# Tillage effects on soil penetration resistance and early crop growth for Red River clay

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Wang, Y., Y. Chen, S. Rahman and J. Froese. 2009. **Tillage effects on soil penetration resistance and early crop growth for Red River clay**. Canadian Biosystems Engineering/Le génie des biosystèms au Canada 51: 2.xx–2.xx. Understanding tillage effects on soil penetration resistance is essential for selection of tillage practices to improve soil structure and crop performance in clay soils. A field study was carried out from 2003 to 2005 to investigate alternative tillage systems for poorly drained Red River clay in Manitoba. The crops were barley in 2003, oat in 2004, and wheat in 2005. The field trial included three tillage systems: subsoiling (SS), direct seeding (DS), and conventional tillage (CT). The subsoiling was further studied for three different scenarios: the 1st year (SS1), 2nd year (SS2), and 3rd year (SS3) after subsoiling to examine the persistence of the subsoiling effect. Soil properties (soil cone index and soil moisture content) and early plant performance (speed of crop emergence, plant density, and plant biomass) and weed biomass were also measured. The results showed that when compared with CT, SS tended to promote lower soil moisture content, reduced soil penetration resistance, improved the plant performance, and reduced weed biomass. Mixed results of soil moisture content were obtained when comparing DS with CT. As for soil cone indices and the crop performance, DS was better than or comparable with CT. Effects of different subsoiling scenarios on the soil cone index followed the trend: SS1 < SS2 < SS3, i.e., soil was recompacted over time following subsoiling. However, both SS1 and SS2 generally had a lower soil cone index and better crop performance than CT, meaning that the benefit of subsoiling persisted for at least two years. **Keywords:** Tillage, seeding, subsoiling, moisture, cone index, plant, biomass.

Il est essentiel de comprendre les effets du travail du sol sur la résistance du sol à la pénétration pour sélectionner les pratiques de travail du sol qui améliorent la structure du sol et les rendements des cultures dans des sols argileux. Une étude au champ a été réalisée entre 2003 et 2005 pour évaluer des systèmes alternatifs de travail du sol dans des sols argileux mal drainés de la Rivière Rouge au Manitoba. Les cultures évaluées étaient de l'orge en 2003, de l'avoine en 2004 et du blé en 2005. Les essais au champ incluaient trois types de travail du sol: sous-solage (SS), semis direct (SD) et travail du sol conventionnel (TC). Le sous-solage a été étudié plus particulièrement afin d'en vérifier la persistance en utilisant trois scénarios différents: la première année (SS1), la deuxième année (SS2) et la troisième année (SS3) après le sous-solage. Les propriétés du sol (indice de cône et teneur en eau), l'établissement des cultures (vitesse d'émergence, densité et biomasse des plantules) et la biomasse de mauvaises herbes ont aussi été mesurés. Les résultats ont montré que lorsque comparé à TC, SS avait tendance à diminuer la teneur en eau du sol, réduire la résistance à la pénétration dans le sol, améliorer l'établissement des plantules et réduire la biomasse de mauvaises herbes. Des résultats divergents de teneur en eau ont été observés lorsque SD et TC étaient comparés. Pour ce qui est des indice de cône et des rendements des cultures, SD s'est avéré supérieur ou comparable à TC. Les différents effets des scénarios de sous-solage sur l'index de cône suivaient la tendance suivante: SS1 < SS2 < SS3, i.e. le sol redevenait compacté avec le temps à la suite du sous-solage. Cependant, SS1 ainsi que SS2 avaient généralement un indice de cône plus bas et de meilleures performances des cultures que TC; ceci signifie donc que les bénéfices du sous-solage persistaient sur au moins deux ans. **Mots clés:** travail du sol, semis, sous-solage, teneur en eau, indice de cône, plante, biomasse.

## INTRODUCTION

The Red River Valley in Manitoba features fine granular black and imperfectly drained soils (MSS 1972). In this region, soil is conventionally tilled in each fall. The overall tillage benefit, in terms of loosening soil, is not clear. Conventionally tilling the soil may not necessarily alleviate the soil compaction. To the contrary, the wheel tracks from the tillage operation may further compact the soil. Surface soil compaction of clay soils can sometimes be alleviated by natural freezing-thawing cycles. In spring, surface soil may have the same status of soil compaction, regardless of the tillage system used in the previous year (Chen et al. 2005). Considering these facts, no-till or direct seeding could be a feasible tillage alternative for Red River clay soils. Furthermore, direct seeding minimises soil erosion and is more energy efficient in terms of fuel consumption (Yalcin and Cakir 2006). However, direct seeding has not been practiced in Red River clay soils due to soil compaction, poor drainage, and potential weed problems.

Although freezing-thawing cycles may alleviate only the surface soil compaction, soil compaction in subsoil layers may have to be removed mechanically. Subsoiling mechanically aerates deep layers, which has a positive impact on crop yields when compaction problems were diagnosed (Evans et al. 1996). Botta et al. (2006) found increased sunflower yield and Busscher et al. (2006) found increased cotton yield following subsoiling, as compared with conventional tillage. Subsoiling, however, consumes more power (Karlen et al. 1991), requires more labour for tillage operations, and consequently, raises the production cost, when compared with direct seeding or conventional tillage. According to Chen et al. (2005) the required draft force for subsoiling was four times that of the conventional tillage. Thus, if subsoiling can be done in a longer interval than one year, it will reduce the production cost. The question to answer is how frequently the Red River clay soils need to be subsoiled.

