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Tillage effects on soil strength and crop growth for Red River clay

Y. Wang; Y. Chen* and S. Rahman

Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6; e-mail of corresponding author*: ying_chen@umanitoba.ca

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Abstract

A field study was carried out from 2003 to 2005 to investigate different tillage systems for poorly drained Red River clay soil. The field experiment included three tillage treatments: No-tillage, conventional tillage, and sub-soiling. Soil properties (soil strength and soil moisture content) and crop performance (speed of emergence, plant population, seeding depth, plant biomass, weed biomass, and yield) were measured to compare the tillage systems. As compared with the conventional tillage, the no-tillage resulted higher soil moisture content. Mixed results were obtained in soil strength (cone index) when comparing these two tillage systems. In general, the crop performance of these two tillage systems was comparable. When compared to the conventional tillage, the sub-soiling gave lower soil moisture content, which could be an advantage for wet years. Sub-soiling significantly reduced the soil strength, which could favour better water infiltration and root penetration. As a result of these advantages, sub-soiling significantly improved the crop emergence.

Keywords: tillage, no-tillage, sub-soiling, soil, moisture, cone index, seeding, plant, biomass, yield.

INTRODUCTION

Soil compaction is a major concern in agriculture, especially by the producers who work on heavy clay soils. Compacted soil impedes the normal flow of water and air through the soil profile (Lamarca 1996) and results in poor drainage and hindered crop root development. Soil compaction also causes reductions in crop yield (Arvidsson 2001). No-tillage and sub-soiling could be the solutions to address compacted soil in Red River clay soils (Chen et al. 2005).

As no-tillage system does not require tillage operations, it reduces the time, labour, and fuel consumption associated with the seed bed preparation. Furthermore, no-tillage has many other advantages such as controlling wind and water erosion, conserving soil moisture, increasing soil organic matter and promoting biological activities in soil. However, according to Statistics Canada (1997), no-tillage was practiced on only 7% of Canada's total arable land. This might be due to many reasons, including the low temperature, weed problem, and soil compaction associated with no-tillage systems, especially in clay soils.

The Red River valley in Canada features fine granular black and imperfectly drained soil (MSS 1972). Producers in this area hesitate to practice no-tillage. These soils also have slow water infiltration and root penetration problems (Chen et al. 2005). Sub-soiling can solve these problems by mechanically aerating the soil to deep layers to improve water infiltration and crop root development. However, sub-soiling consumes more power and requires more labour time for tillage operations. The main goal of this study was to investigate if no-tillage and sub-soiling systems are beneficial to producers cropping heavy clay soils. The specific objectives were to compare no-tillage and sub-soiling with the conventional tillage on soil compaction, seeding performance, and crop response under Red River clay soils.

MATERIAL AND METHODS

Site description

Field tillage plots were established in the fall of 2002, and data of soil compaction, and seeding and crop performance were collected in the following three growing seasons (2003 to 2005). The field site was located at the Glenlea Research Station, University of Manitoba, Winnipeg, Manitoba, Canada. The soil was Red River clay (61.7% clay, 20.8% silt, and 17.5% sand). The normal tillage practice at the farm was fall tillage using a field cultivator working at a tillage depth of approximately 100 to 150 mm. The types of crop were barley in 2003, oat in 2004, and wheat in 2005.

Experimental design

A randomized block design was used with three tillage treatments: conventional tillage (CT), no-tillage (NT), and sub-soiling tillage (ST). Each treatment was replicated six times, forming a total of 18 plots. The plot size was 9 m x 30 m to accommodate one pass of the airseeder. The CT plots could accommodate approximately one pass of the conventional tillage implement, while the ST plots could accommodate three passes of the subsoiler.

Field equipment description

The field cultivator (Fig. 1a) was 8.2 m wide and featured narrow sweeps which were mounted on C-shanks (35×50 mm cross-section) with a tool-spacing of 0.6 m. This equipment had been used for the farm's conventional tillage. The subsoiler (Fig. 1b) was 3.3-m wide and had five heavy-duty C-shanks (60 mm×30 mm) spaced 0.6 m apart. The sub-soiling tools were 60-mm wide reversible straight spikes. The tillage depth was 0.15 m for the conventional tillage and 0.35 m for the sub-soiling. The parameters of the tillage equipment used and the treatments are summarized in Table 1. A low-disturbance airseeder with offset double-disc openers was used for seeding.

(a)

(b)

Fig. 1. Tillage equipment used; (a) for conventional tillage; (b) for sub-soiling.

