Soil-straw-tillage tool interaction: Field and soil bin study

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*[1]Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba R3T 5V6, Canada; [2]Department of Soil Science, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada; and [3]Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, Saskatchewan S7H 5A9, Canada. *Email: ying_chen@umanitoba.ca*

Liu, J., Chen, Y., Lobb, D.A. and Kushwaha, R.L. 2007. **Soil–straw–tillage tool interaction: Field and soil bin study.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **49**: 2.1 - 2.6. Experiments were conducted in a field and a soil bin to study soil and straw displacement and straw incorporation by a sweep-type tillage tool. The experimental factors included number of sweeps (one and three sweeps), lengths of flat straw (100, 175, and 250 mm), and residue conditions (with standing stubble and without standing stubble). The soil bin and the field had similar soil texture with high percentage of sand particles. The sweep was 325 mm wide, and it was operated at a constant speed of 5 km/h and depth of 100 mm. Point tracers were used to measure soil and straw displacement in the travel direction of the sweep. The results showed that soil and straw displacements were highly variable. With increasing length of straw, the soil displacement decreased, while the straw displacement increased. Standing stubble significantly reduced soil displacement, but did not significantly affect the straw displacement. Longer straws were less incorporated into the soil than shorter straws. More straw was incorporated in the soil bin condition than in the field condition. For soil displacement, an increased value was observed when using three sweeps per operation as compared with using one sweep due to interactions between adjacent sweeps in the former operation. However, this interaction effect was not found for the straw displacement. **Keywords**: soil, straw, sweep, displacement, incorporation, tillage, tracer, field, soil bin.

Des essais ont été réalisés en plein champs et en bac de sol pour étudier le déplacement du sol et du chaume de céréale et l'enfouissement du chaume avec un outil de travail du sol du type soc patte d'oie (profil en "V"). Les facteurs expérimentaux comprenaient le nombre de socs (un ou trois socs), la longueur de la paille (100, 175 et 250 mm), la disposition de la paille (avec des tiges ancrées dans le sol verticalement ou sans tiges ancrées). Le sol utilisé dans le bac de sol était comparable à celui retrouvé en plein champ, soit un sol sableux. Le soc avait une largeur de 325 mm et était opéré à une vitesse constante de 5 km/h à une profondeur de 100 mm. Des traceurs ponctuels furent employés pour mesurer le déplacement du sol et de la paille dans la direction du travail du sol. Les résultats montrent que les déplacements du sol et de la paille sont très variables. Lorsque les tiges de paille sont plus longues, le déplacement du sol en est moindre et celui de la paille augmente. La présence de tiges de paille encore ancrées dans le sol réduit significativement le mouvement du sol mais n'influence pas le déplacement de la paille. La paille longue est moins bien incorporée que la paille courte. L'incorporation de la paille lors d'essais en bac de sol était plus importante que lors d'essais en plein champ. Au niveau du déplacement du sol, le mouvement était plus important en utilisant trois socs simultanément relativement à un seul soc à cause de l'interaction entre les socs adjacents. Toutefois, cette interaction entre les socs adjacents n'influence pas le déplacement de la paille. **Mots clés:** sol, paille, patte d'oie, soc, déplacement, enfouissement, travail du sol, traceur, bac de sol.