Busscher et al. (2006) stated that subsoiling is not needed every year for non-irrigated in-row subsoiled cotton grown in conventional row widths (0.96 m). Ghosh et al. (2006) also stated that there is no need of subsoiling every year to realise optimum yield of soya/pigeon pea (G*lycine max*/*Cajanus cajan*) intercropping system. Botta et al. (2006) concluded that the frequency of subsoiling in the studied area in Argentina should be every two years for a sunflower crop. This conclusion was based on an observed yield increase in the first and second seasons following subsoiling and the soil recompaction after the second year. Ibrahim et al. (2004) suggested subsoiling period as two years for one-pass and 4–5 years for two-passes of the subsoiling operation for cotton. Olesen and Munkholm (2006) stated that the subsoil loosening effect lasted at least for 3.5 years in light soils. However, the cereal and pulse yield advantages from subsoiling were observed only during dry summers. Ide and Hofman (1990) reported that the beneficial effect of subsoiling on the crop yield lasted as long as 5 years after a plow pan was removed in two Belgian silt loam soils. However, Barber and Diaz (1992) found that there were no differences in soya yields between annual subsoiling and subsoiling only once within several years.

In summary, the literature indicates that the effects of subsoiling differ between soil types and cropping systems (Ghosh et al. 2006). Not all soils and crops are equally susceptible to soil compaction, and not all soils and crops would benefit from subsoiling. The persistence of the subsoiling benefit would also depend on specific soil and crop conditions, as well as climate. Most studies in the literature focused on using subsoiling for light soils (sandy soil and loams). Little has been done to study benefits of subsoiling of heavy clay soils.

The immediate effect of tilling soil is mainly for changing soil physical structure. Thus, the response of soil to different tillage practices are often examined by the structure related parameters, such as soil moisture and cone index. Soil cone index has been used by many researchers to assess soil compaction associated with tillage (Busscher et al. 2006; Botta et al. 2006), and plant root elongation (Letey 1995). Soil moisture is an indication of the drainage capacity of the soil. Crop response, especially the early growth, should also be examined to assess the tillage effects. Ball and O'Sullivan (2006) measured both soil cone index and crop emergence in a tillage study. Cassel et al. (1995) assessed tillage effects using both soil cone index and crop yield. This study was conducted to examine these soil properties and the crop response with the purpose of answering these questions: Would cereal crops, such as barley, wheat, and oat sown on Red River clay soils benefit from subsoiling and how long would the benefit last? Would direct seeding be an alternative tillage system in Red River clay soils? The specific objectives were to: (1) compare subsoiling and direct seeding with conventional tillage on soil and cereal crop response, and (2) investigate the persistence of subsoiling effect in a Red River clay soil.

## MATERIALS and METHODS

### Site description

Field tillage plots were established in the fall of 2002, and data were collected in the following three growing seasons (2003, 2004, and 2005). The site was located at the Glenlea Research Station of the University of Manitoba, Canada. The soil was Red River clay (61.7% clay, 20.8% silt, and 17.5% sand). The plots were seeded with barley in 2003, oat in 2004, and wheat in 2005, which were the Station's crop rotations for that field.

### Experimental design

A completely randomized block design was used in the field experiment with three tillage treatments: subsoiling (SS), direct seeding (DS), and conventional tillage (CT). Each tillage treatment was replicated six times, forming a total of 18 plots. Each SS plot was sub-divided into three sub-plots with one of the three sub-plots being subsoiled per year. In the other years, the remaining sub-plots were directly seeded. The plot layout is shown in Fig. 1. Those sub-plots were designed to study how long the subsoiling effect would persist and they corresponded to three scenarios as summarised in Table 1. In 2003, the sub-plots subsoiled in the fall of 2002 represented the scenario of the first year after subsoiling (SS1). In 2004, those sub-plots represented for the scenario of the second year after subsoiling (SS2), and the sub-plot subsoiled in the fall of

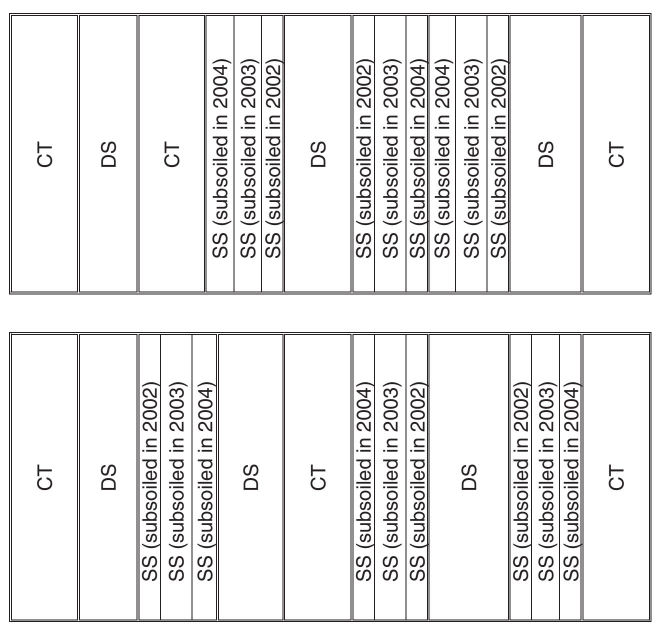


**Fig. 1. Layout of the field plots and sub-plots; SS = subsoiling; CT = conventional tillage; DS = direct seeding.**

**Table 1. Summary of the subsoiling scenarios and their corresponding sub-plots.**

| Year | Subsoiling scenario | Symbol | Sub-plots used |
|---|---|---|---|
| 2003 | | | |
| | The 1st year after subsoiling | SS1 | Subsoiled in 2002 |
| 2004 | | | |
| | The 2nd year after subsoiling | SS2 | Subsoiled in 2002 |
| | The 1st year after subsoiling | SS1 | Subsoiled in 2003 |
| 2005 | | | |
| | The 3rd year after subsoiling | SS3 | Subsoiled in 2002 |
| | The 2nd year after subsoiling | SS2 | Subsoiled in 2003 |
| | The 1st year after subsoiling | SS1 | Subsoiled in 2004 |

2003 represented for the scenario of SS1. Similarly, in 2005 the scenarios included the third year after subsoiling (SS3) and also SS2 as well as SS1. The CT plots were tilled each fall. The DS plots were not tilled starting in the fall of 2002. All plots were 9 m wide and 30 m long. The width of the plot could accommodate one passage of the conventional tillage implement and three passages of the subsoiler.