Table 1. Descriptions of the tillage equipment and tillage depth

Treatment	Tillage implement			Tillage tool		Tillage depth (m)
	Type	Width (m)	Tool spacing (m)	Type	Working width (m)	
Conventional tillage (CT)	Field cultivator	9.0	0.6	Sweep	0.2	0.15
Sub-soiling tillage (ST)	Subsoiler	3.3	0.6	Narrow point	0.06	0.35

Field operations and weather conditions

The main field operations were fall tillage after harvest. For the CT plots, one pass of the field cultivator was performed. The same plots were used for three years of the study. For the ST plots, one pass of the subsoiler was performed each year, covering only one third of the entire plot each year. This means that each year, only the one third of the entire plot which was sub-soiled in the previous fall was used for the measurements. The other field operations, including seeding, spraying and fertilizing were performed according to the farm normal practices.

In 2003, the weather condition and the crop production was close to the normal, while the following two years were very wet in the spring, and consequently there was no harvest, as for most other areas in Manitoba. Due to a wet spring situation and the poor soil drainage, seeding in 2004 was delayed for about a month. The soil moisture (47.5%) was quite high at the seeding time. In 2005, the soil was also wet at the seeding, followed by heavy rainfall which resulted in flooding of the entire plot area.

Measurements

Soil moisture content 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 soil moisture content (ASAE Standards, 1999).

Soil cone index Soil cone index (CI) was measured using the Rimik cone penetrometer (Model CP 20,Agridy Rimik pty.Ltd. Toowoomba, Australia). The penetrometer was comprised of an inbuilt data logger, an 800-mm long shift, a cone with a base area of 129 $mm^2$and an apex angle of 30^o. The penetrometer was pushed into the soil by hand at a speed of approximately 0-2 mm s^{-1} according to the ASAE Standards.

For the NT and CT plots, two diagonal transects (like an "X") were laid across a plot using a field measuring tape. Starting 3 m in from one corner of each plot, CI measurements was made every 0.5 m following the path of the tape. For the ST plots, only one diagonal transect (like "/") was measured due to their smaller size. Since CI is strongly related to the water content (Materechera and Mloza-banda 1997), CI measurements were performed after a heavy rainfall event in an attempt to maximize uniformity of soil moisture content through the depth profile.

Plant counting The number of plants was counted to determine the speed of crop emergence. Plants at four random locations in each plot, each consisting of three 0.6 m rows, were marked off and counted. In 2003 and 2005, counting was done on three, four, seven days after the initial crop emergence was noticed. In 2004, counting was done every day following the first emergence because of the late seeding and the rapid growing of the plants due to the high temperature. 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):

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

Where

SE = speed of crop emergence per unite area (plant d^{-1} m^{-2}),
N_i = the number of newly emergence seedlings counted per day d_i,
L = the length of the row counted (m), and
s = crop row spacing (m).

The final plant count was used as the final plant population.

Seeding depth Seeding depth measurements were done on the final plant counting day. For each row used for plant counting, five plants were randomly pulled out for seeding depth measurements. The 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 In the middle of the growing season, all aboveground living biomass in 1 m^2 quadrant was harvest at three random locations of each plot. The samples were brought to the laboratory and were separated manually into the barley plants and weeds, and they were dried in cotton sacks for 72 hours at 60 °C to determine the dry matter of plant biomass and weed biomass in kg/ha.

Plant characteristics Before the harvesting, forty plants were randomly pulled-out from each plot. Those plants were brought back to the laboratory and measured for the overall length of the main stem. This measurement was done 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 Hand harvesting was performed at random locations of a plot using 1 m^2 quadrants. Yield samples were taken at five random locations in each plot. The plant material was air dried and then was threshed with a lab-scale threshing unit. The gathered grain was then cleaned on a Carter Precision drum grader and was then sieved to obtain the final cleaned product.

Data analysis

Analysis of variance (ANOVA) was performed on all the data. Means between tillage treatments were compared with Duncan's multiple range tests. A significance level of 0.05 was applied to all analyses.