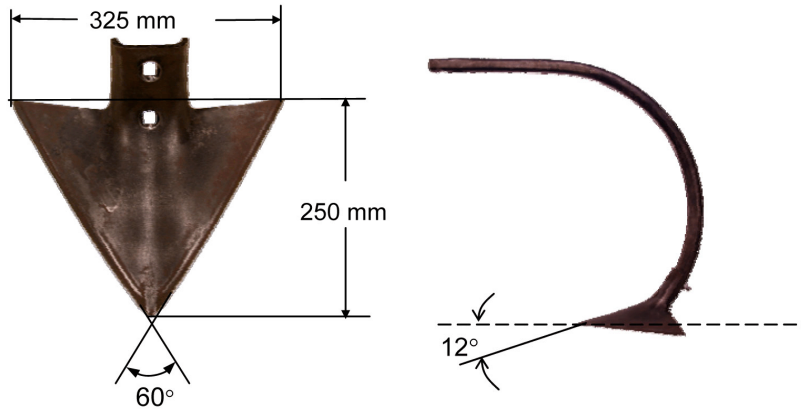
INTRODUCTION

Tillage redistributes surface crop residues and incorporates residue into the soil. Many field experiments have been devoted to the effect of tillage on residue distribution (Woodruff and Chepil 1958; Anderson 1967; McCool et al. 1989; M'hedhbi and Gregory 1989; Hanna et al. 1995; Shelton et al. 1995; Chen et al. 2004). Those researchers found that residue distribution and incorporation were affected by the speed and depth of tillage operation, type of implement, soil conditions, type of crop residues, and height of stubble. However, little research has been done on how interactions between tillage tools and the length of residue affect the soil and residue distribution.

Like any other soil engaging tools, tillage tools cause soil movement. Soil movement affects the draft requirement of the tool and the roughness of the soil surface. It also influences the likelihood of movement and incorporation of surface residue. Research has been done in the area of soil movement resulting from tillage tools. The latest work in this area was reported by Rahman et al. (2005). In their work, sweep type tillage tools were tested in an indoor soil bin and the soil movement in three directions was measured using aluminum point tracers. The results showed that increasing tillage depth and tool forward speed produced greater soil movement. However, that research, like most other existing research, was conducted without the presence of crop residue. Furthermore, whether the results obtained from an indoor soil bin can represent field conditions was not verified in the literature.

Soil in a soil bin is heavily manipulated with frequent disturbance by tillage and compaction with soil preparation tools. The soil has no plant residues, as plants are not normally growing in a soil bin. In a field, soil undergoes tillage less frequently, and it consolidates by natural forces such as rainfall and unconsolidates through freeze-thaw cycles. A field also has plant roots, standing stubble, and flat residue on the soil surface or mixed into the soil. Although an artificial residue cover can be created in a soil bin, effects of standing stubble and plant roots on soil and crop residue movement can not be readily examined in a soil bin.

It is well known that flat residue and standing stubble have different impacts on many aspects, such as soil moisture and the performance of seeding operation (Doan et al. 2005). Researchers also studied the effect of standing stubble on total surface residue after tillage and straw burial as affected by the



(a) (b)

Fig. 1. Sweep geometry: (a) top view of the sweep (McKay 50-12K); (b) side view of the sweep and shank.

height of standing stubble (Woodruff et al. 1965; Anderson 1967). However, information on soil and straw movement affected by standing stubble and plant roots and the interaction between standing stubble and the length of flat straw was not found in previous studies.

The goal of this study was to better understand the process of tillage tool–soil–residue interaction. The specific objectives were to study the following aspects under different straw lengths: (1) soil and straw displacement caused by tillage under a field condition with and without standing stubble; (2) differences of soil and straw displacement as well as straw incorporation between field and soil bin conditions; and (3) effects of tool interaction on soil and straw displacement.

MATERIALS and METHODS

Description of the soil bin and field

The indoor soil bin used was 1.5 m wide, 15 m long, and 0.6 m deep with a loamy sand soil (10% clay, 4% silt, and 86% sand). The soil bin was located in the Department of Biosystems Engineering at the University of Manitoba, Winnipeg, Manitoba. A complete description of the soil bin and soil preparation procedures can be found in Liu (2005).

A field with sandy loam (17% clay, 9% silt, and 74% sand) located at the Carman Research Station in Carman, Manitoba was selected for the field experiment. Oats with a row spacing of 150 mm were swathed and then combined prior to the experiment. The height of the standing stubble was 165 mm.