### Field equipment description

Conventional tillage was performed with a 9-m field cultivator (Fig. 2a). The cultivator featured sweeps which were mounted on C-shanks ($35 \times 50$ mm cross-section) with a tool-spacing of 0.3 m. Subsoiling was performed with a 3-m subsoiler (Fig. 2b). The subsoiler had five heavy-duty C-shanks ($60 \times 30$ mm cross-section) spaced 0.6 m apart. The subsoiling tools were 60-mm wide reversible narrow points. The tillage depth was 0.10 m for the conventional tillage and 0.35 m for the subsoiling. The parameters of the tillage equipment are summarized in Table 2. A no-till airseeder (Fig. 2c) with offset double-disc openers was used for seeding all plots. Seeding was performed perpendicular to the plots (Fig. 2d). The other field operations, such as herbicide and fertiliser applications, were performed according to the Research Station's normal practices.

### Measurements

**Soil moisture content** Soil moisture content was measured when the crop was between milk and dough stages in 2003 (July 28 and August 18) and 2005 (July 28), and at early growing stage in 2004 (May 3). Soil samples were taken to a depth of 400 mm with a soil core sampler (diameter: 11.35 mm). Ten samples were taken in each plot at random locations. Samples were oven-dried at 105°C for 24 hours to determine the gravimetric soil moisture content.

(a) (b) (c) (d)

**Fig. 2. Field equipment and field operations; (a) field cultivator for the conventional tillage (CT); (b) subsoiler for the subsoiling (SS) (c) disc airseeder used; (d) seeder crossing the plots.**

Table 2. **Descriptions of the tillage equipment and tillage depth.**

| | Tillage implement | | | Tillage tool | | |
|---|---|---|---|---|---|---|
| Treatment | Type | Width (m) | Tool spacing (m) | Type | Working width (m) | Tillage depth (m) |
| Conventional tillage (CT) | Cultivator | 9.0 | 0.3 | Sweep | 0.2 | 0.1 |
| Subsoiling (SS) | Subsoiler | 3.0 | 0.6 | Narrow point | 0.06 | 0.35 |

**Soil cone index** A penetrometer (Rimik, Model CP 20, Agridy Rimik Pty. Ltd. Toowoomba, Australia) was used to measure soil cone index following the requirements of ASABE Standards (ASABE 2004). Transect method (Bédard et al. 1997) was used for the measurements. For the DS and CT treatments, two diagonal and intersecting transects (like an "X") of tapes were laid across each plot (Fig. 3a). Starting 3 m from one corner of each plot, flags were placed every 0.5 m along the tapes. For the sub-plots of SS, only one diagonal transect (like "/") was flagged due to the narrow width of the plots (Fig. 3b). Cone index was measured at each flag at 25 mm intervals to a depth of 400 mm. Since soil cone index is related to the soil moisture content (Materechera and Mloza-Banda 1997), cone index measurements were performed shortly after a heavy rainfall event in an attempt to maximize uniformity of soil moisture content through the depth profile.

**Speed of crop emergence and plant density** The number of plants was counted to determine the speed of crop emergence and plant density. Four random locations in each plot or sub-plot were selected. At each location, three 0.6-m plant row were flagged (Fig. 4), and the number of plants contained within each row were counted. Counting was done 4, 7, 10, and 17 days after the initial crop emergence was noticed. The speed of crop emergence was expressed as the average number of seedlings that emerged per day per unit area ($m^2$), which was calculated by the following formula (Tessier et al. 1991):

$$SE = \frac{\sum(N_i/d_i)}{L \cdot s} \tag{1}$$

Where SE is speed of crop emergence per day per unit area (plants $d^{-1}$ $m^{-2}$), $N_i$ is the number of newly emergence seedlings counted per day, $d_i$, L is the length of the row counted (0.6 m), and s is crop row spacing (0.3 m). The final plant count was used as the final plant density, expressed as number of plants per square meter.

**Seeding depth** Seeding depth measurements were done right after the final plant count. From each row used for plant counting, five plants were randomly pulled out. The seeding depth was measured from the centre of the seed to the point where chlorophyll became present in the plant's stem (Tessier et al. 1991).

**Plant and weed biomass, as well as plant characteristics** Aboveground living biomass in 1 $m^2$ quadrant was harvested at three random locations of each plot or sub-plot. The samples were brought to the laboratory and were separated manually into the plants and weeds, and they were dried in cotton sacks for 72 hours at 60°C to determine their respective dry matter contents. In

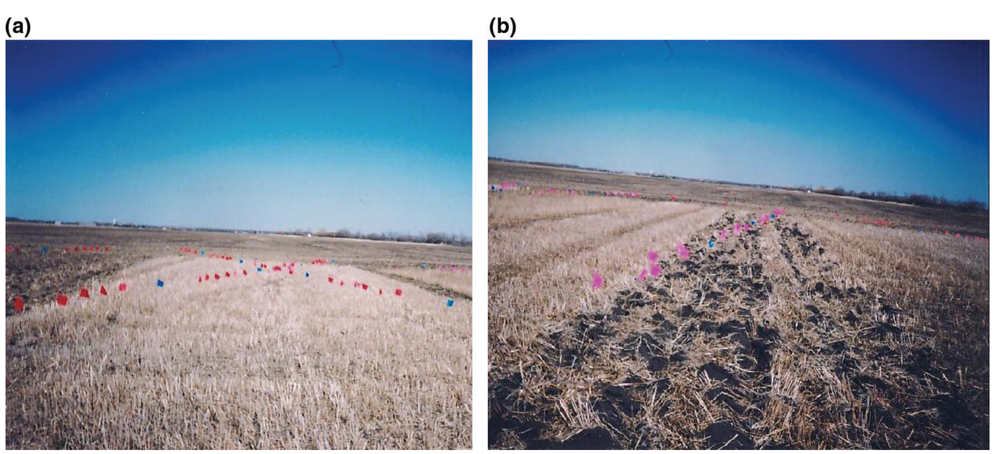

**Fig. 3. Photos showing flags where soil cone index measurements were performed; (a) an "X" transect for the direct seeding plots (the same protocol was followed for the conventional tillage plots); (b) an "/" transect for the subsoiling sub-plots.**

