD Test at P=0.05.

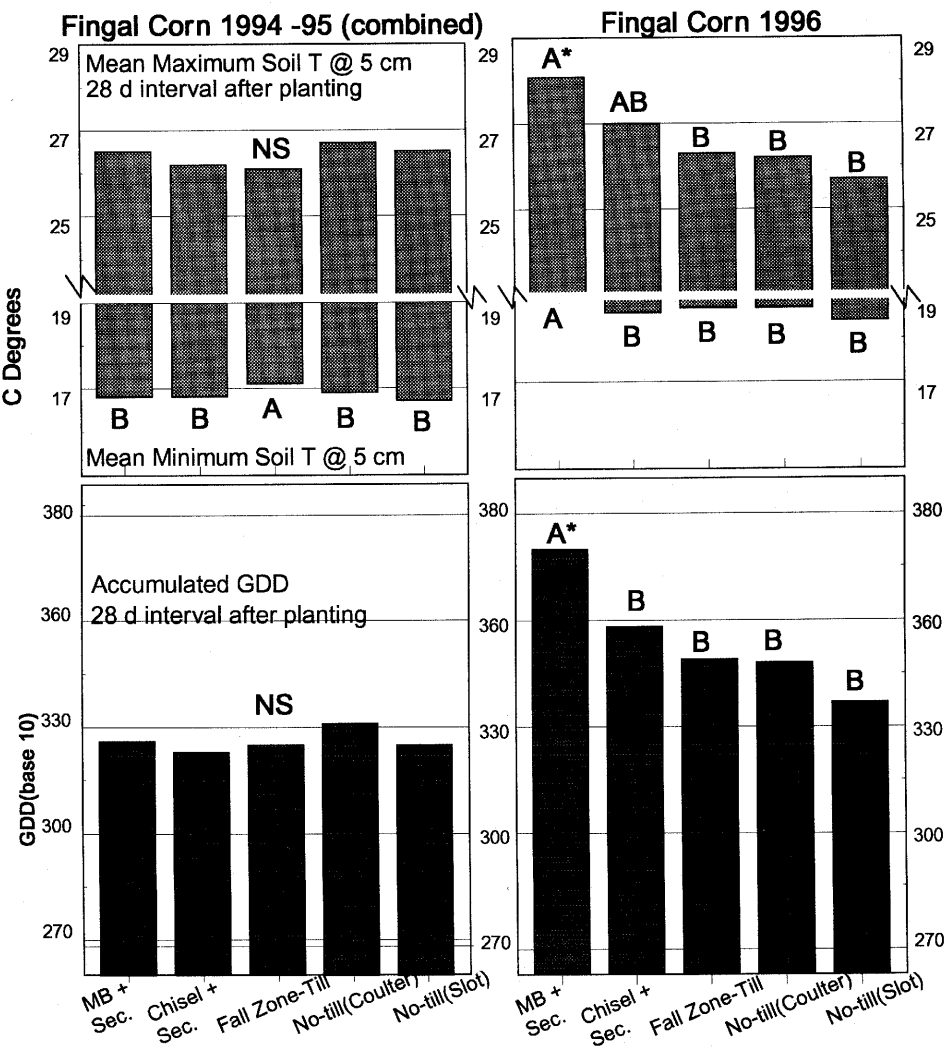


Figure 6. Tillage effects on mean maximum and minimum soil temperatures and accumulated growing degree days (GDD) at the 5 cm depth in-row during a 28 d interval following corn planting at Fingal.

*Bars with the same letter within each figure are not different according to the Protected LSD Test at P=0.05.

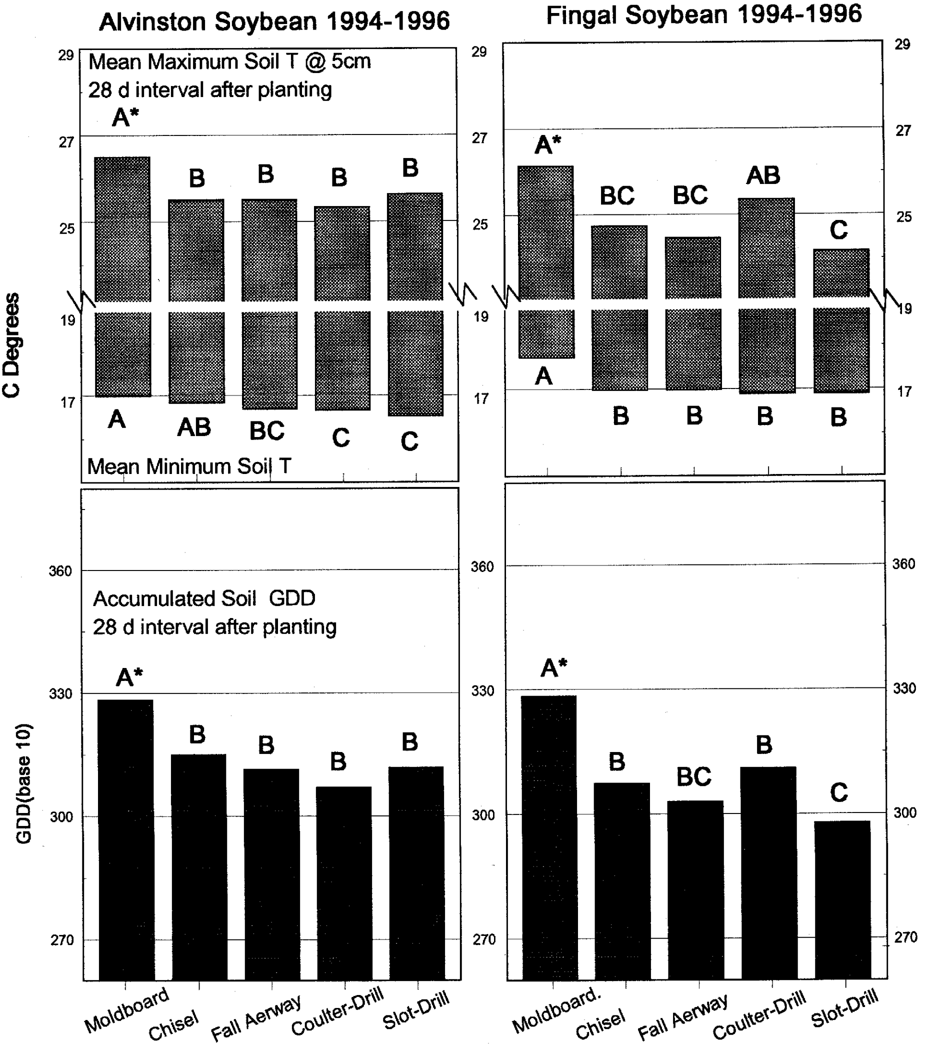


Figure 7. Tillage effects on mean maximum and minimum soil temperatures and accumulated growing degree days (GDD) at the 5 cm depth in-row during a 28 d interval following soybean planting at Alvinston and Fingal.

*Bars with the same letter within each figure are not different according to the Protected LSD Test at P=0.05.

OBJECTIVE B: CONSERVATION TILLAGE FOR CORN AND SOYBEANS AFTER WHEAT

RESEARCH OBJECTIVES

Field experiments in this objective were initiated following wheat harvest to examine the effects of tillage and no-till straw management on 1) rates of spring seedbed dry-down prior to corn or soybean planting, 2) in-row seedbed physical properties (aggregation, soil strength), and 3) soybean and corn growth and yield.

Site cooperators and location

Centralia

Cooperator: Eric DeVlaemink
Location: Concession 1, Lot 9, Stephen Township Huron County

Wyoming

Cooperator: David Brand
Location: Concession 12, Lot 14, Enniskillen Township, Lambton County

METHODOLOGY

Experimental Design and Treatment Descriptions

Each site was initiated on a wheat stubble field shortly following wheat harvest. A description of soils for each location and year of the study is presented in Table 7. The soil texture classification for the corn and soybean sites at Centralia differed during 1994 and 1996 and therefore soil texture information is presented for each crop. Generally the soil texture at Centralia was a loam to clay-loam. Soil texture for each crop at Wyoming within each year was more consistent with the texture ranging from a silty clay loam to silty clay.

The experimental site at each location was split with one side cropped to soybeans and the other to corn. For each crop, the experimental design was a randomized complete block with 4 replications. The tillage, and straw management treatments are:

1. **Fall Moldboard (Baled)** Fall moldboard plow (15 cm deep) plus secondary tillage.
2. **Fall Chisel (Baled)** Fall chisel plow (12 cm deep) equipped with 10-cm twisted shovel teeth plus secondary tillage.
3. **Fall disc (Baled)** Fall tandem disc (10 cm deep). No additional tillage in the spring.
4. **Fall Zone-till (Baled)** In-row soil loosened using a Trans-till (17 cm deep) in the fall.
5. **No-till (not baled)** Wheat straw was added back to plots to simulate no-till planting into a wheat field where straw chopped and returned while combining. Crops planted no-till.
6. **No-till (baled)** Only wheat residue present is stubble. Crops planted no-till.
7. **No-till (Bare)** All residue, including stubble, raked from plots about 2 to 3months following wheat harvest. Crops planted no-till.

Soybeans only

8 **No-till (baled 38 cm)** Similar to treatment 6 except soybeans were planted in 38 cm rows.

Field Preparation and Cultural Practices

Soft white winter wheat was harvested by the cooperating farmers using commercial harvesting equipment and straw was baled. Standing stubble heights ranged from 20 to 30 cm.

Primary tillage (i.e. moldboard plowing, chisel plowing, discing or zone-tillage) was performed during October or early November following wheat harvest. Secondary tillage always consisted of two passes with a field cultivator and packer just prior to corn or soybean seeding. About 1 week prior to corn or soybean planting, glyphosate was sprayed at 1.3 kg ai ha^{-1} to burn down perennial weeds and any volunteer wheat.

Corn and soybeans were planted using a John Deere model 7000 Conservation planter with 76-cm row spacing and equipped with a single 5-cm fluted coulter (i.e. planter mounted, positioned directly in front of the seed disc openers) plus a starter fertilizer coulter positioned 5 cm to the side of the row. The planter was also equipped with a unit-mounted “Dawn” trash wheel.

Corn

Corn 'Pioneer 3790' (1994, 1995, 1996) at Centralia and 'Pioneer 3760' (1994 1995) or ‘Pioneer 3769' (1996) at Wyoming was planted at a seeding rate of 74,000 seeds ha^{-1}. The hybrid was changed at Wyoming for 1996 because ‘Pioneer 3760' was no longer commercially available. The planting dates were 1 June 1994, 5 May 1995 and 28 May 1996 at Centralia and 31 May 1994, 8 May 1995 and 30 May 1996 at Wyoming. Starter fertilizer (mono-ammonium phosphate) was side-band applied through the planter 5 cm to the side of the row, 5 cm below seeding depth, at a rate of 125 kg ha^{-1}. Additional nitrogen was injected between rows, about 4 to 5 weeks after planting, as urea-ammonium nitrate at a rate of 150 kg N ha^{-1}.

Weed control for corn consisted of a pre-emergence broadcast application of cyanazine and metolachlor at rates of 2.1 and 2.4 kg ai ha^{-1}, respectively. Dicamba was applied post emergence at a rate of 0.34 kg ai ha^{-1} to control broadleaf weed escapes.

Soybeans

Soybeans 'OAC Shire' at Centralia and 'Asgrow 1929' at Wyoming were planted at a seeding rate of 35 seeds per linear m of row. Seeding dates were 1 June 1994, 1 June 1995 and 29 May 1996 at Centralia and 31 May 1994, 6 June 1995 and 30 May 1996 at Wyoming. The starter fertilizer coulter remained on the planter when soybeans were planted; however, starter fertilizer was not applied. The no-till (baled 38 cm) treatment was planted by double planting with the row-crop planter. The seeding rate for the narrow-row treatment was adjusted to 28 seeds per linear m of row.