The soil moisture content and bulk density were maintained near constant in the soil bin and the corresponding values were 16.3% (dry basis) and 1.22 Mg/m^3. The field soil moisture content was kept similar to that of the bin soil by spraying water as necessary. The field soil moisture content and dry bulk density were 18.4% (dry basis) and 1.33 Mg/m^3.

Description of tillage tool and operation

A sweep type tillage tool (Fig. 1) was used in both the field and soil bin experiments. For the field experiment, an implement carrier (Fig. 2a) was designed to have a parallel linkage and four wheels to keep the carrier horizontal. It had the capacity for using three sweeps. The travel direction of the tillage implement was perpendicular to the crop rows. For the soil bin experiment, sweeps were mounted on the carriage of the soil bin (Fig. 2b). For both the field and soil bin experiments, the tillage depth was 100 mm and the tillage speed was 5 km/h.

Straw preparation

Prior to the experiments, observations were made on straw lengths in threshed windrows. It was found that the straw length ranged from 50 to 250 mm with most straw being between 100 and 250 mm. Therefore, the straw lengths of 100, 175, and 250 mm were selected for the experiments. Oat straw was collected from field windrows. Only the stem portion of the straw was used. The straw was cut into the desired lengths using a band saw. Different lengths were stored separately. These straw

(a) (b)

Fig. 2. The test units: (a) tool carrier used for the field experiment; (b) tool carriage used for the soil bin experiment.

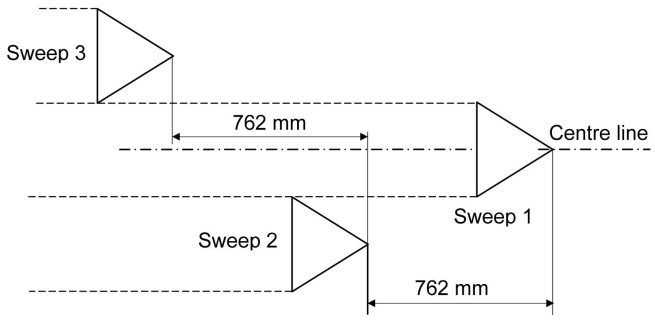


Fig. 3. Diagram showing the top view of sweep arrangement for the tool operations.

pieces were used as the flat straw applied to plots for both field and soil bin experiments. Each length was assigned in a plot to form a treatment.

Experimental design

Soil bin In the soil bin experiment, three straw lengths (100, 175, and 250 mm) were used. For each straw length, three tillage treatments (1Pass-1Sweep, 1Pass-3Sweep, and 3Pass-1Sweep) were examined. The three treatments corresponded to three tool operations: one pass with a single sweep, one pass with three sweeps, and three passes with a single sweep. The tool spacing of the 1Pass-3Sweep and 3Pass-1Sweep treatments is shown in Fig. 3. There was neither gap nor overlap between any two adjacent sweeps or passes. For the 1Pass-1Sweep treatment, the Sweep 1 shown in Fig. 3 was the sweep position. For the 3Pass-3Sweep, the first pass was done at the Sweep 1 position, while the second and third passes were done at the Sweep 2 and Sweep 3 positions, respectively. Three plots were randomly assigned in each test run. Each plot was 1.5 m long. The distance between two plots was 1 m. Each treatment was replicated three times.

Field A randomized block design was used in the field experiment. The experiment included three straw lengths (100, 175, and 250 mm) and two residue conditions (With-Stubble and Without-Stubble) which is described below, forming six treatments. For each straw length, two tillage treatments (1Pass-1Sweep and 1Pass-3Sweep) were examined. The plot was 3 m long and 0.975 m wide (three times the sweep width). Each treatment was replicated three times. Treatments for the soil bin and field experiments are summarized in Table 1.

Table 1. Summary of the treatments for the field and soil bin experiments.