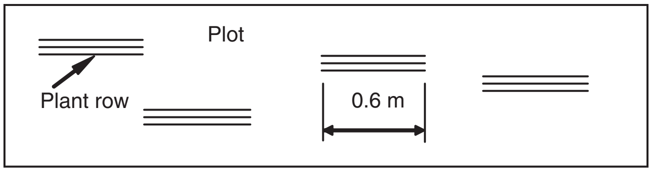


**Fig. 4. Diagram of a plot or sub-plot showing crop rows where plant counting was performed; three 0.6-m plant rows were counted at each location and four random locations were selected in each plot.**

addition, 40 plants were randomly pulled from each plot and brought back to laboratory to measure the length of the main stem of each plant, defined as the distance from the base of the node of the plant to the tip of the grain head. The number of tillers and the number of heads per plant were also counted.

**Crop yield** In 2003, hand harvesting was performed using five randomly placed 1 $m^2$ quadrants in each plot or sub-plot. The plant material was air dried and then threshed with a lab-scale threshing unit. The gathered grain was cleaned on a drum grader and was then sieved to obtain the final cleaned grain yield.

**Data analysis** Analysis of variance (ANOVA) was performed using the statistical model for a completely randomised block design. The significance of effects of tillage treatments on the soil and plant variables were examined. Means between treatments were compared with Duncan's multiple range tests. A significance level of 0.1 was applied to all analyses because of the inherent high variability of soil and plant data.

## RESULTS and DISCUSSION

### Precipitation conditions

In general, all three springs (May or June) were wet, as compared with the 30-year normal (Table 3). In 2003, the seeding in May was manageable and the crop growth was close to normal, while the following spring (May 2004) was extremely wet, and the seeding was delayed for about a month. Consequently, no grains could be harvested in that year. In 2005, the seeding in May was fine; however, the seedlings were drowned in June due to the much higher precipitation (169.4 mm) than the normal (93.8 mm).

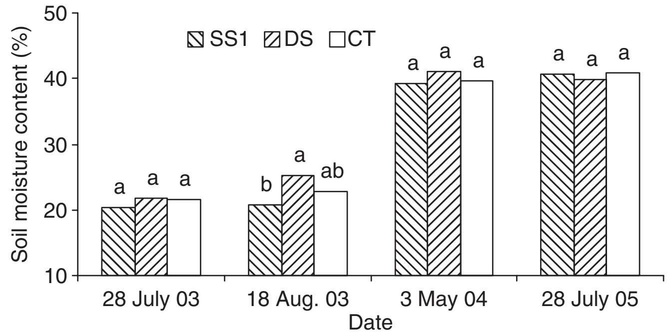


**Fig. 5. Gravimetric soil moisture content measured for subsoiling (SS1), direct seeding (DS), and conventional tillage (CT); means with different letters within the same date were statistically different ($p \leq 0.1$).**

### Comparisons of different tillage systems

**Soil moisture content** The tillage effect on the soil moisture content was not significant on three dates out of four (Fig. 5). The lack of response could be attributed to the extremely wet spring conditions, which may have masked any effect. On August 18, 2003, SS1 had significantly lower moisture content than DS, and DS and SS1 plots were approximately 10% wetter and dryer, respectively, when compared with CT. The loosing soil condition in SS1 promoted water evaporation loss (Jolata et al. 2001), while DS, where the soil was not tilled, conserved moisture. Evans et al. (1996) also found lower soil moisture content in the subsoiled area than non-subsoiled area of the field. Residue cover in DS likely has contributed to the high moisture content by reducing the amount of drying.

**Soil cone index** Values of soil cone index (Fig. 6) measured in all years were under 1500 kPa,which were below the agronomic threshold of 1800 kPa for crop development (Letey 1995). Thus, root penetration is not likely limited in this soil, but rather water infiltration may be the limiting factor. Cone index data taken prior to the seeding in the spring of 2003 (i.e. prior to the start of wheel traffic of the season) increased smoothly with the soil depth (Fig. 6a), while those taken in the later season in the following year showed a rapid increase up to 75 mm depth (Fig. 6b). A

**Table 3. Summary of the monthly average precipitation during three growing seasons (http://www.climate.weatheroffice.ec.gc.ca).**

| Year | Total precipitation (mm) | | | | | |
|---|---|---|---|---|---|---|
| | April | May | June | July | Aug | Sept |
| 2003 | 32.4 | 74.1 | 115.3 | 39.1 | 104.8 | 43.0 |
| 2004 | 24.9 | 169.4 | 67.5 | 58.9 | 168.3 | 124.4 |
| 2005 | 29.6 | 73.5 | 169.4 | 162.4 | 34.0 | 50.6 |
| Normal* | 28.6 | 62.1 | 93.8 | 80.1 | 67.7 | 54.3 |

*Normal = 30-year normal.