Weed control for soybeans consisted of a pre-emergence application of linuron and metolachlor @ 0.9 and 2.4 kg ai ha^{-1}, respectively.

Field and Laboratory Measurements

Wheat residue biomass was determined during early November following wheat harvest (Fall) and late spring following corn and soybean planting (June) by collecting all surface wheat residue from two 0.50 m^2 quadrants on an individual plot basis from the no-till (not baled) and no-till (baled) treatments. Cross-row percent residue cover was determined shortly after corn and soybean planting (within 5 days) using the line transect method (Sloneker and Moldenhauer, 1977) by placing a rope with 50 markings diagonally across 2 rows (i.e. starting in the centre of the inter-row, diagonally crossing 2 rows, and finishing in the centre of the inter-row) within each plot. Three determinations were done per plot.

Volumetric soil moisture (0 to 15 cm depth) was determined on numerous dates between mid-April to early June using the Time Domain Reflectometer (Topp et al., 1980). Random measurements of volumetric soil moisture were done five times per plot, except in zone-till plots where measurements were restricted to the loosened zones.

In-row surface seedbed soil aggregate size distribution was determined shortly after corn and soybean planting (within 5 days) by collecting 3 minimally disturbed soil samples per plot centred on the row using a cylindrical cor (7 cm diameter, by 7 cm deep). The soil samples were then oven dried at 30^{o}C until a constant weight was achieved. The samples were then sieved through a nest of sieves (>10 mm, 10 mm, 5 mm, 2 mm, 1 mm, < 1 mm in diameter) with a shaker (Kemper and Chepil, 1965). Aggregate size distribution data for Objective B was summarized by calculating the percentage of aggregates, by mass, that were less than 5 mm in diameter.

Following corn planting at Centralia during 1996 hourly in-row soil temperature at a depth of 5 cm was recorded for the first 5 weeks following corn planting. Soil temperature was measured using 2 copper-constantan thermocouples per plot. Due to limited availability of thermocouples, soil temperature was not measured on the fall chisel treatment. The accumulation of soil thermal units was quantified by summing soil growing degree days (GDD) calculated on a daily basis. Soil GDD was calculated by averaging the daily minimum (min) and maximum (max) temperature measured in ^{o}C and then subtracting 10. When GDD were calculated, any min or max temperatures less than 10^{o}C were substituted with a value of 10. Likewise, any max temperatures exceeding 30^{o}C were substituted with a value of 30.

In-row soil resistance measurements were conducted about 7 to 9 weeks after planting (mid-July) using a Rimik hand-held recording penetrometer. The cone at the tip of the penetrometer shaft had a surface area of 2 cm^{2} with a 60^{o} angle. The recording penetrometer recorded soil resistance at 1.5 cm intervals up to a potential depth of 45 cm. Soil resistance data for Objective B was summarized by averaging 3 consecutive depth intervals up to 22.5 cm. The depth assigned to the averaged soil resistance values presented in figures was the mean depth of the averaged resistances (i.e. 3.0, 7.5, 12.0, 16.5 and 21.0 cm).

Corn

Early season corn plant growth was quantified by determining the mean mass of 15 consecutive plants during the 5th and 7th week after planting. Corn mass was determined after drying to a constant weight in forced air ovens set to 80^{o}C. Grain corn yield was determined after reaching physiological maturity by hand harvesting from a 7.6 m^{2} area, mechanically shelling grain from the ears and then recording the mass and moisture content of the shelled grain. Grain corn moisture was determined using a Dickey John (GAC II) moisture meter. Grain corn yield is expressed as t ha^{-1} at 15.5% moisture.

Soybeans

Early season soybean plant growth was quantified by determining the mass of soybeans from 2 adjoining representative 2 m section of rows during the 5th and 7th week after planting. Soybean plants were dried using forced air ovens set at 80^{o}C until a constant weight was achieved and then expressed as g m^{-2}. Soybean seed yield was determined after reaching harvest maturity by mechanically harvesting 2 adjoining 76 cm spaced rows for the entire length of the plots (approximately 16 m for a total harvest area of approximately 24 m^{2}) or 3 adjoining 38 cm spaced rows (approximately 18 m^{2}).

Soybean seed moisture was determined at the time of harvest using a Dickey-John (GAC II) moisture meter and yields were expressed as t ha^{-1} at 14.0% moisture.

Data presentation

Analysis of variance for each parameter was conducted both within and across years. Where possible, soil and crop data presented in either tables or figures are averaged over years. Thus, whenever the treatment by year interactions are not significant at the 0.05 level of probability, treatment means over years are reported. This helped to simplify presentation of the results.

RESULTS AND DISCUSSION

Weather Patterns

The mean air temperature for May at both locations during all 3 years was below the long-term normals (Table 8). During 1994 and 1995, mean air temperatures between 1 June to 30 September did not differ substantially from the long-term normals. During all three years, sufficient thermal units were accumulated from planting until killing frosts to ensure that corn and soybeans reached physiological maturity.

Dry weather conditions at Wyoming for 1994 during the latter part of May and early June resulted in dry seedbed conditions at planting which adversely affected corn and soybean emergence rates on the fall moldboard and chisel plow tillage systems. Although May and June precipitation during 1995 at Wyoming was above normal, it was not evenly distributed and thus resulted in periods with relatively dry soil conditions (Table 8). Precipitation patterns at Centralia were either close to or above normal during 1994; however, during 1995 precipitation was below normal later in the growing season. The 1996 growing season at both Centralia and Wyoming can be characterized as receiving above normal precipitation during May and June, below normal during August and above normal during September. In fact, both sites had a 5 week period starting early August until early September where very little precipitation was received. Later than intended corn planting dates for 1994 and 1996 were due to wet weather conditions at both sites during late April and early May.

At Centralia, a hail storm occurred just prior to corn tasselling in 1994 which severely shredded, but not totally stripped, corn and soybean leaves. Little, if any, reduction in corn or soybean plant population occurred as a result of this hail storm; however the damage was severe enough to reduce yield potential.

Spring Seedbed Conditions

All sites followed winter wheat with uniform growth and grain yields exceeding 4 t ha^{-1}. Fall straw biomass amounts in the no-till system where straw was not baled ranged from 3 to 5 t ha^{-1} higher than where straw was baled (Table 9). Significant reductions of straw biomass occurred in the no-till system between the fall and late spring (June) sample dates with the amount of straw present by mid-June generally being about 50 to 75% of the amount of straw present the previous fall.

Volumetric soil moisture contents were evaluated on numerous sample dates prior to corn and soybean seeding at both locations during all years. The volumetric soil moisture results presented for each location/year in Table 10 are representative of trends observed for the other dates for that particular location/year. Volumetric soil moisture contents for each location/year are the average of the corn and soybean sites.

Generally, the volumetric soil moisture was lowest in the fall moldboard system and highest with no-till where straw had not been baled and lowest in the fall moldboard system (Table 10). During 2 of the 3 years (1994 and 1995) reducing the amount of straw present in the no-till system was associated with lower volumetric soil moisture contents, especially when all straw had been removed (i.e. bare). Fall discing was associated with drier soil conditions than no-till, provided that all straw had not been removed, for 2 out of 3 years (1994 and 1995). This indicated that fall discing was often associated with faster soil dry-down rates than no-till. Volumetric water contents within the zone loosened by the zone-till implement the previous fall were consistently less than no-till (provided that all straw had not been removed), and often did not differ substantially from either the fall moldboard or fall chisel systems; indicating that spring soil dry-down rates for the zone-till system did not differ substantially from either the fall moldboard or chisel plow systems.

Cross-row residue cover determined shortly following corn or soybean planting indicated that the no-till, provided that all straw had not been removed, fall zone-till and fall disc systems maintained at least 30% residue cover (data not presented). The residue cover in the fall moldboard and fall chisel plow systems were less than 20%.

At 5 out of 6 location/years, the in-row proportion of fine aggregates (<5 mm in diameter) in the surface 7 cm after corn and soybean planting often tended to be higher in the fall moldboard and chisel plow systems when compared to no-till (Table 11). At Centralia during 1996, however, the proportion of in-row fine aggregates in the no-till system where straw was either baled or totally removed did not differ from either the fall moldboard or chisel plow systems. Whenever differences occurred among the fall tillage systems, fall discing and zone-tilling often resulted in in-row proportions of fine aggregates that were lower than fall moldboard and/or chisel plowing but greater than no-till. In-row seedbed fineness within the no-till system was affected by straw amounts with the proportion of fine aggregates declining as the amount of straw increased.

Following corn planting at Centralia during 1996, reducing the amount of straw in the no-till system increased maximum daily in-row soil temperature and the rate of soil GDD accumulation (Table 12). In the no-till system, baling straw did not affect the minimum in-row soil temperature but did increase the maximum temperature by 1.8^{o}C and accumulated soil GDD by 37 (12%). Totally removing all straw increased maximum daily soil temperature by an additional 0.9^{o}C and accumulated GDD by 14 (4%). Soil temperature and accumulated soil GDD in the fall moldboard, fall disc and fall zone-till treatments were similar to no-till when straw was either baled or totally removed.

Tillage affected in-row soil strength at soil profile depths less than 16.5 cm (Figures 8 and 9). Generally, within profile depths less than 16.5 cm, minimal differences among the various no-till straw management treatments occurred. Only resistances for no-till where straw was baled are presented in Figures 8 and 9. Whenever differences among tillage systems occurred, the fall moldboard, fall chisel and fall zone-till systems generally had lower resistances than no-till at profile depths less than 7.5 cm. At profile depths of 12.0 cm and occasionally at 16.5 cm, the fall moldboard and fall zone-till systems often continued to have lower soil resistances than no-till.

Corn Response

Fall tillage tended to increase early season corn growth rates compared to no-till, particularly when all wheat straw had not been removed (Table 13). Corn responses to tillage and no-till straw management observed during the 5th week after planting generally were similar to those observed during the 7th week; therefore, only corn mass data for the 7th week will be discussed. Whenever differences occurred, the fall tillage systems tended to produce corn plants that were more massive than no-till, especially where straw was not baled. Significant differences in 7 week corn plant mass among the fall tillage systems did not occur except at Centralia during 1995 where fall moldboard corn plants were more massive than those in either the fall chisel, fall disc or fall zone-till systems. Except at Wyoming during 1994, early season no-till corn growth rates decreased as the amount of straw increased; with no-till corn plant mass at 7 weeks where all straw was removed (bare) being about 30 to 50% more massive than where straw had not been baled.

Harvest corn plant population did not vary significantly among the various tillage and no-till straw management treatments with populations exceeding 90% of the seeding rate of 74,000 seeds ha^{-1} (Table 14). Numerically, the lowest corn plant populations were associated with no-till where straw had not been baled.

The highest harvest grain corn moisture contents occurred in the no-till system where straw had not been baled, which averaged over both locations was 2.0% higher than no-till where straw was baled (Table 14). At Centralia, fall discing tended to result in harvest grain corn moisture contents that were over 1.0% higher than those obtained in the other fall tillage systems. Otherwise, statistically significant differences did not occur among the tillage systems.

Tillage and no-till straw management both affected grain corn yields; however, at both locations the magnitude of differences and/or ranking of treatments were not consistent over years (Table 15). During 1994 and 1995 grain corn yields for the fall tillage systems were numerically greater than no-till, provided that all straw had not been removed. During 1996, however, many of the fall tillage systems resulted in yields that were similar to or slightly inferior to no-till where straw had been baled. At Centralia during 1996, grain corn yields in the fall chisel, fall zone-till and fall disc systems were at least 0.68 t ha^{-1} lower than fall moldboard. Otherwise, statistically significant differences among the fall tillage systems could not be identified.