Factor	Straw length (mm)					
	Field experiment			Soil bin experiment		
	100	175	250	100	175	250
Tillage treatment						
1Pass-1Sweep	x	x	x	x	x	x
1Pass-3Sweep	x	x	x	x	x	x
3Pass-1Sweep				x	x	x
Residue treatment						
With-Stubble	x	x	x			
Without-Stubble	x	x	x	x	x	x

The Without-Stubble condition in the field experiment was designed to examine the differences of soil movement between a field soil and a bin soil (without stubble). For this comparison, the standing stubble was removed with a lawn mower and the flat straw was removed by hand. Thus, the only difference between the field soil and the bin soil was the presence of roots in the field soil. The With-Stubble condition in the field was designed to study the effect of standing stubble on soil and straw movement and on straw incorporation in a field condition. In the With-Stubble plots, the standing stubble was kept and the flat straw on the soil surface was manually removed.

The field was divided into twelve 4-m wide and 40-m long blocks along the direction perpendicular to the stubble rows. Each block contained three plots. The 12 field blocks were divided into two groups. One group was for the 1Pass-1Sweep treatment and the other was for the 1Pass-3Sweep treatment. The six combinations of straw lengths and residue conditions with three replications were randomly assigned in each group.

For both soil bin and field experiments, treatments of straw length were created by manually applying the pre-cut straw of the desired length on the soil surface at the base of the standing stubble. This straw is referred to as flat straw. On average, the straw density applied was 108 g/m^2 which is approximately the field straw cover in a conversation tillage system.

Measurements

Soil and straw displacement Only forward displacement of soil and straw was measured in this study. These are referred to as soil displacement or straw displacement. Soil displacement was measured with aluminum cubes (10 mm on a side) as point tracers, and straw displacement was measured with straw tracers. The straw tracers were red-painted straw pieces with the center of its length wrapped with a white tape. The straw tracers were numbered on the white tape. The lengths of the straw tracers in a plot were the same as those of the flat straw applied to that plot.

Nine aluminum cubes were inserted into the soil. The top surface of the tracer straws was even with the soil surface to represent surface soil movement, and to identify the differences of displacement between soil and crop residues at and near the soil surface. It was assumed that straw tracer orientation did not significantly affect the straw displacement. The length of the tracer was placed parallel to the direction of the sweep travel in order for them not to interact with each other. Nine straw tracers were placed in the central third of a plot. Then the flat straw was applied and all the tracers were covered. An apparatus was made to measure the tracers' positions before and after tillage. The apparatus for the soil bin measurements (Fig. 4) consisted of a vertically movable pointer on a frame which had four small wheels traveling along the soil bin. For the field measurement of tracers, a second frame was made to support the apparatus (Fig. 4). The displacements of soil and straw were determined from the tracer's positions before and after tillage operation.

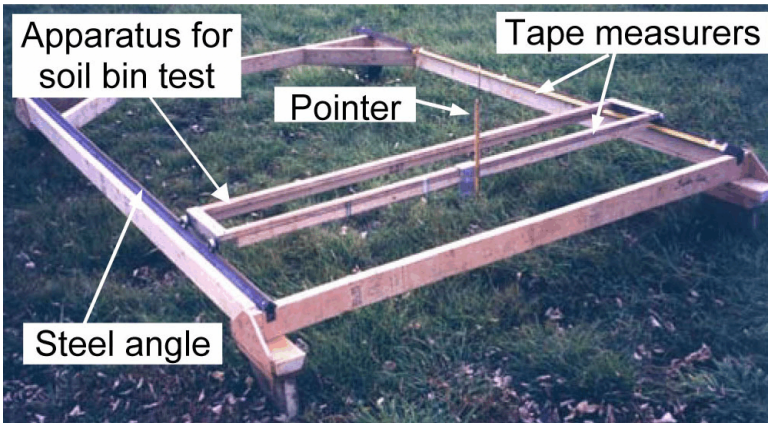


Fig. 4. The device for measuring the displacement of soil and straw.