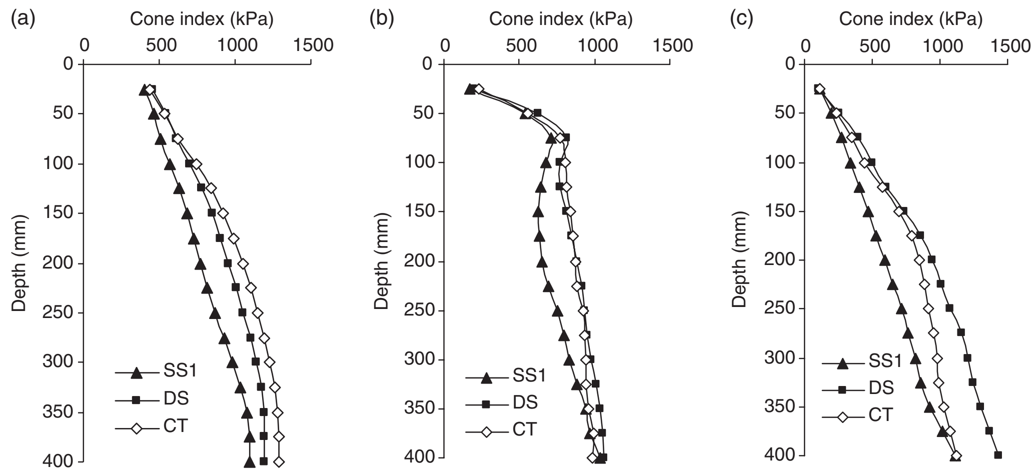


**Fig. 6. Soil cone index at different depths for subsoiling (SS1), direct seeding (DS), and conventional tillage (CT) treatments; (a) June 4, 2003, (b) August 2, 2004; (c) May 29, 2005.**

relatively compacted surface soil layer was likely caused by the wheel traffic associated with the seeding operation, spraying, and any other field operations during that growing season, according to the concept of the profile analysis (Chen and Tessier 1997). Interestingly, the compact layer of 2004 vanished in the spring of 2005 (i.e., prior to the start of wheel traffic of the season) (Fig. 6c). Given this pattern of cone index variation over time, one can conclude that surface soil compaction of clay soil resulting from the wheel tracks during the growing season may be eliminated over winter in Manitoba by freezing-thawing cycles, in accordance with the similar findings by Chen et al. (2005) for a clay soil in the Red River Valley.

For all years, SS1 had lower soil cone indices than both DS and CT due to the more intensive soil disturbance of the subsoiling. Statistically significant differences in cone index between SS and CT were found at depths from 50 to 250 mm in 2003, from 125 to 325 mm in 2004, and from 50 to 400 mm in 2005.

Wilkins et al. (2002) reported that short-term no-tilled soil had higher soil strengths than tilled soil. As CT plots were tilled to 100 mm depth, one expected that CT would have a lower cone index than DS within this depth range, and similar cone index below 100 mm. However, this was not the case in this study. In 2003, values of cone index observed from DS were significantly lower at the depth range of 125–150 mm. This may be explained by the wheel traffic effect associated with the previous fall tillage in the CT plots. In both 2004 and 2005, there were no differences in cone index at the depth range of 100 mm between DS and CT. Reasons for the significant differences in cone index below the tillage depth (100 mm) between DS and CT in 2005 were unknown.

**Seed placement** The seeder was set to a target seeding depth of 40 mm. The actual seeding depths of DS were nearly constant over years, while those of SS and CT varied from 38 to 51 mm (Fig. 7). As the seeder's depth setting was kept the same for all years, the variation of the actually measured seeding depths was entirely a function of the soil condition. SS1 had 12, 11, and 3% greater seeding depth than CT in 2003, 2004, and 2005, respectively. These differences were statistically significant in 2003 and 2004. The greater seeding depth in SS1 was attributable to the more loosened seedbed of the subsoiled plots. Chen et al. (2005) also found that a more loosened seedbed favoured greater seeding depth. As compared with CT, DS had 14% shallower seeding depths in 2004 and similar seeding depths in 2003 and 2005. The shallower seeding depth of DS in 2004 was the result of its firm seedbed.

**Crop performance** Due to the extreme weather conditions, grains were not mature in 2003, i.e. no yields were measured in that year; in 2005, only speed of crop emergency and plant density were measured during the

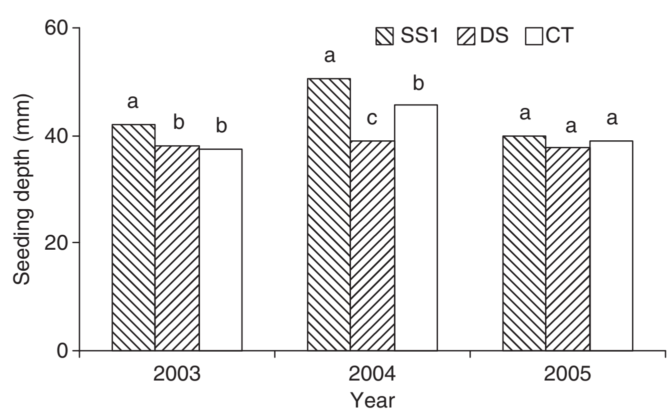


**Fig. 7. Seeding depths for the subsoiling (SS1), direct seeding (DS), and conventional tillage (CT). Crop was barley in 2003, oat in 2004, and wheat in 2005. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