Averaged over years, fall discing or fall zone-tilling produced grain corn yields which were essentially similar to those obtained in either the fall moldboard or fall chisel plow systems and at least 0.49 t ha^{-1} (5%) greater than no-till, provided that all straw had not been removed. At Centralia, fall discing produced the second highest corn yield which was statistically similar to the yield obtained in the fall moldboard system and 0.39 t ha^{-1} (5%) higher than no-till where straw had been baled. The small yield response to fall zone-tilling at Centralia was primarily due to relatively poor yields obtained during 1996. When averaged over 1994 and 1995, fall zone-tillage at Centralia produced corn yields that were similar to the yield obtained in the fall moldboard plow system and 0.66 t ha^{-1} (8%) higher than no-till where straw was baled.

Within the no-till system, decreasing the amount of straw generally increased corn yields at all locations (Table 15). Averaged over locations, totally removing all straw (i.e. bare) produced the highest no-till grain corn yield which was 0.88 t ha^{-1} (10%) higher than where straw had not been baled. The yield response associated with baling straw (i.e. baled vs. not baled) was larger at Centralia than at Wyoming, with a grain yield increase associated with straw baling at Centralia of 0.61 t ha^{-1} (8%).

For all six location/years, early season corn plant mass at 7 weeks was positively correlated with the in-row proportion of fine aggregates (Table 16). Except at Wyoming during 1996, grain corn yield was also positively correlated with the in-row proportion of fine soil aggregates. At 3 out of 6 location/years the mass of 7 week corn plants was inversely correlated with mean in-row soil resistance within profile depths of 1.5 to 4.5 cm. Grain corn yield was never significantly correlated with in-row soil resistance.

Corn growth and yield responses to the various tillage and no-till straw management treatments may also be due to differences in early season in-row soil temperatures. At Centralia during 1996, both early season plant mass (r=0.74) and final yield (r=0.71) were positively correlated (n=24) with the amount of in-row soil GDD accumulated for the first 5 weeks after planting.

The corn growth and yield correlations with in-row soil properties suggest that tillage goals for corn following wheat on medium and finer textured soils should focus on preparing a finely aggregated seedbed within the surface 7 cm rather than performing deep tillage with the intent of loosening the soil at depths below 10 cm. In fact, the relatively high corn yields obtained by just fall discing support the conclusion that deep intensive tillage is not necessary to produce top corn yields following wheat on the medium and finer textured soils of southern Ontario. It is interesting to note that at Centralia during 1996, the proportion of fine aggregates between no-till (not baled) did not differ from those obtained in the fall moldboard system; neither did early season corn growth or yields; which was contrary to what occurred during previous years.

Soybean Response

During 1994 and 1995, soybean plant populations in the fall moldboard plow system did not differ from no-till where straw had been baled, however, during 1996 no-till plant populations were at least 18% lower than those obtained in the fall moldboard plow system. Soybean populations were lowest in 5 of 6 site/years with no-till where straw had not been baled (Table 17). Higher soybean plant population associated with no-till in 38-cm rows was due to a seeding rate which was approximately 1.6 times greater on an area basis than the 76-cm row width.

Tillage and no-till straw management effects on the amount of soybean biomass during the 5^{th} week after planting were similar to those observed during the 7^{th} week; therefore, only results for the 7^{th} week will be discussed. Soybean biomass in either the fall moldboard or fall chisel plow systems were greater than either the fall disc or fall zone-till systems in 4 out of 6 site/years (Table 18). Soybean biomass was similar for moldboard and chisel treatments except at Wyoming during 1995 where soybean biomass in the fall chisel system was lower and similar to those obtained in either the fall disc or fall zone-till systems. No-till soybean biomass where straw had been baled was numerically lower than those in either the fall disc or fall zone-till systems, differences were statistically significant at Wyoming during 1994 and 1996.

Within the no-till system, soybean biomass at 7 weeks declined as the amount of straw increased; biomass increases associated with totally removing all wheat residue, relative to where straw had not been baled, always exceeded 25% and often exceeded 50% (Table 18). Extremely low biomass amounts associated with no-till where straw had not been baled during 1996 were due to low plant populations. Baling straw was associated with biomass increases of at least 14% over where straw had not been baled. Higher biomass quantities associated with the no-till 38 cm row width treatment was primarily a function of the higher number of soybean plants m^2 compared to the wide (76 cm) row treatments.

Tillage and no-till straw management both affected soybean seed yields, however, the magnitude of response among treatments differed over years (Table 19). At Centralia, similar soybean yields were obtained in the fall moldboard and fall chisel systems which were greater than those obtained in the fall zone-till and fall disc systems during 1994 and in the fall disc system during 1995. At Wyoming during 1996, fall discing resulted in soybean yields that were greater than those obtained with the fall moldboard system. Otherwise, statistically significant yield differences among the various fall tillage systems could not be identified. At Centralia during 1994 and 1995 and at Wyoming during 1994 all of the fall tillage systems produced soybean yields that were greater than no-till where straw had been baled.

Averaged over years and locations, fall discing produced soybean yields that were 0.20 t ha^{-1} (7%) higher than no-till where straw had been baled (Table 19). When yields were averaged over years at Wyoming fall discing produced soybean yields that were similar to those obtained with fall moldboard plowing. At Centralia, however, a further 0.22 t ha^{-1} (8%) yield increase was realized with either the fall moldboard or fall chisel plow systems when compared to fall discing. Fall zone-tillage produced higher soybean yields than no-till where straw was baled, with an average yield increase over years of 0.26 t ha^{-1} (10%) at Centralia.

Within the no-till system, soybean yields declined as the amount of wheat residue increased (Table 19). This effect was especially large during 1996 when poor plant populations were associated with the no-till system where straw was not baled. In fact, soybean populations obtained would have likely prompted most soybean producers to reseed. When averaged over years, totally removing straw increased yields by at least 0.19 t ha^{-1} (6%) over where only straw had been baled (i.e. stubble left).

There were indications that substantial yield penalties are associated with wide-row soybean production at these locations. Planting soybeans in 38-cm rows increased no-till yields, where straw had been baled, averaged over locations and years, by 0.49 t ha^{-1} (15%) over 76-cm rows. Although fall zone-tillage increased wide-row soybean yields over no-till, the row width restrictions associated with the fall zone-till system evaluated in this study limits it's ability to produce soybean yields as high as other conservation tillage systems such as fall disc or no-till which can readily capitalize on the yield advantage associated with narrower row widths.

Early season wide-row soybean growth (i.e. biomass at 7 weeks) was positively correlated to the in-row proportion of fine aggregates at all 6 location/years (Table 20). At 5 out of 6 location/years, wide-row soybean seed yields were also positively correlated with the in-row proportion of fine aggregates. At Centralia during 1994 and Wyoming during 1995, soybean seed yield was also inversely correlated with mean in-row soil resistance within the profile depth interval of 1.5 to 4.5 cm. At Wyoming during 1996, soybean seed yield was positively correlated with soil resistance.

As with corn, the early season wide-row soybean growth and seed yield correlations with in-row seedbed properties also suggest that tillage goals for soybean production on Ontario's medium and finer textured soils should focus on producing a finely aggregated seedbed rather than deep loosening. As with corn, the ability of the fall disc system to produce soybean yields that are not substantially different from either the fall moldboard or fall chisel plow systems indicate that deep tillage is not always necessary to produce top soybean yields following wheat on many of Ontario's medium and finer textured soils.

CONCLUSIONS AND RECOMMENDATIONS

Generally, no-till corn and soybean productivity following wheat on Ontario's medium and finer textured soils can be expected to increase as the quantity of straw is reduced. In fact, no-till corn and soybean yields were usually similar to those obtained using conventional (i.e. fall moldboard) tillage practices when all wheat residue was removed. Although the total removal of wheat straw substantially increase no-till corn and soybean productivity following wheat, the results of this study should not be used to promote the practice of total wheat straw removal by baling or burning because of the potential long-term detrimental effects associated with reduced organic matter contributions and/or substantial increased risk for wind and water erosion. Instead, efforts should focus on production practices which overcome, or at least minimize, the detrimental effects on corn and soybean productivity associated with large amounts of surface placed wheat straw without reducing organic matter contributions and substantially increasing the risk for erosion.

Fall discing or zone-tillage, with no additional spring secondary tillage, often produced corn and wide-row soybean yields that were greater than no-till and similar to those obtained with the more conventional tillage systems (i.e. either fall moldboard or fall chisel plow with spring secondary tillage). In fact, the fall disc and fall zone-till systems often substantially increased corn and wide-row soybean productivity when compared to no-till, while maintaining sufficient amounts of residue cover so as to not substantially increase the risk for wind or water erosion. Also, both fall discing and fall zone-tilling were often associated with faster rates of spring soil dry-down than no-till which could potentially increase the likelihood for earlier planting dates and number of optimal planting days available when compared to no-till.

The relatively high corn and soybean yields obtained with the relatively shallow tillage depths associated with the fall disc system suggest that deep intensive tillage is not necessary to produce top corn and soybean yields on Ontario's medium and finer textured soils. In fact, corn and soybean performance was more closely correlated to the proportion of aggregates in the surface 7 cm rather than soil looseness at deep tillage depths (i.e. 10.5 to 13.5 cm). Therefore, tillage recommendations for corn and soybean production following wheat should emphasize that creation of favourable surface seedbed conditions is more important to attaining high yields than is deep tillage which is intended for loosening soil at depths below 10 cm.

Either fall discing or fall zone-tillage, with no additional spring secondary tillage, are viable tillage practices for corn production following wheat on Ontario's medium and finer textured soils, often producing corn yields that are similar to those obtained in the fall moldboard system and greater than no-till. However, the yield penalties associated with wide-row soybean production limits the potential for the fall zone-till system evaluated in this study to produce top soybean yields. In fact, although fall zone-tilling often increased soybean yields over no-till in wide rows, often even greater soybean yield increases were realized when planted no-till in narrower rows (i.e. 38-cm row spacing). The fall disc system is an interesting tillage option for soybean production following wheat because of the potential for this system to produce higher soybean yields than no-till while maintaining sufficient residue cover to provide significant erosion protection and the flexibility to capitalize on the potential yield increases associated with planting in narrower row widths.

Table 7. Texture and organic matter content of soils at the experimental sites for Objective B.

Location	Year	Soil Texture	Clay	Silt	Sand	Organic Matter
Centralia Corn			------------------------------	%	------------------------------	
1993/94		Clay Loam	29	45	26	2.7
1994/95		Clay Loam	31	47	22	3.1
1995/96		Silt Loam	16	51	33	2.0
Centralia Soybean						
1993/94		Loam	20	45	34	2.2
1994/95		Clay Loam	30	48	22	2.9
1995/96		Loam	17	48	35	1.9
Wyoming Corn and Soybean						
1993/94		Silty Clay Loam	38	49	13	4.6
1994/95		Silty Clay Loam	35	54	11	3.4
1995/96		Silty Clay	43	49	8	4.9

Table 8. Monthly mean air temperature and total rainfall at Centralia and Wyoming during 1994-96.

Location	1994		1995		1996		Normal	
Month	Temp	Rain	Temp	Rain	Temp	Rain	Temp	Rain
Centralia	°C	mm	°C	mm	°C	mm	°C	mm
May	11.8	76.7	10.7	76.3	12.0	102.7	12.7	73.5
June	18.8	118.3	68.8	19.0	18.7	164.3	17.5	71.2
July	20.5	81.6	21.3	76.4	19.1	87.3	20.4	79.6
August	18.0	54.8	21.0	57.6	19.9	46.2	19.5	92.8
September	15.6	57.4	16.3	38.1	15.8	344.3	15.4	99.5
Wyoming								
May	13.2	46.0	12.4	125.2	12.7	108.4	15.5	71.4
June	19.6	88.8	20.4	99.6	20.1	225.2	18.9	91.1
July	21.7	36.1	21.5	44.8	20.1	75.6	21.8	69.2
August	19.5	72.6	23.4	96.6	21.6	42.8	20.0	86.6
September	17.4	70.7	15.0	16.6	16.9	260.0	17.0	88.2

Table 9. Straw biomass present in the no-till system during early November following wheat harvest (fall) and following corn/soybean planting (June).