Surface straw cover The percent cover of straw was measured by photographing a square area (650 by 650 mm) between the second and third furrows after the tillage operation for the 1Pass-3Sweep treatments in both the soil bin and field experiments. The images were processed using digital imaging software (Lamari 1999) to determine the values of straw cover on the soil surface before and after tillage.

Data analysis

Data were analysed to detect significant differences by ANOVA with the Duncan test at a significance level of 0.1. The software used was the ANOVA procedure in SAS V8.0 for Windows. Three replicates were used to generate error bars illustrated in the results. The differences in means were detected by comparing them with a one-way ANOVA.

RESULTS and DISCUSSION

Soil displacement

The soil displacement ranged from 70 to 300 mm. The average of the soil forward displacement (146 mm) reported by Rahman et al. (2005) was within this range for a similar sweep working on a similar condition, but without residue present.

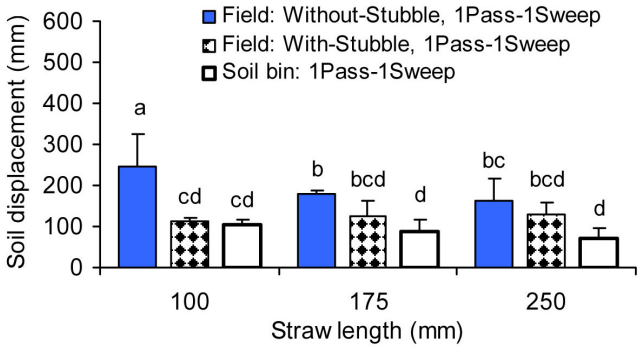


Fig. 5. Means and standard deviations of forward soil displacement measured for the tillage operation with one sweep in the field and soil bin. Means with the same letter are not significantly different at the 10% level (Duncan test).

1Pass-1Sweep treatment The length of flat straw did not affect the field soil displacement when standing stubble was present in the field (Fig. 5). When there was no standing stubble in the field, the soil displacement tended to decrease with increasing length of flat straw. The same trend held true for the soil bin condition, although statistically significant differences were not detected. The flat straw had a stronger effect on reducing soil displacement in the field than in the soil bin.

Within each straw length, the displacement of the field soil was significantly greater than that for the bin soil. A 100% greater soil displacement was found for all three lengths of flat straw when there was no standing stubble in the field. The results also demonstrated that the differences of soil displacement between the bin and the field Without-Stubble condition were caused by differences in soil conditions, not by the existence of stubble. The large soil displacement in the field may have been caused by soil rolling, as visually observed. Roots in the field may hold the soil together to form root balls. Those root balls might be responsible for the soil rolling. The expected stronger vibration of the tool carrier during the field operations could also increase soil displacement compared to the stable carriage of the soil bin.

Field soil With-Standing stubble significantly reduced the soil displacement at the 100-mm straw length, when compared to that Without-Stubble. The same trend was observed for the other two straw lengths. This result implies that standing stubble interferes with the soil displacement, possibly by preventing soil from rolling.

1Pass-3Sweep treatment Similar trends as the 1Pass-1Sweep treatment were observed for the 1Pass-3Sweep treatment. The trend shows that greater values of soil displacement were observed at the 100-mm straw length when compared to those at the other straw lengths (Fig. 6). The soil displacement for the 1Pass-3Sweep in the field Without-Stubble was larger than that in the soil bin, regardless of straw length. This may be attributable to the fact that the field soil rolled more than that of the bin soil as aforementioned.

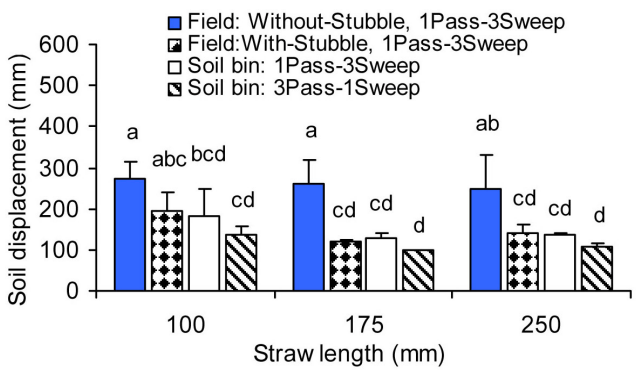


Fig. 6. Means and standard deviation of forward soil displacement measured for different tillage treatments. Means with the same letter are not significantly different at the 10% level (Duncan test).