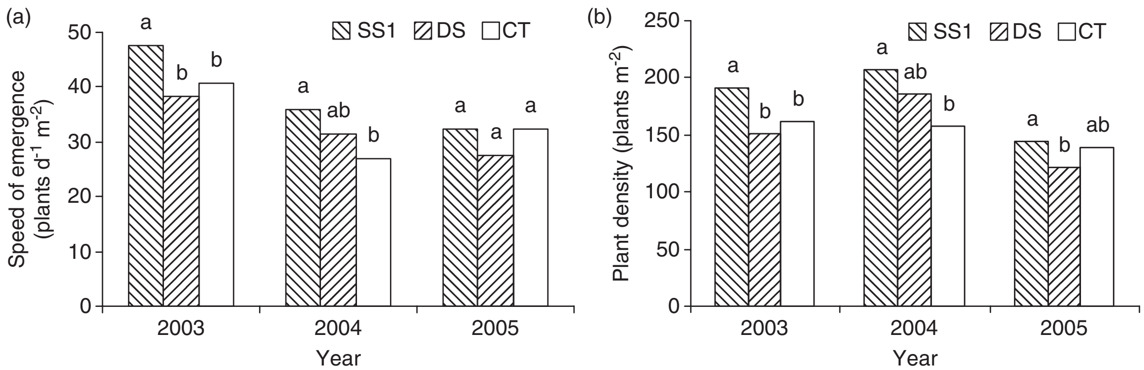


**Fig. 8. Early crop performance for the subsoiling (SS1), direct seeding (DS), and conventional tillage (CT); (a) speed of crop emergence; (b) plant density. Crop was barley in 2003, oat in 2004, and wheat in 2005. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

early stage of the growing season. In 2005, plants emerged at the similar speed over all tillage treatments (Fig. 8a). In 2003 and 2004, SS1 had significantly higher speed of crop emergence than CT, and DS had a statistically similar speed of crop emergence as CT. This may have been because the subsoiled soil was softer and possibly warmer as it was somewhat drier, which favoured emergence. In addition, SS1 may also have had better seedbed drainage in the wet springs of 2003 and 2004. Faster emergence with subsoiling was also reported by others (e.g., Yalcin and Cakir 2006). The results of plant density measurements (Fig. 8b) showed the same trend as those of speed of crop emergence, i.e., SS1 had significantly higher plant density among the three tillage treatments, and plant populations of DS and CT were not statistically different.

Values of plant main stem length varied from 750 to 950 mm. There was some evidence that stems of DS were longer than those of SS1 and CT (Fig. 9a). All plants counted had two tillers and heads, or less, irrespective of tillage treatment. In 2003, all the tillage treatments produced the similar number of tillers or heads per plant, while in 2004, SS1 and DS had greater number of tillers or heads per plant than CT (Fig. 9b,c).

In 2003, SS1 produced 30% more plant biomass than CT, and DS produced a similar amount of plant biomass as CT (Fig. 10a). The 2004 biomass yields were low for all treatments, due to the late seeding, and there were no significant differences in plant biomass among any of these tillage treatments. The weed biomass followed the trend: SS1 < DS < CT (Fig. 10b). The least amount of weeds for SS1 may be the result of the highest intensity of tillage action, which may have mechanically buried the weed seeds. The higher plant biomass of SS1 may also have suppressed the weed growth. However, the significantly higher weed biomass in CT than DS in 2004 was not expected. The higher weed biomass of CT could be the result of some weeds being stimulated by the tillage.

The 1 year yield data taken in 2003 showed a trend of SS1 > DS > CT (Fig. 10c). The other factors which contributed to the higher yield of SS1 could be attributable again to better soil aeration. Many other researchers, for example, Yalcin and Cakir (2006), also reported yield increase with subsoiling, when compared with conventional tillage.

## Persistence of subsoiling effect

**The second year after subsoiling (2004)** The 2004 subsoiling scenarios included SS1 and SS2. The soil moisture contents were not significantly different among SS1, SS2,

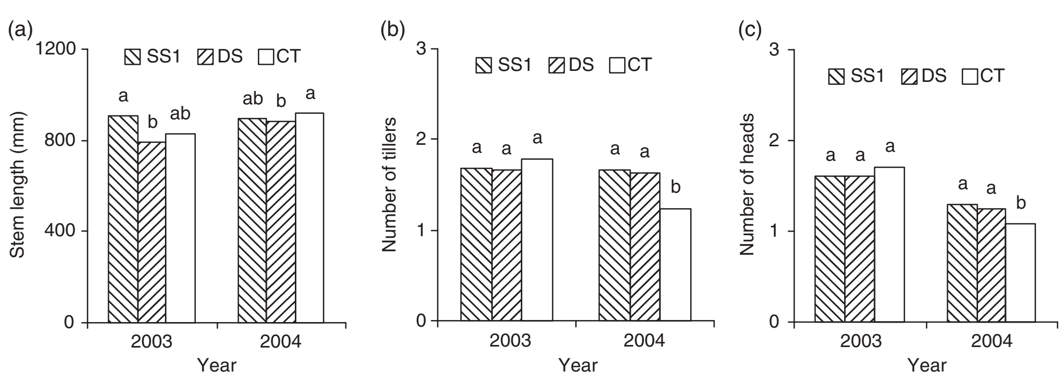


**Fig. 9. Plant characteristics for the subsoiling (SS1), direct seeding (DS), and conventional tillage (CT); (a) plant main stem length; (b) number of tillers per plant; (c) number of heads per plant. Crop was barley in 2003 and oat in 2004. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

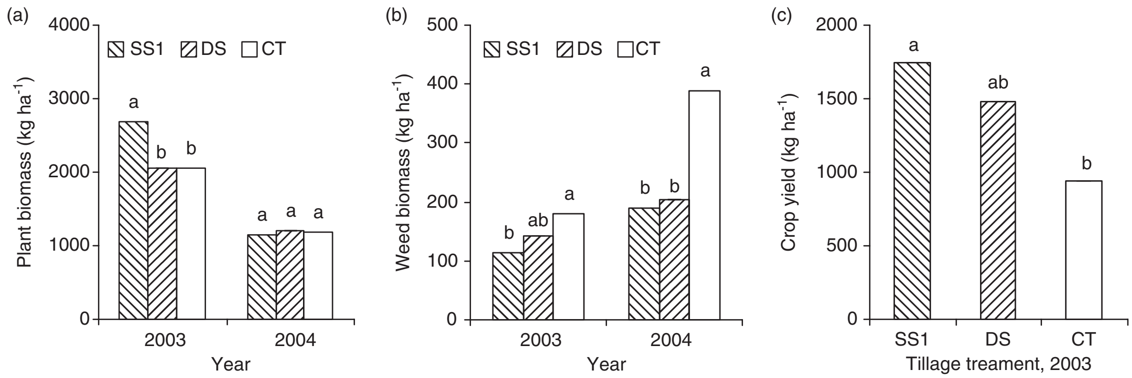


**Fig. 10. Crop performance for the subsoiling (SS1), direct seeding (DS), and conventional tillage (CT); (a) dry matter of plant biomass; (b) dry matter of weed biomass; (c) 2003 yield. Crop was barley in 2003 and oat in 2004. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