Location	1993/94		1994/95		1995/96	
Straw Management	Fall	June	Fall	June	Fall	June
Centralia	------------------ t ha^{-1} ------------------					
Baled	3.96	2.43	4.46	2.18	3.16	1.71
Not Baled	6.30	4.80	7.30	4.29	8.35	5.77
Wyoming						
Baled	3.36	1.68	4.17	2.28	3.15	1.40
Not Baled	7.59	5.24	7.69	4.75	8.02	4.33

Table 10. Tillage and straw management system effects on soil volumetric water content (0 to 15cm) on selected pre-planting dates (DDMMYY) at Centralia and Wyoming.

Tillage/Straw	Centralia			Wyoming		
Management	20MY94	03MY95	08MY96	09MY94	16AP95	14MY96
	------------------ % ------------------					
Fall Moldboard	17.4c+	25.2d	25.5c	17.6f	25.4c	28.8c
Fall Chisel	19.8bc	25.2d	28.1b	19.6ef	25.6c	32.3b
Fall Disc	21.4b	26.8c	32.5a	20.1de	26.6c	33.1b
Fall Zone-till	22.1b	25.8cd	28.1b	22.3cd	26.3c	29.2c
No-till (Not Baled)	27.1a	33.0a	32.0a	29.2a	34.2a	35.9a
No-till (Baled)	26.1a	31.3b	32.3a	25.4b	30.9b	33.0b
No-till (Bare)	21.0b	26.2cd	32.5a	22.6c	25.4c	32.8b

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 11. Tillage and straw management system effects on the proportion of in-row soil aggregates less than 5mm in diameter shortly after corn planting.

Tillage/Straw	Centralia			Wyoming		
Management	1994	1995	1996	1994	1995	1996
Corn	------------------------------------- % --					
Fall Moldboard	48.6a+	48.7a	47.9a	54.8a	42.7b	52.9a
Fall Chisel	43.0ab	37.5b	48.3a	43.1b	55.8a	47.3ab
Fall Disc	34.2c	35.0b	49.4a	45.0b	41.3bc	37.4c
Fall Zone-till	41.6b	36.9b	44.8a	42.6b	41.1bc	43.1bc
No-till (Not Baled)	25.5e	20.8c	18.8b	29.0e	28.0e	14.9e
No-till (Baled)	27.0de	27.8bc	47.0a	33.7d	33.7de	27.0d
No-till (Bare)	32.7cd	32.9b	50.6a	38.3c	35.6cd	39.57c
Soybean						
Fall Moldboard	41.4a+	47.6a	48.5a	47.4a	40.0a	48.5ab
Fall Chisel	42.9a	52.6a	46.8a	45.1ab	35.5ab	49.3a
Fall Disc	40.0a	36.4b	44.6a	38.5cd	37.3a	37.0c
Fall Zone-till	39.7a	36.6b	45.3a	41.9bc	35.0ab	40.0abc
No-till (Not Baled)	25.9b	21.8c	31.7b	24.7f	25.2d	18.8d
No-till (Baled)	30.0b	27.3bc	52.5a	31.7e	27.7cd	35.7c
No-till (Bare)	37.7a	31.9bc	54.8a	38.4d	31.4bc	38.5bc

+Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 12. **Tillage and straw management system effects on in-row daily mean mininum and maximum soil temperature and accumulated growing degree days (GDD) for the first 5 weeks following corn planting at Centralia during 1996.**

Tillage/Straw Management	Minimum	Maximum	Growing Degree Days
	---------------- °C	------------------	GDD
Fall Moldboard	16.0a+	23.0ab	342a
Fall Disc	15.2a	22.6b	322b
Fall Zone-till	15.9a	22.8ab	336ab
No-till (Not Baled)	15.6a	20.7c	294c
No-till (Baled)	15.9a	22.5b	331ab
No-till (Bare)	15.9a	23.4a	345a

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 13. **Tillage and straw management system effects on corn plant mass 7 wk after planting.**

Tillage/Straw	Centralia			Wyoming		
Management	1994	1995	1996	1994	1995	1996
	------------------------------		g $plant^{-1}$	--------------------------------		
Fall Moldboard	37.8a+	11.9a	23.7a	50.7a	9.6a	34.2a
Fall Chisel	37.4a	8.0cd	26.9a	48.5a	9.0ab	33.5a
Fall Disc	37.4a	9.4bc	20.0ab	50.5a	8.1ab	33.3a
Fall Zone-till	36.7a	8.9bc	21.7ab	48.2a	9.1ab	35.9a
No-till (Not Baled)	26.7b	4.8e	13.6b	48.0a	5.5c	22.1b
No-till (Baled)	28.3b	6.5de	25.2a	47.3a	7.9b	31.7a
No-till (Bare)	36.9a	9.8b	25.9a	49.8a	7.9ab	34.5a

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 14. Tillage and straw management system effects on corn plant population and harvest grain moisture averaged over 1994-96.

Tillage/Straw	Plant Population		Grain Moisture	
Management	Centralia	Wyoming	Centralia	Wyoming
	--------- 1000 pl ha^{-1} ---------		-------- % ---------	
Fall Moldboard	71.7a[+]	68.6a	25.5c	27.8b
Fall Chisel	69.6a	68.1a	25.8c	28.3b
Fall Disc	69.3a	70.2a	26.8b	27.4b
Fall Zone-till	71.3a	73.5a	25.5c	27.4b
No-till (Not Baled)	66.1a	67.6a	28.4a	29.7a
No-till (Baled)	69.9a	71.3a	26.2bc	27.9b
No-till (Bare)	71.8a	70.9a	25.6c	27.3b

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 15. **Tillage and straw management system effects on grain corn yield adjusted to 15.5% moisture content.**

Tillage/Straw Management	1994	1995	1996	Mean
Centralia	---------------------- t ha^{-1} ---------------------			
Fall Moldboard	8.24ab[+]	9.61a	9.77a	9.20a
Fall Chisel	8.34a	9.35a	8.64c	8.78bc
Fall Disc	8.34a	9.23ab	9.09bc	8.89ab
Fall Zone-till	8.00ab	9.38a	8.83c	8.74bc
No-till (Not Baled)	7.18c	8.34c	8.14d	7.89d
No-till (Baled)	7.63bc	8.44bc	9.44ab	8.50c
No-till (Bare)	7.83abc	9.22ab	9.56ab	8.87abc
Wyoming				
Fall Moldboard	11.75a	7.78a	10.47a	10.00a
Fall Chisel	11.30ab	7.83a	10.08a	9.73ab
Fall Disc	11.42ab	7.59ab	10.60a	9.87a
Fall Zone-till	11.09ab	7.56ab	11.32a	9.99a
No-till (Not Baled)	10.13c	6.81c	10.57a	9.17c
No-till (Baled)	10.71bc	7.19bc	10.25a	9.38bc
No-till (Bare)	11.22ab	7.58ab	11.01a	9.94a

\+ Within column means for each location followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 16. Correlations between corn plant mass 7 weeks after planting or grain yield with the in-row proportion of fine aggregates (<5mm) and soil resistance at shallow (1.5 to 4.5cm) and deep (10.5 to 13.5cm) tillage depths.

Location		Fine Aggregates	Soil Resistance	
Year	Corn Response	<5mm	1.5 - 4.5cm	10.5 - 13.5cm
Centralia			------------ r -----------	
1994	Biomass at 7 wk	0.72**	-0.47*	-0.18
	Yield	0.39*	-0.27	0.12
1995	Biomass at 7 wk	0.76**	-0.55**	-0.17
	Yield	0.66**	-0.33	-0.03
1996	Biomass at 7 wk	0.50**	-0.25	-0.31
	Yield	0.63**	0.15	0.03
Wyoming				
1994	Biomass at 7 wk	0.45*	-0.01	-0.01
	Yield	0.49**	-0.01	-0.22
1995	Biomass at 7 wk	0.43*	-0.41*	-0.23
	Yield	0.58**	-0.33	-0.02
1996	Biomass at 7 wk	0.54**	-0.03	0.18
	Yield	-0.05	0.15	0.06

* ,** indicate correlations (n=28) that are statistically significant at the 5% and 1% level of probability, respectively.

Table 17. Tillage and straw management system effects on soybean plant population

Tillage/Straw Management	Centralia 1994	Centralia 1995	Centralia 1996	Wyoming 1994	Wyoming 1995	Wyoming 1996
	---------------------------- 1000 pl ha^{-1}			-------------------------------		
Fall Moldboard	313b[+]	334bcd	330b	276b	339bc	360b
Fall Chisel	316b	354bc	267bcd	275b	344bc	318bc
Fall Disc	293bc	356b	222d	306b	350b	337bc
Fall Zone-till	293bc	339bc	293bc	329b	352b	330bc
No-till (Not Baled)	260c	304d	106e	317b	314c	76d
No-till (Baled)	278bc	324cd	256cd	314b	344bc	296c
No-till (Bare)	299bc	350bc	280bcd	321b	368b	336bc
No-till (Baled 38 cm)	444a	648a	432a	457a	656a	508a

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 18. Tillage and straw management system effects on above-ground soybean biomass 7 weeks after planting.

Tillage/Straw Management	Centralia 1994	Centralia 1995	Centralia 1996	Wyoming 1994	Wyoming 1995	Wyoming 1996
	--------------------------biomass g m^{-2}			----------------------------		
Fall Moldboard	186bc[+]	165a	77a	144b	143a	98b
Fall Chisel	189b	164a	86a	147b	105bc	98b
Fall Disc	164cd	120b	58b	143b	109bc	113b
Fall Zone-till	170bcd	121b	52b	142b	104c	104b
No-till (Not Baled)	135e	81c	17c	115d	58d	20d
No-till (Baled)	156de	96bc	51b	131c	99c	76c
No-till (Bare)	166cd	125b	86a	144b	125ab	115b
No-till (Baled 38 cm)	258a	167a	82a	232a	137a	151a

\+ Within column means followed by the same letter are not statistically different according to the protected LSD test at the 5% level of probability.

Table 19. Tillage and straw management system effects on soybean seed yield adjusted to 14.0% moisture.

Location Tillage	1994	1995	1996	Mean
Centralia	------------------ t ha^{-1} -----------------			
Fall Moldboard	2.99b+	3.25a	3.22a	3.15ab
Fall Chisel	3.03b	3.27a	3.33a	3.21ab
Fall Disc	2.81c	2.81b	3.14a	2.92c
Fall Zone-till	2.80c	2.92ab	3.20a	2.97c
No-till (Not Baled)	2.45e	2.33c	1.53b	2.10e
No-till (Baled)	2.61d	2.35c	3.17a	2.71d
No-till (Bare)	2.75cd	3.04ab	3.40a	3.06bc
No-till (Baled) 38cm	3.40a	3.11ab	3.32a	3.28a
Wyoming				
Fall Moldboard	3.88ab	2.99ab	3.78d	3.55b
Fall Chisel	3.83b	2.78bc	3.82cd	3.47bc
Fall Disc	3.91ab	2.87bc	3.97abc	3.58b
Fall Zone-till	3.81b	2.83bc	3.83bcd	3.49bc
No-till (Not Baled)	3.46d	2.44d	1.61e	2.50d
No-till (Baled)	3.51cd	2.75c	3.86bcd	3.38c
No-till (Bare)	3.81bc	2.92abc	4.00ab	3.57b
No-till (Baled 38 cm)	4.14a	3.11a	4.13a	3.79a

\+ Within column means for each location followed by the same letter are not statistically different at the 5% level of probability.