RESULTS AND DISCUSSION

Soil moisture content

At seeding time in 2003, the average moisture content was 49.3% for the NT, 39.2% for the CT and 33.9% for the ST. Those soil samples were pooled within each treatment before the measurements. Therefore, statistical analysis could not be performed. However, these values showed a trend of tillage effect on the soil moisture content, which followed the trend of tillage intensity. The loosing soil condition in the ST promoted water evaporation loss (Jolata et al. 2001). Therefore, those plots were the driest, followed by the CT and the NT where the soil was not tilled. Residue cover in the NT might have contributed to the highest moisture content by reducing the amount of drying. The aforementioned trend in soil moisture content, NT>CT>ST, was apparently maintained later in the season that year (Fig. 2). This trend was significant for the measurement taken on August 18, where the NT and ST plots were approximately 10% wetter and dryer, respectively, when compared to the CT plots. The soil moisture content data taken in 2004 seemed to follow the same trend. However, the treatment differences in this year and the year after were not significant.

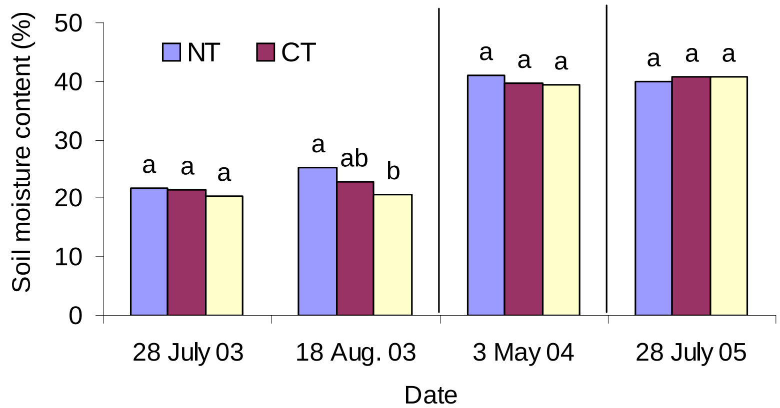
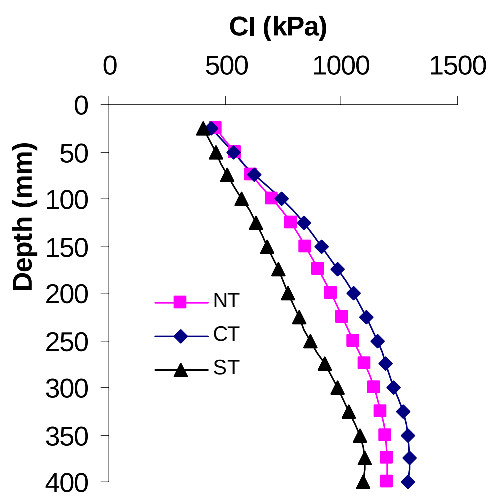


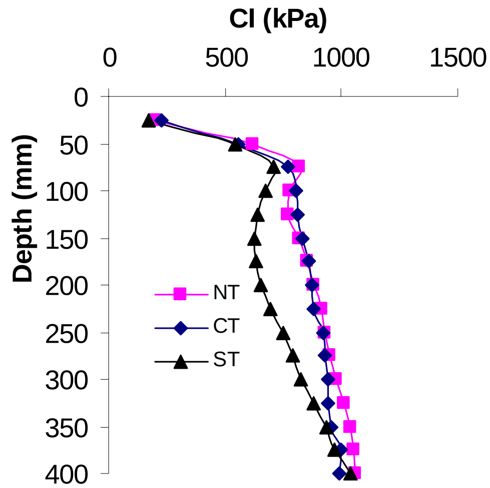
Fig. 2. Soil moisture content measured at different dates for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); means with different letters within the same date were statistically different.

Soil cone index

Cone index data taken prior to the seeding in the spring of 2003 increased smoothly with the soil depth. The ST treatment had the lower soil cone index than the CT due to the more intensive soil disturbance of the ST tillage (Fig 3a), a trend which was statistically significant at depths from 50 to 250 mm. The no-tilled had also lower cone index than the conventionally tilled soil within this depth range. This may be explained by the wheel traffic effect associated with the previous fall tillage in the CT plots.



(a)



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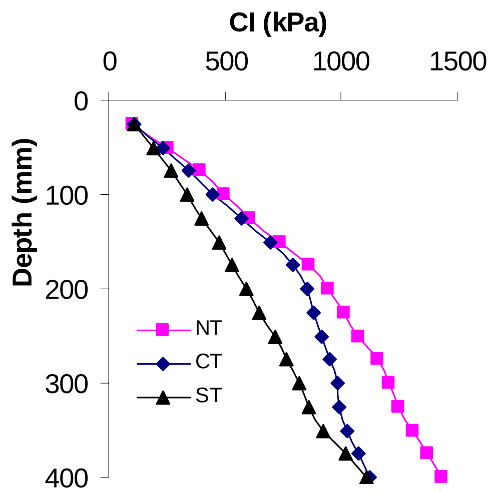


(c)

Fig. 3. Soil Cone index profiles for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); (a) in June 2003, (b) in August, 2004; (c) in May, 2005.