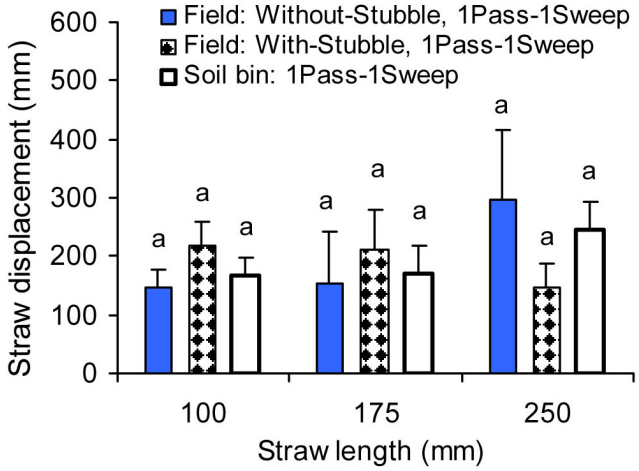


Fig. 7. Means and standard deviations of forward straw displacement measured for the tillage operation with one sweep in the field and the soil bin. Means with the same letter are not significantly different at the 10% level (Duncan test).

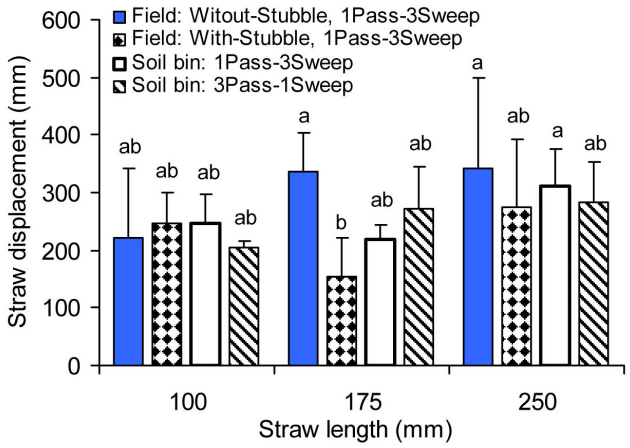


Fig. 8. Means and standard deviations of forward straw displacement measured for different tillage treatments. Means with the same letter are not significantly different at the 10% level (Duncan test).

Again, the existence of standing stubble reduced the soil displacement, as indicated by the differences between the field Without-Stubble and With-Stubble conditions. This effect was significant for the 175- and 250-mm straw lengths. This implies that longer flat straw on the soil surface interacts with the standing stubble during the tillage operation. Results also demonstrated the differences of soil displacement between the bin and the field Without-Stubble condition with the field soil having greater soil displacement.

Effect of tool interaction When comparing the soil displacement between the 1Pass-1Sweep (Fig. 5) and 1Pass-3Sweep (Fig. 6), we found that the latter treatment produced greater soil displacement than the former. The difference was caused by the interaction among sweeps. In the 1Pass-3Sweep treatment, soil moved by a sweep was impacted by its adjacent sweep while the soil was moving. It was expected that this interaction depended on not only tool spacing but also tillage speed. However, effects of tool spacing and tillage speed were not examined in this study. This interaction effect was further confirmed with the results of soil displacement for the 3Pass-1Sweep (Fig. 6) which was considered as a treatment which did not have tool interactions. The 1Pass-3Sweep treatment produced larger soil displacement than the 3Pass-1Sweep treatment, although the difference between these two treatments was not significant.