Table 20. Correlations between wide-row soybean plant mass 7 weeks after planting and grain yield with the in-row proportion of fine aggregates (<5mm) and soil resistance at shallow (1.5 to 4.5cm) and deep (10.5 to 13.5cm) tillage depths.

Location		Fine Aggregates	Soil Resistance	
Year	Soybean Response	<5mm	1.5 - 4.5cm	10.5 - 13.5cm
Centralia			------ r -------	
1994	Biomass at 7 wk	0.75**	-0.30	-0.65**
	Yield	0.75**	-0.42*	-0.65**
1995	Biomass at 7 wk	0.73**	-0.26	0.00
	Yield	0.66**	-0.19	-0.01
1996	Biomass at 7 wk	0.48*	-0.13	-0.15
	Yield	0.54**	0.16	0.15
Wyoming				
1994	Biomass at 7 wk	0.78**	-0.31	0.00
	Yield	0.56**	-0.36	-0.05
1995	Biomass at 7 wk	0.57**	-0.59**	0.25
	Yield	0.31	-0.41*	0.16
1996	Biomass at 7 wk	0.58**	-0.04	0.65**
	Yield	0.66**	0.06	0.70**

*,** indicate correlations (n=28) that are statistically significant at the 5% and 1% level of probability, respectively.

Figure 8. Tillage Effects on Penetrometer Resistance at Centralia (1994 - 96)

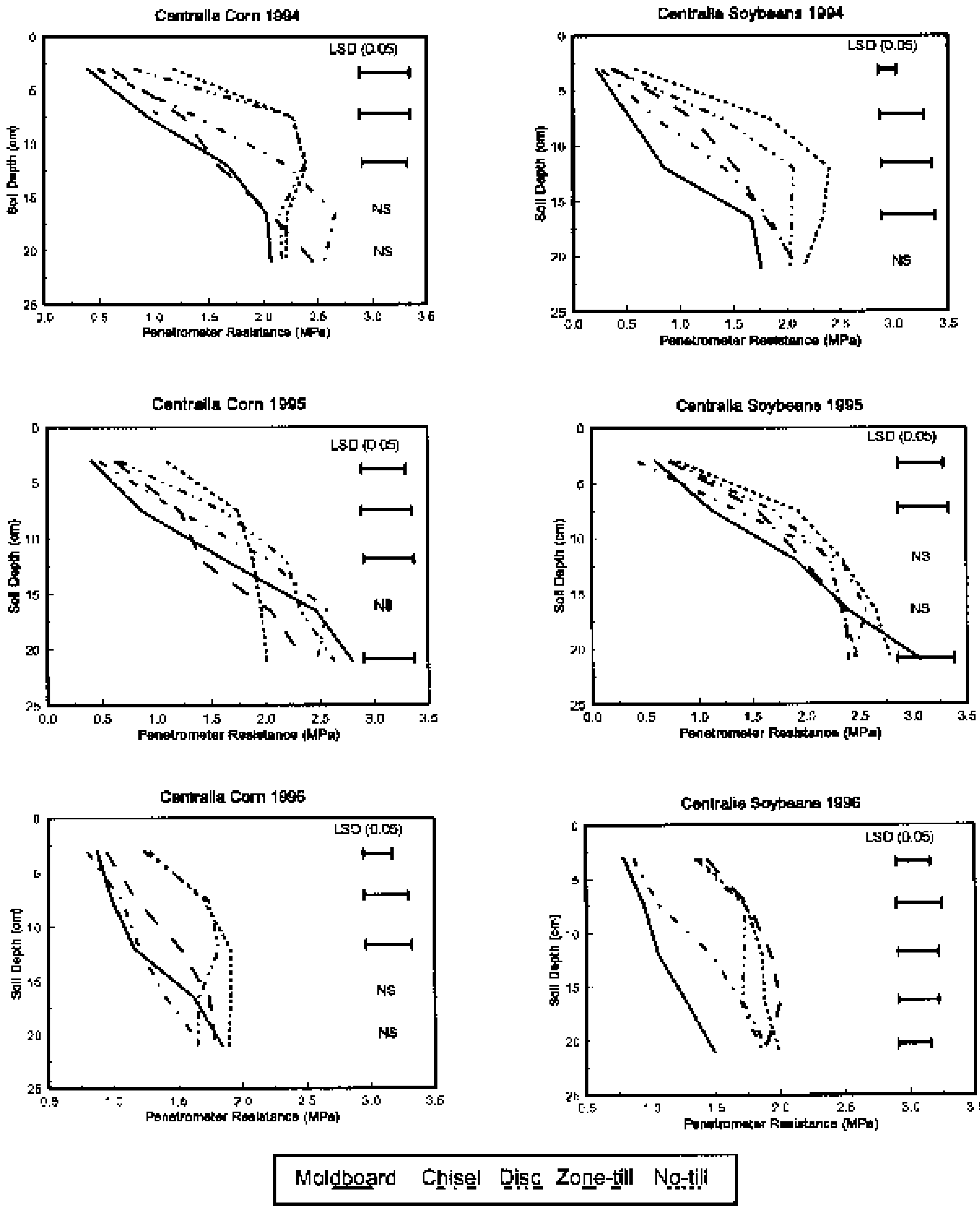
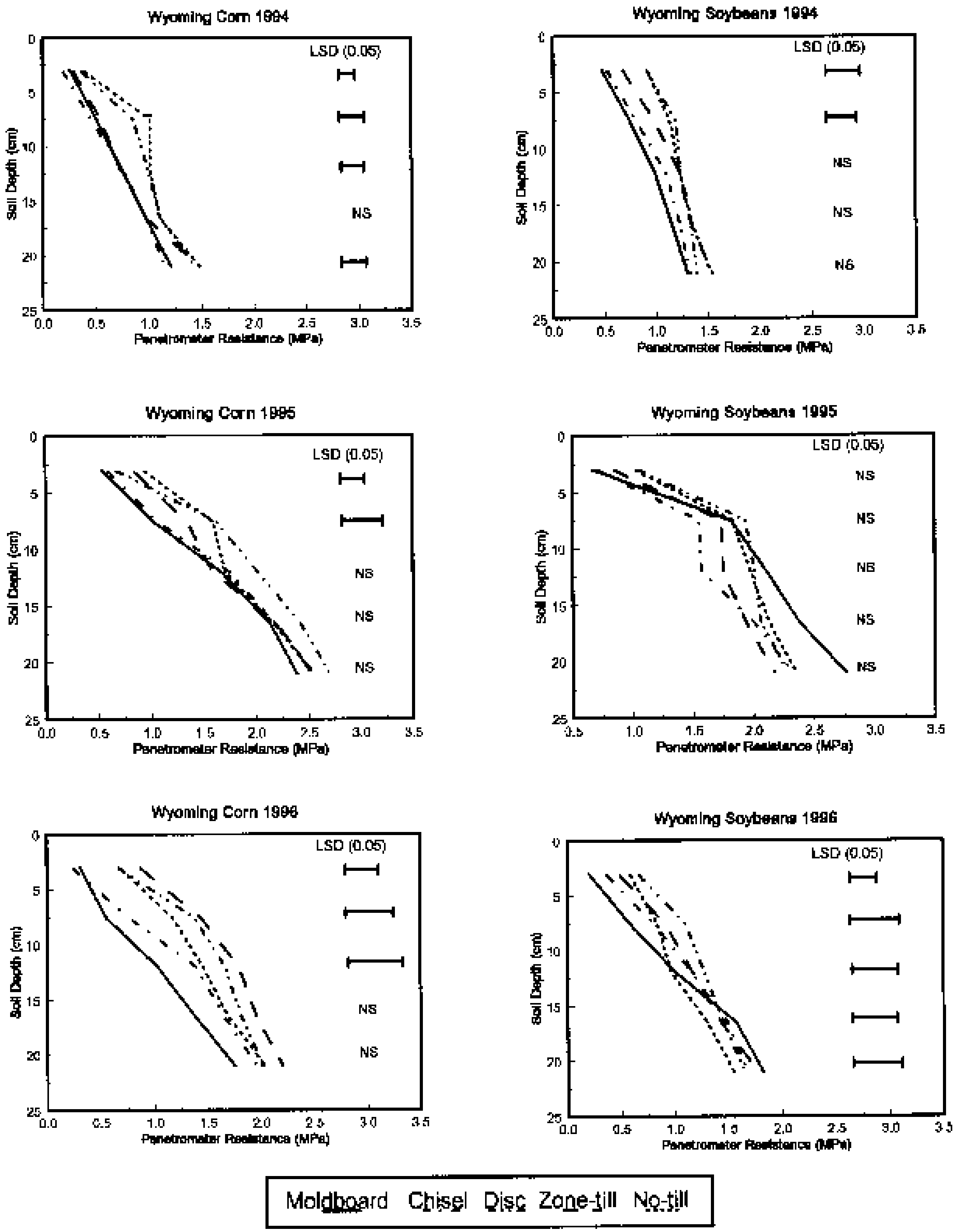


Figure 9. Tillage Effects on Penetrometer Resistance at Wyoming (1994 - 96)



OBJECTIVE C: WEED SEEDBANKS AND SEEDLING EMERGENCE

RESEARCH OBJECTIVES

Research in this objective evaluated the short-term effects of newly adopted conservation tillage systems on 1) weed seedbank decline and 2) the vertical distribution of weed seeds. Tillage and preceding crop effects on weed seedling emergence were also to be evaluated in this objective. We attempted to evaluate weed seedling emergence during 1994 and 1995, however, sample sizes were not large enough to allow for statistical comparisons. Therefore attempts to evaluate tillage and preceding crop effects on weed seedling emergence on clay soils were discontinued.

METHODOLOGY

Seed banks were sampled on the Alvinston site described in Objective A following both corn and soybeans for the following tillage systems: 1) Fall Moldboard; 2) Fall chisel; 3) Spring Aerway and 4) No-till (coulters). For a detailed description of these tillage systems see the methodology section for Objective A. We chose these four tillage systems to establish a wide range of disturbance for comparative purposes. Using a hand-corer, we sampled the seedbank in May 1994 and May 1996 for each of the corn and soybean fields. Twenty soil cores per plot were removed using a W-shaped sampling grid. The cores were divided into three 5 cm layers to analyze vertical seed distribution and placed in containers in a growth room. Seeds in the sample were germinated for 3 months and then were cold-stratified for 3 months. The seeds then were germinated for 2-3 additional months. To germinate seeds, we mixed the soil cores with promix (1 part promix for 4 parts soil core), put each core in a separate cell within a potting flat, and watered the seeds every 3 days. We then remixed (stirred) the cores every month to prevent the soil from becoming abnormally compacted (even for clay soils). In 1996, we modified the germination procedure by adding the 1:4 (promix:soil core) ratio every month during remixing and enlarging the drainage holes in the potting flats to reduce the possibility of anoxia caused by super-saturation of soil during normal watering.

Data was analyzed using ANOVA appropriate for a blocked split-plot design (means separated with Tukey's Honestly Significant Difference; $HSD_{0.05}$) to compare the numbers of weed seeds that germinated in response to different tillage practices (sub-plots) and rotation sequences (whole plot blocks) and to compare if the percentage of weed seeds varied with sampling depth (and any interactions with tillage, rotation [block], or year). Percentage data were arcsine-square root transformed for normality.

Weed species diversities (in response to year, tillage practice, rotation sequence, and sampling depth) were analyzed using a block split-plot ANOVA (Tukey's HSD) of values of the Shannon-Weiner diversity index (H'). The Shannon-Wiener diversity index (H') is $-\Sigma[p_i(\ln p_i)]$, where $p_i = n_i/N$, the proportional abundance of a species (i), n_i = # of individuals of a species (i), and N = total # of individuals of all species. H' represents both "numerical species richness" (species density, the number of species per number of sampled individuals, number of species) and species evenness (how many of each species exist in a sample, i.e. how abundant or common is each species). ANOVAs are possible because the variance for Shannon-Weiner values are calculable as
$H'_{var} = N^{-1}\{\Sigma p_i(\ln p_i)^2 - [\Sigma p_i(\ln p_i)]^2\} - \{(2N^2)^{-1}[S-1]$, where S = total number of species in a sample).