The CI results in August 2004 (Fig. 3b) taken after harvest showed that the soil strength of the NT treatment was as high as the CT treatment, while ST treatment had significantly lower soil strength from 125 to 325 mm depth. A relatively compacted soil layer existed along the soil depth profile at the depth 75 mm. According to the concept of the profile analysis method (Chen and Tessier, 1997), this layer in the soil could be the result of grousers of tractor tires penetrating and shearing the soil from the wheel traffics from seeding, spraying, harvesting and any other field operations during the growing season. However, the compacted layer would not be a potential limiting factor for plant root development, as the values of CI were below the agronomical threshold of 1800 kPa (Letey, 1995).

As observed in the previous years, sub-soiling in 2005 reduced soil strength below 50 mm depth (Fig. 3c). However, comparisons between no-tillage and conventional tillage were different, with no-tillage had significantly higher soil cone index below 175 mm depth. Wilkins et al. (2002) also reported that a short-term no-tilled soil had higher soil strengths than a tilled soil.

Seed placement

Seeding depths (Fig. 4) over three years varied from 38 to 50 mm that was within the range of target depth for cereal crop recommended by Manitoba Agriculture, Food, and Rural Initiatives. As compared with the CT, the NT had a similar seeding depth in 2003 and 2005, but shallower seeding depth in 2004. The ST had 12, 11, and 3% greater seeding depth than for the CT, which was significant in 2003 and 2004. The greater seeding depth in the ST was attributable to the more loosened seedbed of the sub-soiled plots, while the shallower seeding depth of the NT was the result of its firm seedbed. Chen et al. (2005) also found that more loosened seedbed favoured greater seeding depth.

The standard deviations reflect the uniformity of seeding depth. A lower standard deviation means a more uniform seeding depth. Chen et al. (2005) reported that as compared to conventional tillage, sub-soiling caused less uniform seeding depth due to its looser seedbed, while no-till soil favours more uniform seeding depth due to its firm seedbed. In this study, there were no significantly differences in the uniformity of seeding depth between the tillage treatments. The average value for each tillage treatment was indicated in Fig. 4.

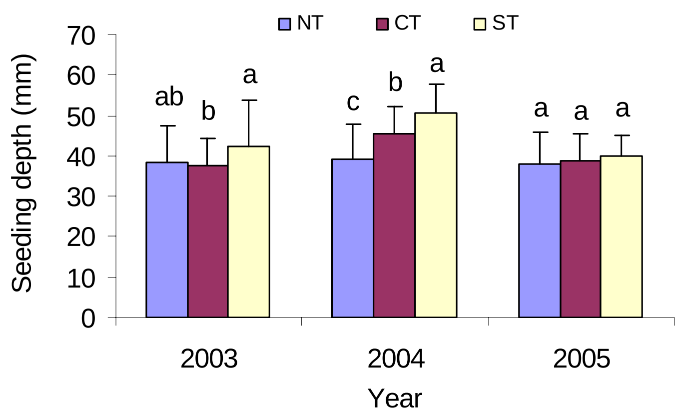
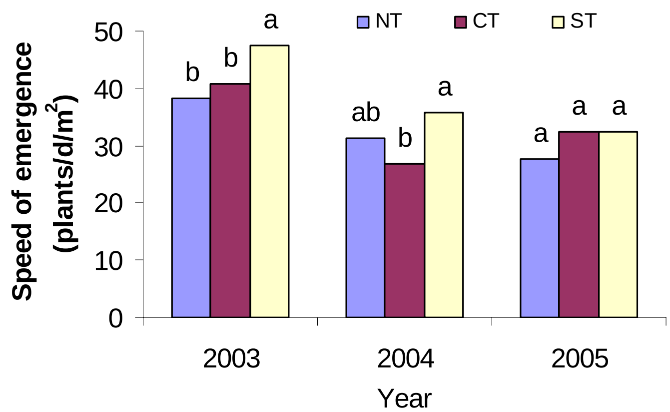