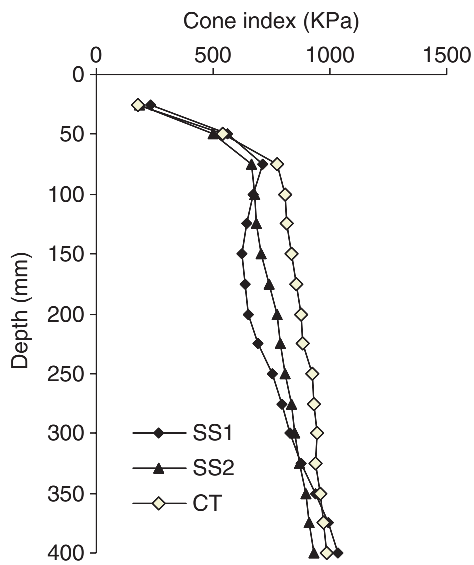


**Fig. 11. Soil cone index profiles in 2004 for the first year (SS1) and the second year (SS2) after subsoiling, as well as conventional tillage (CT).**

and CT (data not shown). The result of soil cone index showed that soil was more loosened the first year after subsoiling than the second year after, as demonstrated by the significantly lower soil cone index of SS1 at depths from 125 to 275 mm (Fig. 11). This suggests that the soil profile of SS2 was recompacted over the year. However, it was interesting to find that SS2 still had significantly lower cone indices than CT at the depths from 125 to 275 mm, implying that some of the soil loosening benefit of the subsoiling persisted into the second year.

The first year after subsoiling (SS1) fostered a more rapid emergence compared to conventional tillage (CT) (Fig. 12a). In the second year after subsoiling (SS2), the crop also tended to have higher speed of emergence than CT, although the difference between SS2 and CT was not significantly different. As for plant density, improved performance of subsoiling persisted to the second year (Fig. 12b).

The plant characteristics data showed that plants from SS1 and SS2 had similar main stem lengths as those from CT (Fig. 13a). However, both subsoiling treatments produced a greater number of heads and tillers per plant than CT. This may be the result of an improved drainage

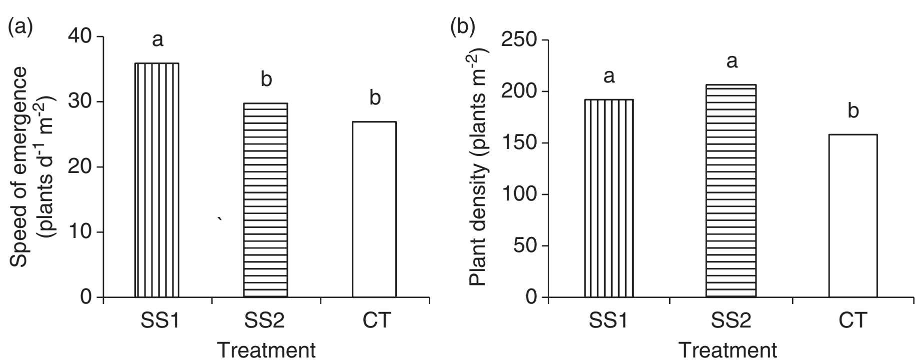


**Fig. 12. Early plant performance in 2004 for the first year (SS1) and second year (SS2) after subsoiling, as well as conventional tillage (CT); (a) speed of crop emergence; (b) plant density. Crop was oat. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

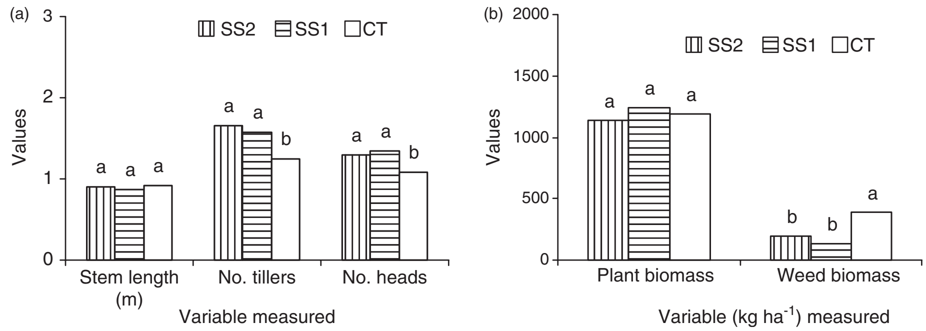


**Fig. 13. Midseason plant performance in 2004 for the first year (SS1) and second year (SS2) after subsoiling, as well as conventional tillage (CT); (a) plant main stem length, number of tillers per plant, and number of heads per plant; (b) dry matter of above ground plant and weed biomass. Crop was oat. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

effect given the wet condition in 2004. There were no significant differences in plant biomass between treatments (Fig. 13b). However, both SS1 and SS2 had fewer weeds than CT. The higher weed biomass of CT may have had an adverse effect on the aforementioned emergence speed and plant density. Overall, the results demonstrate that the benefits of subsoiling to plant growth still existed in the second year following subsoiling.