RESULTS AND DISCUSSION

How does the adoption of different conservation tillage practices affect the weed spectrum?

To summarize a rather complicated number of possible permutations, we have presented the weed species diversity values without comment in Tables 21 and 22. The main results were:

A) Generally, there were no significant differences in weed species diversity caused by the rotation sequence, i.e. the same trends occurred for both corn and soybeans. The one exception was that weed species diversity increased between 1994 and 1996 only in the corn plots (Table 21).

B) Aggregate (total) weed species diversity tended to increase among tillage systems in the order of fall moldboard plow, fall chisel plow, no-till (coulters) and spring Aerway in 1994. In 1996, weed species diversity differences among tillage systems was significant and was ranked fall moldboard plow < fall chisel plow < no-till (coulters) = spring Aerway.

C) weed species diversity increased significantly from 1994 to 1996 in the no-till (coulters) and spring Aerway tillage systems within the 0-5 cm layer and decreased significantly in the 5-10 and 10-15 cm layers. There was also a significant increase in weed species diversity in the 0-5 cm layer within the fall chisel plow system between 1994 and 1996 in soybean (temporal changes in weed species diversity in corn could not be analyzed because the sample size for the fall chisel plow system was zero in 1994). Weed species diversity did not change significantly within the fall moldboard plow system between 1994 and 1996 except in corn within the 0-5cm depth interval; this exception is an artifact of the small sample size (1 seed) in 1994.

D) There were significantly more weed species in the 0-5 cm layer of soil in the no-till (coulters) or spring Aerway systems than in the fall chisel plow or fall moldboard plow systems in 1996. In 1996, there were significantly more weed species in the 10-15 cm layer in the fall moldboard and fall chisel plow systems than in either the no-till (coulters) or spring Aerway systems.

Unless otherwise indicated, all of these results were based on our use of a split-plot ANOVA with Tukey's $HSD_{0.05}$.

In 1994, the weed spectrum was dominated by redroot pigweed (*Amaranthus retroflexus*), velvetleaf (*Abutilon theophrasti*) and ragweed (*Ambrosia artemisiifolia*). These species accounted for 47.9%, 13.8% and 11.4% of all weed seeds that germinated, respectively. Other species that germinated included white clover (*Trifolium repens*), lamb's-quarters (*Chenopodium album*), annual sow-thistle (*Sonchus arvensis*), green foxtail (*Setaria viridis*) and black nightshade (*Solanum nigrum*). By 1996, the dominant species (of the seedbank) in the no-till (coulters) and spring Aerway systems had become lamb's-quarters (37.9% and 31.1% of all weed species that germinated within these systems, respectively). In the no-till (coulters) system there was a more even distribution of weed seed germination (i.e. the 8 species listed above tended to be equally represented in our samples).

In 1996, we detected barnyardgrass (*Echinochloa crus-galli*) and quackgrass (*Elytrigia repens*) in the no-till (coulters) and spring Aerway systems. These changes account for some portion of the significant increases in weed species diversity from 1994 to 1996 in the fall chisel plow, no-till (coulters) and spring Aerway systems (Tables 21 and 22). Most of the changes in weed species diversity within the no-till (coulters) and spring Aerway systems indicate that more weeds were found in the top 0-5 cm of soil and were becoming eliminated from the other two depths sampled. In other terms, weed species diversity was correlated ($r^2 = 0.96$, $\underline{P} < 0.001$) with the number of weed seeds germinated. There had been trends towards higher species diversity (across all depths sampled) in the fall chisel plow, no-till (coulters) and spring Aerway systems in 1994 (Tables 21 and 22) but the high variances (not shown) of the values of H' meant that the differences in species diversity (weed spectrum) were not significant at that time.

How do changes in the weed spectrum caused by changing tillage practices affect the ability to manage weed seed banks?

After 3 years of tillage operations, weed seeds in the fall chisel plow, no-till (coulters) and spring Aerway systems were concentrated in the upper 5 cm of soil (Tables 23 and 24). In the no-till (coulters) and spring Aerway systems, over 60% of all weed seeds that germinated were from the upper 5 cm of soil (Tables 23 and 24). The increase in the number of weed seeds that germinated in 1996 does not appear to represent a sudden increase in the actual number of weed seeds in the soil but probably reflects our refined (improved) technique of seed germination (see methods). In support of this hypothesis, our visual inspections in 1994, 1995, and 1996 indicated there was no increase in above-ground weed biomass or numbers in the field (data not shown). The reduction of the numbers (relative percentage) of weed seeds in the 10-15 cm layer indicates that farmers using either no-till or shallow tillage systems (eg. Aerway) should be able to deplete the weed seedbank at this level. If the seeds from layers above 10 cm depth produce seedlings that either are destroyed naturally or are able to be controlled with one timely, economical intervention, then fewer weeds will set seed.

Do producers need to be concerned with the effect of the type of crop rotation on weed spectra under different tillage practices?

With the one artifactual exception (see Table 21), we did not detect any significant effects of the cropping sequence (order) of the corn-soybean rotation used (see Tables 21-24). For clarity, we did not explicitly comment on all possible analyses of rotational effects in Tables 21-24; however, inspection of these tables illustrate that there were no effects of the crop (corn versus soybean) on our results. This was expected because the blocking effects were arbitrary and there did not appear to be large-scale differences in the physiography between the corn and soybean blocks.

Why are these phenomena occurring?

Differences in diversity of the weed seedbank may be related to differing rates of seed mortality among tillage systems. Generally, adoption of alternative tillage systems results in altered weed species composition and abundance (Froud-Williams 1988, Cousens and Moss, 1990, Cardina et al. 1992, Frick and Thomas 1992, Derksen et al. 1993, Kapusta and Krausz 1993, Swanton et al. 1993, Thomas and Frick 1993) but this usually takes between 3-10 years to become detectable (Gebhardt et al. 1985, but see Benoit et al. 1991). In conventional tillage, many weed species rely on a single regenerative strategy consisting of germination from a large, persistent soil seedbank. Part of the reason the seedbank is persistent is that most seeds are buried by moldboard plowing (Cousens and Moss 1990, Ball 1992, Cardina et al. 1992, Yenish et al. 1992). For many species, buried seeds remain viable and will germinate in subsequent years when returned to a suitable depth by tillage. In contrast, seeds remain on or near the soil surface in less disturbed soils in alternative tillage systems (Ball 1992, Cardina et al. 1992, Yenish et al. 1992, Mohler 1993, Swanton et al. 1993). Adequate aboveground weed control may cause seeds present in the upper layer of soil to diminish within a few years because the seeds become desiccated, germinate homogeneously (making it easier to eliminate more weeds with a single control action), emerge concurrently where increased seedling competition causes more weeds to die before reaching maturity, or are more susceptible to herbivory or pathogenic destruction (Clements et al. 1994, 1996, Swanton and Murphy 1996a,b). Thus, species that rely on regeneration from seedbanks and historically have been problematic in conventional tillage systems may become less of a problem in alternative tillage systems (Clements et al. 1994, 1996, Swanton and Murphy 1996a,b). There are indications that weed species such as redroot pigweed and lamb's-quarters have a more predictable and reduced rate of successful germination and field emergence in alternative tillage systems (Swanton and Murphy 1996, Oryokot et al. 1997a,b, C. J. Swanton, unpub. data). We had initially designed our experiment to test this at the Alvinston site but could not because there were relatively few weeds emerging to permit a sufficient sample for statistical analysis. We caution that this is atypical of most farms in clay soil regions and has few implications beyond our inability to complete a field emergence trial in this particular study.

CONCLUSIONS

In spite of its potential importance in determining relative weed pressures among different tillage regimes, relatively few studies have accounted for vertical distribution of weed seeds in the soil. This is especially true in clay soils because of the difficulties in adopting non-conventional tillage practices. Our study indicates that most of the seeds become concentrated in the upper 5 cm of soil even after only 3 years. We caution that although this generally means that these seeds are more likely to be destroyed by desiccation, competition or herbivory, we need to test these hypothesis further because the water content in clay soils may alter the outcome of changes in the vertical profile of weed seeds. For example, will the weed seeds in the upper 5 cm of moisture-laden clay soils become anoxic and die or will they adapt and become more likely to germinate? Our study also indicates a rapid increase in weed species diversity occurred as early as 3 years after beginning either a no-till (i.e. no-till (coulters)) or shallow tillage (i.e. spring Aerway) tillage system.

This increase in weed seedbank diversity was not accompanied by an increase in above-ground weed biomass or diversity. Again, the implications of this change are unclear. It may mean that interspecific weed species competition will reduce the chances of an uncontrollable weed mono- or di-culture. It may also mean that more weed species can potentially adapt to clay soils. Finally, the idea of increased ability to control homogeneously emerging weed species with one timely intervention is excellent in theory but its success depends on the ability of farmers to predict when this will occur and whether farmers can get access to heavy clay soils when most weeds are germinating. The problem of predicting germination currently is being investigated with weed modelling (Swanton and Murphy 1996, Oryokot et al. 1997a,b); the problems of equipment access are equally complicated but are also being addressed. As with all research, we do not expect this study to be a panacea but rather one step in developing a more economical, efficient and environmentally benign farming system to be used in areas with clay soils.

Table 21. Changes in weed species diversity, relative to the tillage system and sampling depth, between 1994 and 1996 in soybean fields at Alvinston, Ontario. Diversity was measured using the Shannon-Wiener diversity index. The crop rotation used (1993-1996) was corn-soybean-corn-soybean.

Tillage system	Aggregate weed species diversity		Weed species diversity with each sampled depth					
			0-5 cm		5-10 cm		10-15 cm	
	1994	1996	1994	1996	1994	1996	1994	1996
Fall Moldboard	1.314	1.418	1.288	1.219	1.356	1.671	2.251	2.192
Fall Chisel	1.908	2.203	1.997	2.389	2.074	2.044	1.764	1.181
No-till (coulters)	2.361	3.972	2.176	4.133	2.502	1.871	2.461	1.009
Spring Aerway	2.181	4.006	2.231	4.451	2.264	1.238	2.101	1.689

Table 22. Changes in weed species diversity, relative to the tillage system, and sampling depth, between 1994 and 1996 in corn fields at Alvinston, Ontario. The crop rotation used (1993-1996) was soybean-corn-soybean-corn.

Tillage system	Aggregate weed species diversity		Weed species diversity within each depth sampled					
			0-5 cm		5-10 cm		10-15 cm	
	1994	1996	1994	1996	1994	1996	1994	1996
Fall Moldboard	0.000	1.217	0.000	1.346	-	1.161	-	2.808
Fall Chisel	1.004	2.312	-	2.379	1.409	2.761	1.561	2.531
No-till (coulters)	2.171	4.176	1.807	4.421	2.310	1.167	2.681	0.706
Spring Aerway	2.099	4.220	2.514	4.459	1.906	1.162	2.144	0.224

Table 23. Changes in the number of weed seeds germinating, relative to the tillage system and sampling depth, between 1994 and 1996 in soybean fields at Alvinston, Ontario. The crop rotation used (1993-1996) was corn-soybean-corn-soybean.