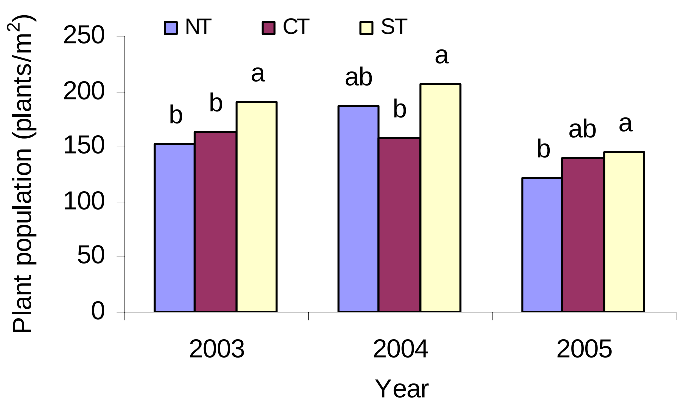
Fig. 4. Seeding depths and their standard deviation (represented by the error bars) for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); means with different letters within the same year were statistically different; error bars stands for standard deviation.

Speed of crop emergence and plant population.

In two out of three years, the ST treatment had significantly higher speed of emergence than the CT treatment (Fig. 5a). This may have been the result of the soil in the ST treatment was warmer and softer which favoured the emergence. The ST treatment may also have the better drainage of the seedbed in wet spring in 2004. The NT treatment had a similar speed of crop emergency as the CT. The results of plant population showed the same trend as those of speed of emergence, in terms of tillage effect. The ST treatment had significantly higher plant population among the three tillage treatments, and plant populations in the conventional tillage and the no-tillage treatment had no significant differences (Fig. 5b).



(a)



(b)

Fig. 5. Early crop performance for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); (a) speed of crop emergence; (b) plant population; means with different letters within the same year were statistically different.

Plant characteristics

Values of plant main stem length varied from 750 to 950 mm. In 2003, the ST treatment had longer main stems than the CT (Fig. 6a), while in 2004, there were no differences in the main stem length between these two tillage treatments. The trend showed that the NT treatment had shorter stem lengths than the CT in both 2003 and 2004. No data were available for 2005, as plants were drawn at the early growing stage.