Straw displacement

1Pass-1Sweep treatment No significant differences among treatments were detected for straw displacement under the 1Pass-1Sweep treatment (Fig. 7). The trends show that straw displacement slightly increased with increasing straw length in the field Without-Stubble and soil bin conditions. When standing stubble was present in the field, this trend seemed to be reversed. The straw displacement measured in the field Without-Stubble and the soil bin was statistically comparable. However, the results of the field experiment had larger variability compared to those of the soil bin. There were no particular trends for effects of standing stubble on the straw displacement.

1Pass-3Sweep treatment Compared to the treatment with one sweep, the differences in straw displacement among treatments were smaller for the treatment with three sweeps (Fig. 8). The straw displacement increased with increasing straw length if there was no standing stubble. However, this was not statistically significant. Within each straw length, the Without-Stubble condition resulted in similar or greater straw displacement when compared to the With-Stubble condition in the field. Standing stubble reduced the straw displacement for the 175-mm and 250-mm lengths of flat straw. The reason could be that the stubble prevented the flat straw from moving during the tillage operation. Within each straw length, the straw displacement measured in the field Without-Stubble was similar to that measured in the soil bin.

Effect of tool interaction When comparing the straw displacement between the 1Pass-1Sweep (Fig. 7) and 1Pass-3Sweep (Fig. 8), we found that the latter treatment produced greater straw displacement than the former. This was attributable to the interactions between sweeps. This interaction effect can be also explained by comparing the 1Pass-3Sweep and the 3Pass-1Sweep. The latter is considered as a treatment which did not have tool interaction. The lower straw displacement of the 3Pass-1Sweep treatment at the 100- and 250-mm straw lengths (Fig. 8) confirmed the interaction effect between sweeps. Another interesting phenomenon is that straw displacement was greater than the soil displacement in all cases.

Straw incorporation

Values shown in Fig. 9 are the ratios of straw cover after and before the 1Pass-3Sweep treatment for three conditions: soil bin, field With-Stubble, and field Without-Stubble. It is assumed that a smaller ratio means more straw being incorporated through the tillage operation. The trend for the soil bin was that the ratio of straw cover increased with increasing straw length, and the increasing trends were linear. A similar trend was true for the field Without-Stubble condition. These

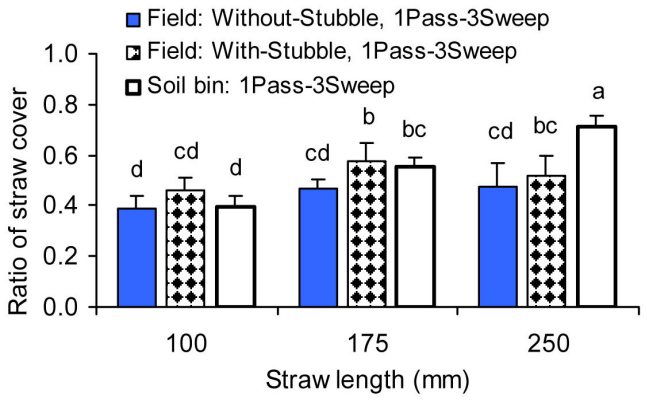


Fig. 9. Ratio of straw cover after and before tillage with three sweeps. Means with the same letter are not significantly different at the 10% level (Duncan test).

results showed that longer pieces of straw were less incorporated than shorter ones in both the soil bin and field. For the two residue conditions in the field, the ratios of straw cover were higher when standing stubble existed compared to the case of the Without-Stubble. The difference was significant for the 175-mm straw length.

In the soil bin, less straw was incorporated than in the field Without-Stubble condition, as indicated by the higher ratio of straw cover for the former condition. The differences in the ratio of straw cover between the soil bin and the field Without-Stubble condition were larger with increasing length of straw, and the difference was significant for the longest straw (250 mm). This indicated that the aforementioned greater soil displacement in the field Without-Stubble condition could favour straw incorporation.