Tillage system	Total number of weed seeds that germinated (all depths sampled)		% of germinated weed seeds from each sampled depth					
			0-5 cm		5-10 cm		10-15 cm	
	1994	1996	1994	1996	1994	1996	1994	1996
Fall Moldboard	36	127	22.2	26.0	55.6	54.3	22.2	19.7
Fall Chisel	22	118	36.4	54.4	36.4	23.6	27.2	22.0
No-till (coulters)	48	129	33.3	62.7	20.9	31.0	45.8	6.2
Spring Aerway	30	112	33.3	66.9	36.7	24.2	30.0	8.9

Table 24. Changes in weed seed germination, relative to the tillage system and sampling depth, between 1994 and 1996 in corn fields at Alvinston, Ontario. The crop rotation used (1993-1996) was soybean-corn-soybean-corn.

Tillage system	Total number of weed seeds that germinated (all depths sampled)		% of weed seeds emerging from depth sampled					
			0-5 cm		5-10 cm		10-15 cm	
	1994	1996	1994	1996	1994	1996	1994	1996
Fall Moldboard	1	91	100.0	24.2	0.0	45.0	0.0	30.8
Fall Chisel	7	89	0.0	48.3	42.9	23.6	57.1	28.1
No-till (coulters)	8	108	12.5	63.0	37.5	30.5	50.0	6.5
Spring Aerway	15	91	20.0	62.8	6.7	35.2	73.3	2.2

OBJECTIVE D:
WEED CONTROL STRATEGIES FOR REDUCED-TILL SOYBEANS

RESEARCH OBJECTIVES

The experiments in this objective were designed to evaluate the impact of 1) a spring killed winter rye cover crop which was seeded after soybean harvest the previous fall and 2) row width on weed management strategies and yield for soybeans planted no-till on clay textured soils. Weed management strategies examined were 1) glyphosate burn-down only; 2) broadcast pre-emergent and post-emergent herbicides and 3) row cultivation with and without banded pre-emergent herbicides (wide-row only).

METHODOLOGY

The field trials were established in 1993, 1994, and 1995 at sites near Southwold, Middlesex Co., and Alvinston, Lambton Co. At Southwold the soil was a clay (9% sand, 39% silt, 52% clay, 5.4% organic matter and pH 6.5), and at Alvinston the soil was a silty clay (10% sand, 47% silt, 44% clay, 5.6% organic matter and pH 6.6). There was a minimum two year history no-till at both locations at the onset of the experiment. Soybeans were the previous crops at both locations.

Treatment Description

Selected combinations of weed control treatment and rye cover crop were compared in wide (76cm) and narrow (19cm) row soybeans. The experiment consisted of a total of 18 treatments arranged in a randomized complete block design with 4 replications. Plots were 3 m wide by 15 m long.

Herbicide treatments consisted of: Imazethapyr (Pursuit) at 75 g/ha plus 480 g/ha of metribuzin (Sencor), applied preemergence 1) broadcast in both wide and narrow rows, or 2) in a 30 cm band over the crop row plus 2 inter-row cultivations in wide rows only. 3) Acifluorfen (Blazer) at 150 g/ha plus 840 g/ha of bentazon applied postemergence when soybeans had one to two trifoliate leaves and common ragweed seedlings had 2-to-8 leaves. In 1996 only, 96 g/ha of quizalofop-ethyl (Assure) was tank-mixed with the postemergence treatment to control annual grass weeds at both locations. 4) Inter-row cultivation (x2) in wide rows only. 5) Glyphosate (Roundup) applied preplant in the spring to control the over-wintered rye and established weeds. This was included as a separate treatment and was applied over all other treatments, except 6) An untreated weedy control without rye was included for both wide and narrow rows.

All herbicides were applied in 200 L/ha of water at a pressure of 180 kPa using a bicycle wheel plot sprayer. Broadcast treatments were applied with SS8002LP spray tips and banded treatments applied with SS8001E spray tips. Inter-row cultivations were performed in early and late July using a Hinnicker four-row, cultivator with 50cm sweeps and ridging discs, set to operate at a depth of 3-to-5 cm.

All field operations in each year were conducted on the same day at each location. Rye (common seed) was seeded in 20 cm rows at 125 kg/ha with a Tye no-till drill in mid-October after the previous soybean crop was harvested. Glyphosate was applied preplant at 0.9 kg/ha on May 25, 18, and 26, in 1994, 1995, and 1996, respectively, to all plots except the weedy treatments, to control the over wintered rye cover crop and common ragweed seedlings. At the time of spraying, the rye was 23-to-73 cm tall and common ragweed seedlings were at the cotyledon-to-two leaf growth stage. Soybean c.v. S20-20 was planted in 19 cm and 76 cm row spacings on May 30 1994, May 23 1995 , and June 5 1996. In narrow rows, soybeans were planted at populations of 70 seeds/m^2, with a 750 John Deere no-till drill. In wide rows, soybeans were planted at populations of 45 seeds/m^2, with a John Deere 7000 corn planter, equipped with notched disc (1994) or finger (1995 and 1996) row-cleaners and a 5cm wavy coulter for in-row zone tillage.

Rye, Soybean and Weed Measurements

Rye shoot biomass and contribution to ground cover was assessed in mid-November and at the time of soybean planting. Biomass production was determined from 4 randomly selected 0.3 m^2 quadrats. A modified line transect method was used to determine % ground cover. The influence of rye cover crop and soybean row width on soybean growth and development was evaluated under the relatively weed-free conditions obtained in the glyphosate plus broadcast preemergence herbicide treatments. The rate of soybean emergence as a % of the final population was determined 2 weeks after planting. In mid-August soybean plant population, height, and leaf area, and leaf area index were measured in 1 m^2 quadrats in these treatments. At the same time, the amount of light available as photosynthetic photon flux density (PPFD) to weeds growing under the soybean canopy was measured using a quantum line sensor placed diagonally between rows. The influence of rye cover crop residue and soybean row width was determined in the relatively weedy glyphosate only treatments.

Weed control

Permanent 0.23 m^2 quadrants were established in the weedy controls in early May to monitor weed seedling emergence during the season. Weed seedlings were counted by species and removed at weekly intervals. In mid-August weed biomass was harvested in 0.46 m^2 quadrats in all treatments.

Statistical Analysis

All data were analyzed across years and locations to detect significant interactions in crop response to row width, rye cover crop and weed control treatments. Where interactions were not significant ($P>0.05$), main effects only are presented. Weed biomass data was log(10) transformed to obtain homogeneity of variances for ANOVA . Transformed means were separated using Duncan's multiple range test ($P<0.05$). Means were re-transformed and presented as % of the weedy control.

Economics of weed control.

The profitability of weed control treatments in wide and narrow row soybeans was calculated using E Plus^tm^. A soybean selling price of $312/t was used and all production input costs were considered except land costs (Appendix 1). Statistical comparisons of the 3 year average yields were made by ANOVA using yield means for each year x location as replicates.

RESULTS AND DISCUSSION.

Weather Patterns

In both 1995 and 1996 heavy rainfall occurred in the week following planting at both locations, causing soil crusting and reduced soybean emergence. In 1995 at Southwold, localized flooding resulted in the loss of two of the four treatment replications at that site.

Rye cover crop.

What does a producer gain in terms of residue cover by utilizing cover crops and reduced tillage following soybeans?

Rye growth was rapid in the spring and contributed 0.34 to 2.91 t/ha of organic material to the soil. However, in the fall of establishment, rye produced only 35 to 57 kg/ha of biomass by mid-November. Furthermore, incorporation of previous crop residue by the rye drill caused a 3 to 25% reduction in ground cover compared to plots without rye. The presence of the rye cover crop residue had no significant effect on weed biomass at either location. Soybean emergence, final plant populations, and seed yields were not significantly influenced by the presence of rye residue (Table 25).

Soybean row width.

Soybean yields were 18% greater when grown in narrow rows (Table 26). Yield differences were consistent across years and locations and no significant interactions were detected. Uniform seed placement and covering resulted in more rapid emergence of soybeans planted in wide rows than drilled narrow row soybeans. Final plant populations were 40% greater in narrow rows as a result of higher seeding rates. Soybean plant height and leaf area in mid-August was not influenced by row width. However, planting pattern and higher populations resulted in a canopy leaf area index 27% greater in narrow row soybeans than wide row soybeans. The more developed soybean canopy in narrow rows reduced the amount of light (PPFD) available to weeds growing below the crop canopy by 76% compared to wide rows. As a result, weed biomass in the narrow glyphosate only treatment was reduced by 71% compared to wide rows.

Weed control. *What is the most practical/economical weed management strategy for soybeans grown in reduced tillage systems?*

Strategic timing of the glyphosate burn-down was critical to the success of reduced herbicide treatments in no-till soybeans. Approximately 90% of all common ragweed (*Ambrosia artemisiifolia*) seedlings had emerged at the time the preplant burn-down treatment was applied, and were controlled with glyphosate alone (Figure 10). Common ragweed was the predominant species at both locations and in all years with populations of 67 to 277 seedlings/m^2 emerging in the weedy control. Ragweed accounted for 93%, 75%, and 42% of the total uncontrolled weed population at Alvinston, and 92%, 96%, and 64% at Southwold, in 1994, 1995, and 1996 respectively.

At Alvinston in 1995, a total of 40 lamb's quarters (*Chenopodium album*) seedlings/m^2 emerged in the weedy control. Emergence was similar to ragweed, and 86% of the lamb's quarters seedlings emerged before the glyphosate burn-down was applied. In 1996 significant populations of barnyard grass (*Echinochloa crus-galli*) (39/m^2) were present at Alvinston and green foxtail (*Setaria viridis*) (84/m^2) at Southwold. Unlike the broadleaf weeds present, barnyard grass and green foxtail seedlings emerged relatively late. Only 26% of the barnyard grass seedlings and 6% of green foxtail seedlings had emerged when the glyphosate burn-down treatment was applied. Residual soil applied or postemergence treatments were required to control these late emerging species.

Weed control was better in narrow row soybeans as a result of the more developed leaf canopy but was not influenced by rye cover crop residue (Table 27). Total weed biomass was 41% less in narrow rows than wide rows with glyphosate alone. The benefit of narrow rows for weed suppression increased with reduced herbicide use. Average soybean yields were 18% greater in narrow rows compared to wide rows with the broadcast treatment of imazethapyr plus metribuzin but were 39% greater with glyphosate alone and 58% when weeds were uncontrolled (Table 28). In narrow rows, glyphosate alone provided 83% control of total weed biomass and provided 85% of the maximum soybean yield. A broadcast preemergence combination of imazethapyr plus metribuzin gave greater total weed control but similar soybean yields across all years and locations than acifluorfen plus bentazon applied post emergence.

The broadcast postemergence treatment of acifluorfen plus bentazon was less effective in wide rows. Weed biomass was 8% greater and soybean yield reduced by 9% compared to the broadcast preemergence treatment. Weeds emerging after the postemergence treatment was applied may have been more effectively suppressed by the narrow row soybean canopy. Herbicide use was minimized in the integrated treatment of banded herbicide plus inter-row cultivation which gave similar weed control and soybean yields as the broadcast preemergence treatment. Herbicide use was reduced by 60% with the banded treatment while maintaining commercially acceptable weed control. Soybean yields representing 86% of the maximum potential wide row yield were obtained, using a combination of preplant applied glyphosate plus inter-row cultivation, without any residual or in-crop herbicide.

Economics of weed control. *Can producers economically justify soybean production in wide rows in order to facilitate mechanical weed control?*

Narrow row soybeans were more profitable than wide row soybeans (Table 29). The average profit for all broadcast herbicide treatments was 27% greater when soybeans were grown in 19cm rows. Broadcast imazethapyr plus metribuzin, the most profitable treatment in narrow rows, provided a return of $116/ha greater than in wide rows. Glyphosate alone, provided 98% of the maximum potential profit that was obtained in narrow rows. In 76cm row soybeans, glyphosate alone provided 75% of the maximum profit that was obtained. The most profitable treatment in wide rows was the integrated control treatment of imazethapyr plus metribuzin applied preemergence in a 30cm band plus inter-row cultivation.