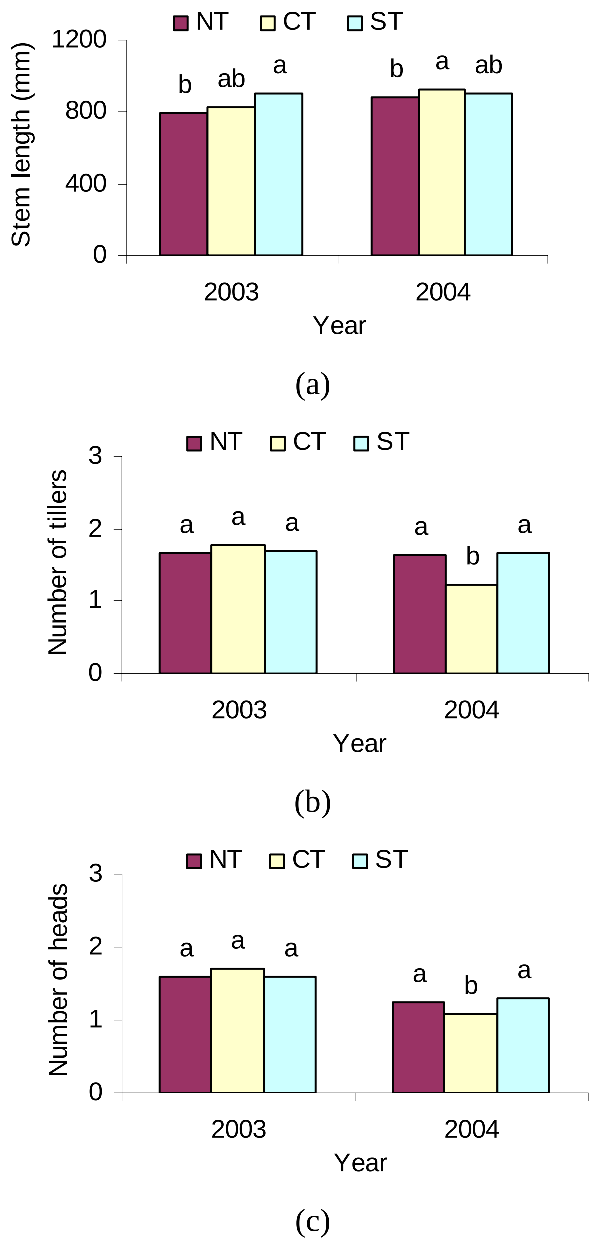


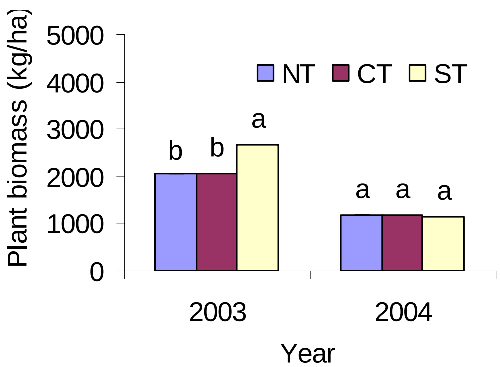
Fig. 6. Plant characteristics for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); (a) plant main stem length; (b) number of tillers per plant; (c) number of heads per plant; means with different letters within the same year were statistically different.

In general, plants had less than two tillers or heads (Fig. 6b,c). In 2003, all the tillage treatments produced the similar number of tillers or heads per plant. In 2004, both the ST and NT produced higher number of tillers or heads per plant than the CT.

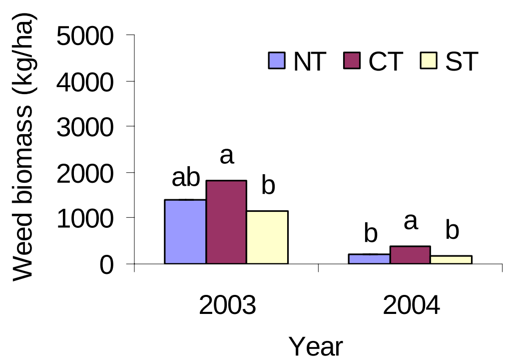
Plant and weed biomass

The ST plots produced 30% higher plant biomass than the CT plots in 2003 (Fig. 7a), and the NT produced a similar amount of plant biomass as the CT. However, in 2004, there were no differences in plant biomass between these any tillage treatments. The higher biomass production of the ST plots in 2003 may be attributable to the loose soil which favoured plant roots penetration and water infiltration in the heavy clay soil.

The trends of weed biomass showed that the ST had the least amount of weeds, followed by the NT and then the CT (Fig. 7b). This may be the result of the highest intensity of tillage action. The higher plant biomass of the ST may also have suppressed the weed growth. However, the lower weed biomass in the NT treatment than the CT were not expected.



(a)



(b)

Fig. 7. Dry matter of above ground biomass for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); (a) plant biomass; (b) weed biomass; means with different letters within the same year were statistically different.

Yield

Yield data were not available for 2004 and 2005, due to crop failure resulting from excess rainfall during the growing season in 2004 and shortly after seeding in 2005. The one year yield data taken in 2003 showed a trend of ST>NT>CT (Fig. 8). This trend in yield seemed to be inversely correlated to that in weed biomass. The other factors which contribute to the higher yield of the ST treatment could be attributable again to the better aeration in the crucial periods of the growing season. The higher yield in the NT could be the results of its higher soil moisture content. However, the statistical differences in yield between the NT and CT were not statistically significant.

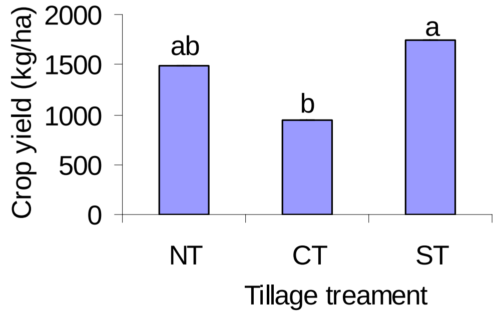


Fig. 8. Crop yield in 2003 for the no-tillage (NT), conventional tillage (CT), and sub-soiling tillage (ST); means with different letters within the same year were statistically different.

CONCLUSIONS

For the Red River clay soil studied, the sub-soiling tillage practice proved effective in reducing the soil compaction and controlling weeds better than the conventional tillage practice. Sub-soiling also increased the speed of crop emergence, plant population and biomass, as well as crop yield. However, when selecting tillage practices, one should consider the fact that sub-soiling requires high tractor power. Overall, the no-tillage system resulted in similar soil strength and moisture content as well as crop performance, when compared to the conventional tillage system. Considering its low cost and comparative performance, no-tillage appears to be a feasible tillage alternative for Red River clay soils. As extremely wet conditions prevailed during two study years out of three, further study is needed to validate the conclusions from this study. Also the agronomic performance of no-tillage in Red River clay needs to be assessed over a longer period of time.

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