CONCLUSIONS

An experimental study was conducted in a field and soil bin with one and three sweeps (325 mm wide) operated at a speed of 5 km/h and tillage depth of 100 mm. For the tillage operation with one sweep, the forward displacement of the field soil was significantly reduced with increasing length of the flat straw on the soil surface; but it was not significant for the treatment with three sweeps. Forward soil displacement in the soil bin was not significantly affected by the length of flat straw. Straw displacement was always greater than the soil displacement. No particular trends were found for the effect of straw length on the straw displacement in both the soil bin and field. Longer straw was less incorporated in the soil bin, and this trend was linearly related to the straw length. Standing stubble reduced the soil displacement, while standing stubble did not significantly affect the straw displacement, regardless of the number of sweeps used. Interaction between sweeps existed, shown by comparing the tillage treatment with one pass of one sweep and one pass of three sweeps. The latter treatment produced greater soil and straw displacement than the former, which was further confirmed by the results from the treatment with three passes of one sweep. As compared to the data from the soil bin, those from the field were more highly variable. The soil displacement in the field without stubble was twice that of the soil bin soil. Therefore, a soil bin may not be suitable to simulate a field condition for soil displacement studies. However, a soil bin may be used to simulate a field condition for straw displacement studies. A soil bin may be also used to simulate a field condition for residue incorporation studies if the length of straw is shorter than 250 mm.

The results can be used to better model soil-straw-sweep interactions and to examine those models of soil-straw-tool interaction which are developed based on soil bin experimental results. The information obtained is also useful for combine straw chopper designers to select the target straw length which is favourable to straw incorporation in subsequent tillage operations.

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REFERENCES

Anderson, D.T. 1967. Factors affecting trash conservation with the wide-blade cultivator. *Canadian Agricultural Engineering* 9: 98-199, 127.

Chen, Y., F. Monero, D.A. Lobb, S. Tessier and C. Cavers. 2004. Effects of six tillage methods on residue incorporation and crop performance under a heavy clay soil condition. *Transactions of the ASAE* 47: 1003-1010.

Doan, V., Y. Chen and B. Irvine. 2005. Effect of oat stubble height on the performance of no-till seeder openers. *Canadian Biosystems Engineering* 47: 2.37-2.44.

Hanna, H.M., S.W. Melvin and R.O. Pope. 1995. Tillage implement operational effects on residue cover. *Applied Engineering in Agriculture* 11: 205-210.

Lamari, L. 1999. ASSESS: Image analysis software for plant disease quantification. *American Psychopathological Society*. St. Paul, MN: APS Press.

Liu, J. 2005. *Study of Tillage Tool-Soil-Crop Residue Interaction*. Ph.D Thesis, Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB.

McCool, D.K., F.L. Young and R.I. Papendick. 1989. Crop and tillage effects on residue cover. ASAE Paper No. 892155. St. Joseph, MI: ASABE.

M'hedhbi, K. and J.M. Gregory. 1989. Tillage effects on residue cover. ASAE Paper No. 891539. St. Joseph, MI: ASABE.

Rahman, S., Y. Chen and D.A. Lobb. 2005. Soil movement resulting from sweep type manure injection tools. *Biosystems Engineering* 91: 379-392.

Shelton, D.P., E.C. Dickey, S.D. Kachman and K.T. Fairbanks. 1995. Corn residue cover on the soil surface after planting for various tillage and planting systems. *Journal of Soil and Water Conservation* 50: 399-494.

Woodruff, N.P. and W.S. Chepil. 1958. Influence of one-way-disk and surface-sweep tillage on factors affecting wind erosion. *Transactions of the ASAE* 1: 81-85.

Woodruff, N.P., C.R. Fenster, W.S. Chepil and F.H. Siddoway. 1965. Performance of tillage implements in a stubble mulch system. I. Residue conservation. *Agronomy Journal* 57: 45-49.