CONCLUSIONS AND RECOMMENDATIONS

From a weed control perspective, the use of rye as a cover crop appears to have little benefit for no-till soybeans. From an economic standpoint, the use of the rye cover crop represents additional expense for seed with no immediate return on investment. More importantly, time spent planting rye in the fall when weather is typically unsettled may result in lost crop harvesting time. Although the use of a rye cover crop may increase soil organic matter and increase the diversity of crop rotation, the benefits of these changes on clay soils are uncertain.

Although an integrated weed control strategy using banded preemergence herbicide plus inter-row cultivation reduced herbicide use by 60% and was the most profitable treatment in wide row soybeans, it was $98/ha less profitable than the most profitable treatment in narrow rows. Furthermore, this integrated approach requires a greater level of crop management and favourable weather and soil conditions at the time of cultivation to be successful.

Both wide row and narrow row soybean cropping systems provided options to minimize grower reliance on herbicides for weed control. Wide row soybeans allowed the use of mechanical inter-row weed control, whereas the rapid canopy development in narrow rows provided effective biological suppression. In terms of crop yield and profit, the narrow row system was more successful. However, this success depended on the strategic timing of a burn-down treatment after the majority of weeds had emerged. The ability to predict weed emergence patterns is fundamental for the effective use of the burn-down treatment and in future efforts to reduce herbicide use.

Table 25. Effect of rye residue on soybean growth and development(Alvinston and Southwold, 1994, 1995, 1996).

Growth parameter[1]	- Rye	+ Rye
Emergence[2] (%)	79	85
Population[3] (plants/m^2)	32	29
Plant ht.[3] (cm)	55	54
Leaf area[3] (cm^2)	676	753
Leaf area index[3]	2.04	2.08
PPFD[3] (% of incident)	13	13
Seed yield (t/ha)	2.8	2.78
Weed biomass (g/m^2)[3]	*68*	*60*

[1] Means designated with * are significantly different (P<0.05)

[2] Sampled 2 weeks after planting.

[3] Glyphosate only treatment sampled in mid-August.

Table 26. Effect of row width on soybean growth and development on clay soils (Alvinston and Southwold, 1994, 1995, 1996).

	Row width	
Growth parameter[1]	76 cm	19 cm
Emergence[2] (%)	87 *	77 *
Population[3] (plants/m^2)	25 *	35 *
Plant ht.[3] (cm)	55	54
Leaf area[3] (cm^2)	739	692
Leaf area index[3]	1.82 *	2.31 *
PPFD[3] (% of incident)	21 *	5 *
Seed yield (t/ha)	2.55 *	3.01 *
Weed biomass (g/m^2)[3]	*117 **	*34 **

[1] Means designated with * are significantly different (P<0.05)

[2] Sampled 2 weeks after planting.

[3] Glyphosate only treatment sampled in mid-August.

Table 27. Effect of weed management on total weed biomass (Alvinston and Southwold, 1994, 1995, and 1996).

Treatment	Dose (kg/ha)	Time	Alvinston 1994	Alvinston 1995	Alvinston 1996	Southwold 1994	Southwold 1995	Southwold 1996	Mean across years and locations
Wide row			% control[1]						
Glyphosate	0.9	Preplant	64 d	33 c	40 d	35 e	56 c	27 d	42 d
Glyphosate + Cultivation (x2)	0.9	Preplant	86 cd	75 bc	69 d	84 de	63 c	98 abc	85 c
Glyphosate + Imazethapyr + metribuzin + Cultivation (x2)	0.90 0.075+0.48	Preplant PRE 30 cm band	96 bc	87 abc	92 bc	95 bcd	98 b	100 a	96 b
Glyphosate + Imazethapyr + metribuzin	0.90 0.075+0.48	Preplant PRE	92 c	92 ab	100 a	97 abc	99 ab	99 ab	97 b
Glyphosate + Acifluorfen + bentazon[2]	0.90 0.15+0.84	Preplant POST	91 cd	80 bc	95 b	83 de	70 c	96 bc	89 c
Narrow row									
Glyphosate	0.9	Preplant	86 cd	46 c	79 cd	90 cd	83 c	93 c	83 c
Glyphosate + Imazethapyr + metribuzin	0.90 0.075+0.48	Preplant PRE	99 ab	98 a	100 a	98 ab	100 a	100 a	99 a
Glyphosate + Acifluorfen + bentazon[2]	0.90 0.15+0.84	Preplant POST	99 a	77 bc	96 b	99 a	99 ab	98 bc	98 b
Weed biomass (g/m²) in the weedy control[3]			*250*	*286*	*204*	*257*	*362*	*73*	*200*

[1] Means (averaged over -/+ rye) within columns with different letters are significantly different ($P<0.05$).
[2] Plus 0.096 kg/ha of quizalofop-ethyl in 1996.
[3] Averaged over row width.

Table 28. Effect of weed management on soybean yields (Alvinston and Southwold, 1994, 1995, and 1996).

Treatment	Dose (kg/ha)	Time	Alvinston 1994	Alvinston 1995	Alvinston 1996	Southwold 1994	Southwold 1995	Southwold 1996	Mean across years and locations
Wide row			t/ha[1]						
Weedy control[2]			*0.44*	*0.33*	*0.69*	*0.99*	*0.97*	*2.03*	*0.9*
Glyphosate	0.9	Preplant	1.55 c	1.24 d	1.27 e	2.08 d	2.62 d	2.32 c	1.79 e
Glyphosate + Cultivation (x2)	0.9	Preplant	2.02 b	1.88 c	1.43 de	2.57 cd	2.77 cd	2.63 abc	2.20 d
Glyphosate + Imazethapyr + metribuzin + Cultivation (x2)	0.90 0.075+0.48	Preplant PRE 30 cm band	1.88 bc	2.83 ab	1.60 cde	2.81 bc	3.07 abc	2.80 ab	2.44 bc
Glyphosate + Imazethapyr + metribuzin	0.90 0.075+0.48	Preplant PRE	2.03 b	2.76 ab	1.87 bcd	3.10 abc	3.25 ab	2.48 bc	2.55 b
Glyphosate + Acifluorfen + bentazon[3]	0.90 0.15+0.84	Preplant POST	2.01 b	2.30 bc	1.73 cde	2.73 c	2.98 bcd	2.64 abc	2.34 cd
Narrow row									
Weedy control[2]			*0.93*	*0.76*	*0.94*	*1.39*	*2.05*	*2.6*	*1.42*
Glyphosate	0.9	Preplant	2.21 b	2.44 bc	1.97 bc	3.33 ab	2.96 bcd	2.65 abc	2.58 b
Glyphosate + Imazethapyr + metribuzin	0.90 0.075+0.48	Preplant PRE	2.70 a	3.21 a	2.56 a	3.39 ab	3.42 a	3.01 a	3.01 a
Glyphosate + Acifluorfen + bentazon[3]	0.90 0.15+0.84	Preplant POST	2.36 ab	2.87 ab	2.30 ab	3.52 a	3.42 a	2.86 a	2.84 a

[1] Means (averaged over -/+ rye) within columns with different letters are significantly different ($P<0.05$).
[2] Means for the weedy control are included for comparison only.
[3] Plus 0.096 kg/ha of quizalofop-ethyl in 1996.

Table 29. Effect of weed management on the profitabilty of no-till soybeans (based on yields for 1994, 1995, and 1996 at Alvinston and Southwold and on costs in 1996).

			Row width	
Treatment	Dose (kg/ha)	Time	76 cm	19 cm
			----$/ha----	
Weedy control			96 e	233 d
Glyphosate	0.9	Preplant	349 c	551 ab
Glyphosate + Cultivation (x2)	0.9	Preplant	430 bc	n/a
Glyphosate + Imazethapyr + metribuzin + Cultivation (x2)	0.90 0.075+0.48	Preplant PRE 30 cm band	466 abc	n/a
Glyphosate + Imazethapyr + metribuzin	0.90 0.075+0.48	Preplant PRE	448 abc	564 a
Glyphosate + Acifluorfen + bentazon[2]	0.90 0.15+0.84	Preplant POST	430 bc	553 ab

[1] Means (averaged over -/+ rye) with different letters are significantly different ($P<0.05$).
[2] Plus 0.096 kg/ha of quizalofop-ethyl in 1996.

Appendix 1. Unit costs of pesticides, seed, field operations and other input costs.

Item	Cost	Unit
Soybean seed cost	18	22.7 Kg bag
Soybean current selling price	312	Tonne
Plant/Drill beans (no-till)	37.5	Ha
Harvest soybeans	77.5	Ha
Harvest hauling charge	4.45	Tonne
Interest	9%	
Spray-broadcast	15	Trip/ha
Spray-band with planter	5	Trip/ha
Inter-row cultivate	16.25	Trip/ha
Glyphosate (Roundup)	8.95	Litre
Imazethapyr (Pursuit 240)	205	Litre
Metribuzin (Sencor DF)	71	Kg
Acifluorfen (Blazer)	21.9	Litre
Bentazon (Basagran forte)	25.25	Litre
Quizalofop-ethyl (Assure)	40	Litre

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TECHNOLOGY TRANSFER

d) Peer Reviewed Journal Publications

Swanton, C.J., T.J. Vyn, K. Chandler and A. Shresthra. 1998. Alternative weed control strategies for no-till soybeans (*Glycine* max) grown on clay soils. Submitted to Weed Technology.

Vyn, T.J., G. Opoku and C.J. Swanton. 1998. Residue management and minimum tillage systems for soybeans following wheat. (March - April)

Opoku, G and T.J. Vyn. 1997. Wheat residue management options for no-till corn. Can. J. Plant Sci. 77:207-213.

Opoku, G., T.J. Vyn and C.J. Swanton. 1997. Modified no-till systems for corn following wheat on clay soils. Agron. J. 89:549-556.

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b) Abstracts of Papers Presented at Conferences

Swanton, C. and T. Vyn. 1998. Integrated weed management for soybeans grown on clay soils. Poster presented at Integrated Crop Management Symposium, March6, University of Guelph.

Vyn, T.J., D.C. Hooker, G. Opoku and C.J. Swanton. 1997. Fall zone tillage for corn after soybeans and winter wheat. ASA Annual Meetings. Anaheim, California (Agron. Abstracts p. 113).

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c) Popular Press Articles

Vyn, T.J. 1998. Conservation tillage options for corn and soybeans on clay soils. Integrated Crop Management Symposium, March 6, University of Guelph, p. 1-4.

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d) Invited Speeches Which Included Conclusions from this Green Plan Research Contract:

Date	Extension Events Involving T. Vyn or Dave Hooker*
March 6, 1998	Integrated Crop Management Symposium, University of Guelph
September 9-12, 1997	Tillage rotation and corn row width Plot Tours for Outdoor Farm Show, Woodstock
September 6, 1997	Essex Conservation Authority, Holiday Beach
July 22, 1997	TFIO Research and Fertilizer Use Education Day, Woodstock
January 23, 1997	Essex Conservation Club, Essex
February, 1997	Becker Farm Equipment Invitational Banquet, Exeter
March 8, 1996	Integrated Crop Management Symposium (Guelph)
March 12, 1996	Middlesex Pre-Tillage Meeting, Lucan
March 26, 1996	AAFC Green Plan Research Workshop (London)
August 31, 1995	Bluewater Conservation Club Field Day. Wilkesport Demonstration Site
January 19, 1995	Becker Farm Equipment, Exeter
March 15, 1995	Agriculture Canada On-Farm Research Workshop, London
July 5, 1995	Focus on Fertility Field Day, Centralia
August, 1994	Bluewater Conservation Club Twilight Tour

*Also included in several integrated weed management speeches by Clarence Swanton

e) Approximately 15 to 25 articles in the farm press from 1994 to 1998 covered highlights from our presentations relating to clay soils. Publications included Ontario Farmer, AgriBook Magazine, Farm & Country, The Furrow, Country Guide and a few U.S. publications.