**The third year after subsoiling (2005)** In 2005, the subsoiling scenarios included SS3, SS2, and SS1 treatments. Significant differences in soil moisture content were observed between the treatments in that year (Fig. 14). At the surface layer (0–10 mm), the loosened soil condition following subsoiling promoted loss of water via evaporation and its greater infiltration. This phenomenon seemed to persist over three years at this layer. At the deeper layers, no particular trends between the subsoiled and conventionally tilled plots were observed.

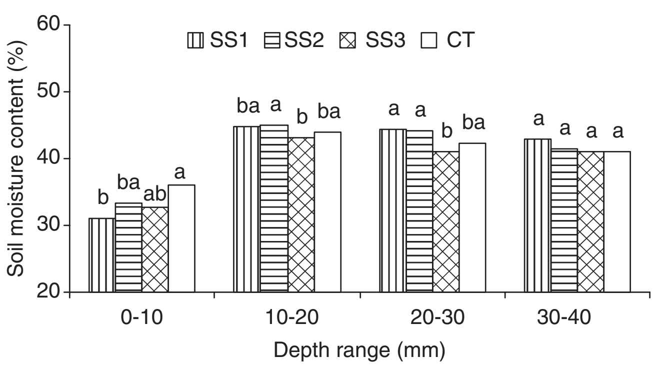


**Fig. 14. Soil gravimetric moisture content in 2005 for the first year (SS1), second year (SS2), and third year (SS3) after subsoiling, as well as conventional tillage (CT). Crop was wheat. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

The subsoiling effect on the soil cone index followed the trend: SS1 < SS2 < SS3, i.e., soil cone index increased over time after subsoiling (Fig. 15), as also reported by Ibrahim et al. (2004). At most depths, lower cone indices were observed for SS1 than for CT. At depths from 150 to 275 mm, SS2 had significantly lower soil cone indices than CT. Only at the depth range of 150–200 mm did SS3 have lower soil cone indices than CT.

For speed of crop emergence (Fig. 16a), SS1 performed similarly to CT, and SS2 performed slightly greater than CT. However, the differences were not statistically significant. All treatments had similar plant density (Fig. 16b).

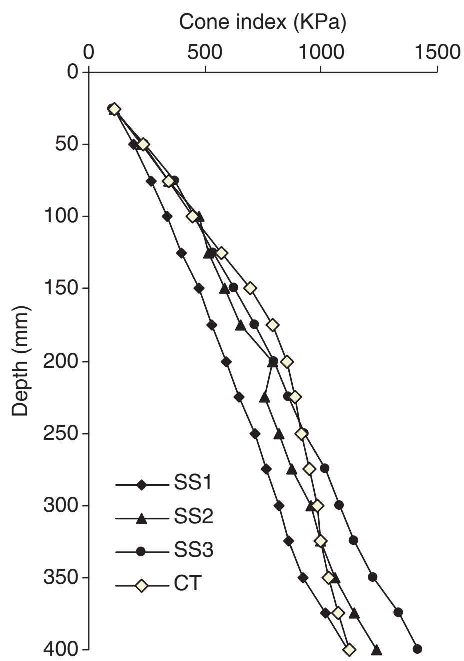


**Fig. 15. Soil cone index profiles in 2005 for the first year (SS1), second year (SS2), and third year (SS3) after subsoiling, as well as conventional tillage (CT).**

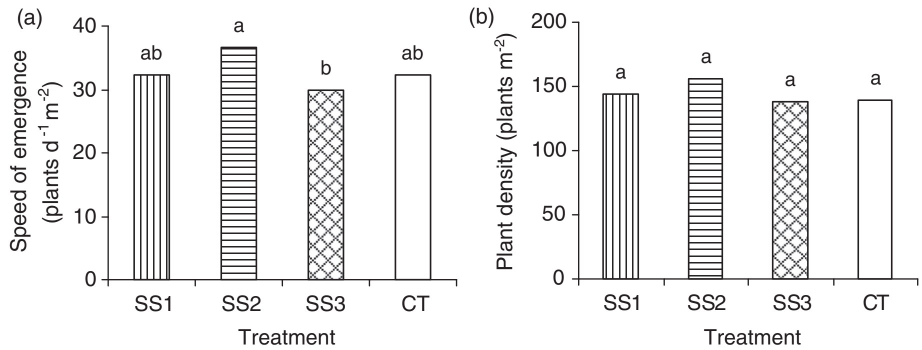


**Fig. 16. Early crop performance in 2005 for the first year (SS1), second years (SS2), and third years (SS3) after subsoiling, as well as conventional tillage (CT); (a) speed of crop emergence; (b) plant density. Crop was wheat. Means with different letters within the same year were statistically different ($p \leq 0.1$).**

## CONCLUSION AND RECOMMENDATIONS

Overall, the direct seeding system resulted in similar soil moisture contents, lower or comparable soil penetration resistance and crop performance, compared to the conventional tillage system. Subsoiling practice proved to be more effective in reducing soil penetration resistance and controlling weeds than the conventional tillage. Subsoiling also increased the speed of crop emergence, plant density and biomass (2 years of data only), as well as crop yield (one year of data only). Although the soil was recompacted over time, the loosening effect of subsoiling persisted for at least 2 years. The benefits of subsoiling for crops also lasted for at least 2 years.

Based on the results from this study, the following recommendations were made. Direct seeding is a feasible tillage alternative for Red River clay soils, considering its low cost. Performing subsoiling every second or third year in the Red River clay is advisable, as subsoiling requires high energy. Between subsoiling operations, tillage may be eliminated to reduce costs without hindering crop development. Thus, the cost of subsoiling could be offset by directly seeding the field, while leaving the surface residue untouched, affording the benefits of both subsoiling and direct seeding.

These conclusions and recommendations are limited on account that the study was carried out only in one location of the Red River Valley. In addition, wet weather was experienced during the study period which adversely affected the data collections. Further research is required to verify the conclusions.

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